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ACCESSIBILITY AND SPACE COVERAGE AS AN ANALYSIS TOOL OF THE PRIMARY ACTIVITY NODES IN SAN ANDRÉS DE TUMACO, COLOMBIA

Jorge Montoya G.[1], Diego Escobar G.[1] and Carlos Moncada A.[2]
[1]Universidad Nacional de Colombia, Sede Manizales, Facultad de Ingeniería y Arquitectura, Departamento de Ingeniería Civil, Grupo de Investigación en Movilidad Sostenible, Campus La Nubia, Bloque, Carrera con Calle, Manizales, Colombia
[2]Universidad Nacional de Colombia, Sede Bogotá, Facultad de Ingeniería, Departamento de Ingeniería Civil y Agrícola, Programa de Investigación en Tránsito y Transporte – PIT, Ciudad Universitariaedificio oficina, Bogotá, Colombia
E-Mail: joamontoyago@unal.edu.co

ABSTRACT

This paper aims to present a territorial accessibility analysis of the set of Primary Activity Nodes in the municipality of San Andrés de Tumaco, Colombia, making use of the municipality's transportation infrastructure network. The research methodology contemplates the application of geo-statistical models of accessibility, executed by making use of digital GIS-type tools and complemented by an analysis of population and area coverage. As main results it is obtained that the maximum coverage times in the municipality do not exceed 22 minutes; likewise, the joint analysis shows some sectors with shortcomings regarding local coverage. With this, it is possible to conclude that the accessibility of the municipality, regarding its activity nodes, is adequate, considering the comparison with access times in other cities.

Keywords: accessibility, coverage, equipment, geo-statistics, infrastructure.

INTRODUCTION

The development dynamics of a society, to a certain extent, depend on the possibility of satisfying the basic needs of its population; taking into account that, a greater attention to these needs, maximizes productivity and, in turn, translates into greater economic growth (Hernández, J., 2010; Rosas, P., & Sánchez, R., 2004, p9; Núñez, C., 1999). In this sense, the Primary Activity Nodes or NAP, are a set of equipment associated with the satisfaction of part of these basic needs, focusing directly on education (basic primary, secondary, technical and higher), health (hospitals, clinics, health centers), security (police, military, firefighters, among others) and recreation (parks, eco-parks, sports centers, etc.) (Escobar *et al*, 2015; Hernámdez, A., 2000).

This set of equipment allows citizens to satisfy their attention requirements to a certain extent, however, there are scenarios in which a large part of this equipment is assigned to specific areas, without considering the different difficulties of users to access each of them; In other words, they are assigned to specific points without considering the means of transport or economic capacities of the service users. For this reason, it is important to carry out a territorial accessibility analysis of the set of equipment of each NAP typology, associated with the population's displacement conditions; thus, by integrating the set of equipment with the transport infrastructure network of the municipality of San Andrés de Tumaco, it is possible to observe the level of coverage offered to the public by each set of equipment.

The municipality of San Andrés de Tumaco, department of Nariño, is located on the Colombian south-western sector (Figure-1), at 1 ° 48′24 ″ north latitude and 78 ° 45′53 ″ west longitude; it has an average elevation of 1 m.a.s.l and an average temperature of 26° C (Tumaco - Nariño District Mayor's Office, 2020). Tumaco, has a total extension of 359, 116.47 hectares, of which 1,110.28 correspond to its urban area, on which 126,782 inhabitants reside (National Administrative Department of Statistics - DANE, 2018).

On the other hand, the economy of the municipality is based mainly on agricultural industry, forestry and tourism projects (Tumaco-Nariño District Mayor's Office, 2020), generating the necessary conditions for growth as a city and therefore, requiring a greater amount of equipment to meet the needs of the inhabitants. In this sense, the city has a total of 97 facilities associated with the different primary activities, which will be located and related to the urban transport network, in order to assess the accessibility conditions and the spatial coverage of the population and area variables, offered by the set of NAP equipment.

Accessibility is a concept used since the beginning of the 20th century (Batty, 2009) and described in 1959 by Hansen as “The potential for opportunities for interaction”. It is basically defined as a measure of the ease of communication among a set of activities, through the use of different modes of transport (Morris *et al.*, 1978), including private transport (car, motorcycle), public transport, bicycle, walk, among others. Thus, starting from this definition, and observing the components described in it, it can be considered as an urban planning tool, as Haig had a presentiment in 1927; however, as it is considered a tool, it must understand the use of some basic components of graph theory (Brigs *et al.*, 1985), because the nodes and arcs are clear abstractions of the equipment and the network of transport. Additionally, it is possible to name some investigations carried out by different authors associated with accessibility; investigations that impact various areas, with interesting solutions for existing problems; some of these are: sustainable development (Kwok & Yeh, 2004; Vega, 2011), transportation (Cui &

Levinson, 2019, Murray, 2001; Murray & Wu, 2003; O´Sullivan *et al*, 2000), tourism (Kastenholz *et al*., 2012), provision and location of services (Calcuttawala, 2006; Higgs *et al*., 2013; Park, 2012), health (Wang *et al*., 2020), among others.

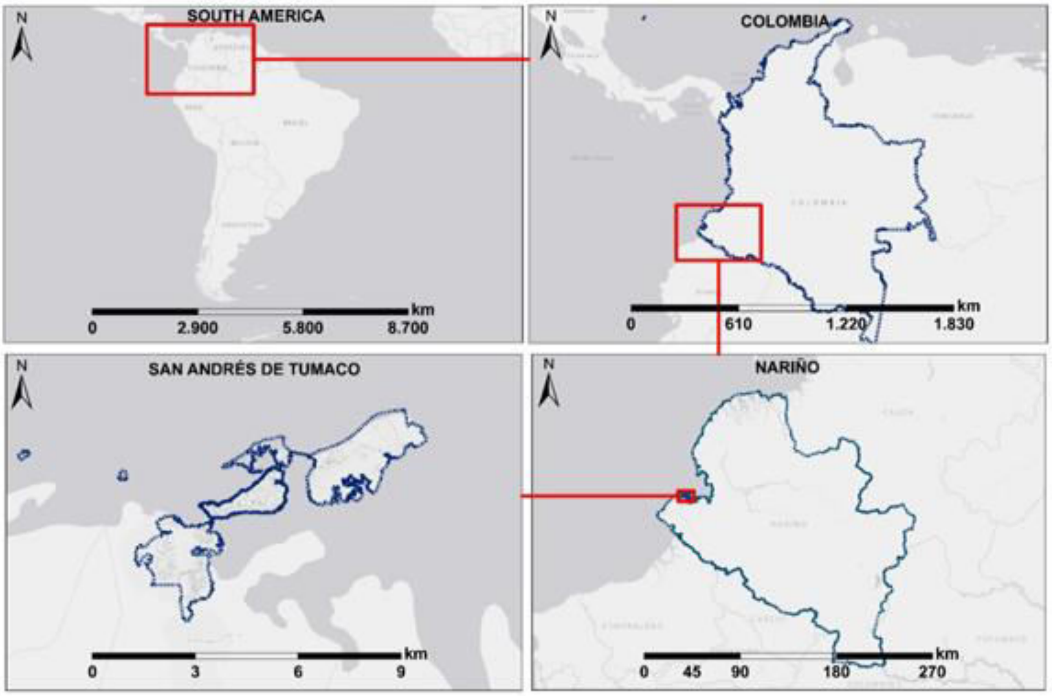

Figure-1. Location of the municipality of San Andrés de Tumaco. Source: self-made.

On the other hand, it is necessary to mention some subdivisions of accessibility, considering that, depending on the study to be carried out; the corresponding methodology must be used. In this sense, we will evaluate 3 approaches of accessibility; relative accessibility, comprehensive average accessibility and global average accessibility. Relative accessibility refers to direct connectivity between two points of interest (Ingram, 1971), based on the network and available transport modes; integral average accessibility defines the connectivity of a set of points, towards one in particular; that is, the willingness to move from different areas of a city (origins), to some point of particular interest (destination) (Ingram, 1971). Finally, the global average accessibility defines the connectivity of all the points to each other; thus, it evaluates the possibility of moving from one origin to the existing destinations, varying the origin as the calculation is made. In the Figure-2, a visualization of the expressed accessibility modes can be appreciated.

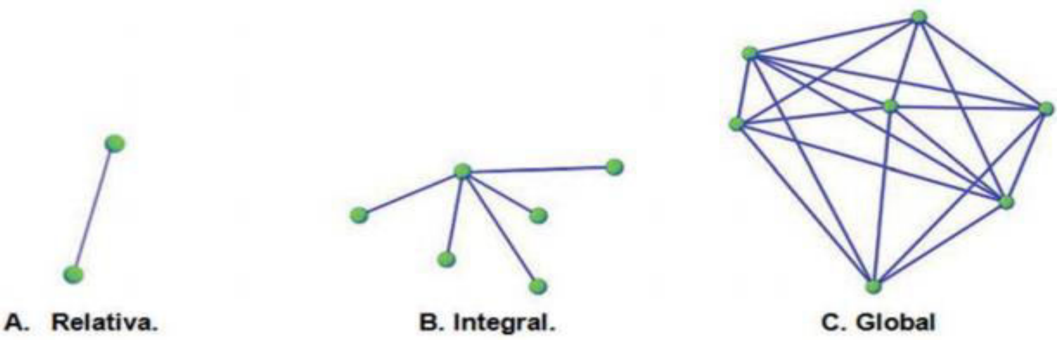

Figure-2. Types of accessibility. Source: Escobar, D. and García, F., 2012.

Considering the above, we prepare to make use of the band associated with comprehensive mean accessibility, as the evaluation tool for the set of nodes of primary activity in the municipality of San Andrés de Tumaco, considering measures of population coverage and area, based on the research methodology presented below.

METHODOLOGY

In order to clarify the performed procedures, a flow chart is presented with the main components executed in the investigation (Figure-3). In total, 5 components are included, which are described below.

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Component 1. Collection and Review of the Base Information

As a first component, an extensive search is carried out in the official databases in order to collect the base information required for the investigation. In the first instance, the existing cartographic base is used in the National Administrative Department of Statistics-DANE, in which the base road network is obtained, which includes the average operating speeds of the different means of transport existing in the municipality; polygon of blocks and resident population in the urban and rural perimeter. On the other hand, using data from the Ministry of Education, Municipal Administration and Individual Search, the 97 facilities associated with the Primary Activity Nodes-NAP are obtained. In Figure-4, the collected base information is appreciated, with some discrepancies between the road network and polygons, which is subsequently corrected.

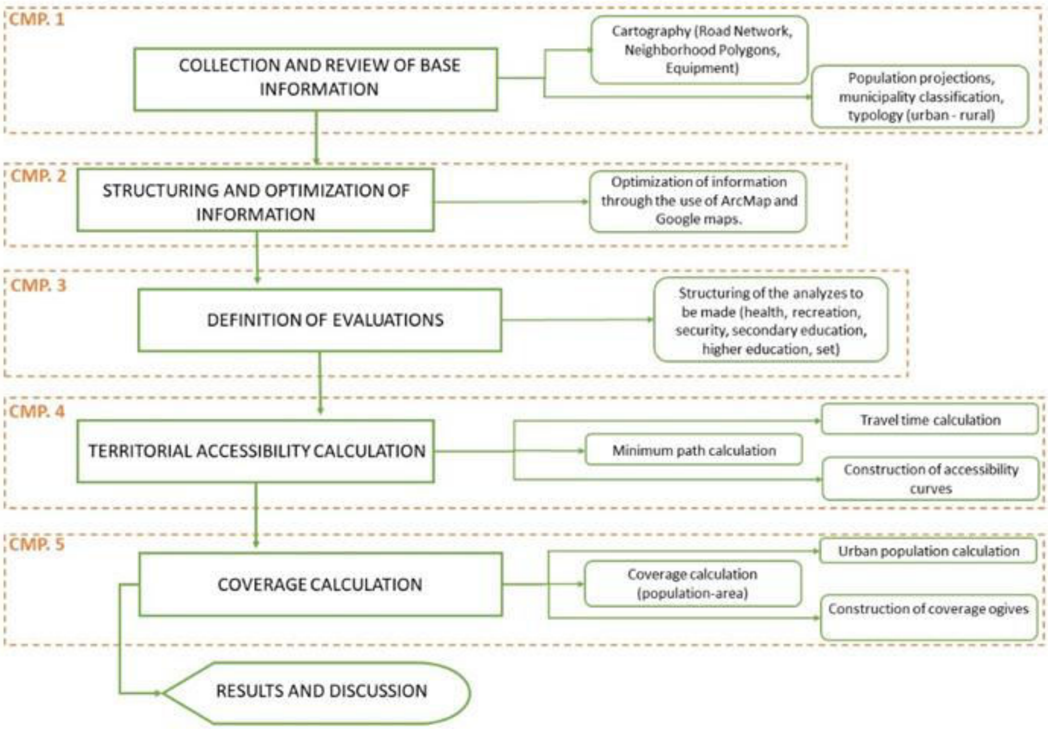

Figure-3. Research methodology. Source: self-made.

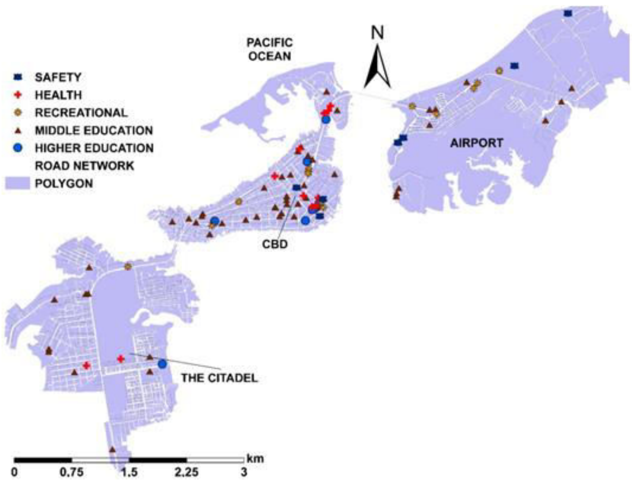

Figure-4. Base information collected. Source: Own elaboration based on information from DANE, the Ministry of Education and the Municipal Administration.

Component 2. Structuring and Optimization of Information

Once the information to be used has been selected, the structuring and optimization of each element to be used are made. In this sense, the connectivity of the road network is verified, as well as the linkage of the operation speeds, length and directionality. The entire procedure is made from the ArcMap tool. Likewise, each of the equipment associated with the NAP is geo-located, and its location is verified using google maps.

Component 3. Definition of Evaluations

In order to make a more appropriate analysis, the different components to be evaluated are defined, based on the existing NAP typologies. Thus, it is decided to make an analysis of each type of equipment (recreational, health and safety). While the Educational facilities are divided into middle education, for those institutions that meet the educational characteristics of basic primary and secondary education, and in higher education, technical and vocational training institutions are grouped. Likewise, a joint analysis of the NAP typologies is made, in order to observe the behavior of the municipality, regarding the existence of the facilities.

Component 4. Territorial Accessibility Calculation

As the next methodological item, we proceed to calculate the integral mean accessibility for each set of equipment associated with the NAP, based on obtaining the minimum travel time vectors. In equation 1, the base structure used to calculate the travel time in the road network is presented; then, the lowest of the travel times for each node of the network is selected, considering the multiple minimum paths obtained by Dijkstra's algorithm (Dijkstra, 1959) as shown in equation 2.

$$Tv_x = \frac{Length_x}{Speed_x} * 60 \quad (1)$$

Where Tv_x is the travel time of arc x, obtained by dividing the length (km) of the arc by the speed (km/h) and multiplying by 60 to operate the time in minutes.

$$Tv_i = \min(Tv_{ij}) \quad (2)$$
$$j = 1:n, \quad Tv_{ij} = \min\{Tv_{ij_1}, Tv_{ij_2}, \ldots, Tv_{ij_m}\}, m = \text{number of paths}$$

Where Tv_i is the travel time from node i to the closest facility, Tv_{ij} is the shortest of the travel times from node i to facility j, within the set of values Tv_{ij_m} obtained from Dijkstra's algorithm. Additionally, the average access time of each node in the network is calculated, to the set of nodes of primary activity (equation 3), this in order to assess globally, the accessibility of the municipality with respect to all its equipment and thus identify the areas with the greatest global deficiency.

$$\overline{Tv_i} = \frac{\sum_{N=1}^{z} Tv_{ik}}{z} \quad (3)$$

Where $\overline{Tv_i}$ is the average time of node i for the NAP N typology and N and z the total number of NAP typology used. Once the minimum travel times of each node in the network and each NAP typology have been obtained, the isochronous accessibility curves are structured. The procedure contemplates the use of the ArcMap Geostatical Wizard extension, in which the geographic interpolation is structured from of the ordinary Kriging method, with linear semivariogram (Wang & Kockelman, 2009), being the most appropriate method when the distance between nodes to be interpolated is short (Wackernagel, 2003).

Component 5. Coverage Calculation

We proceed to determine the percentage of spatial coverage of the population and area variables, offered by each NAP typology and set. In the first instance, the existing population information is associated with the block polygon, obtained from the National Administrative Department of Statistics-DANE.

It is important to clarify that, within the procedure, areas with vacant lots or without any type of construction, identified by Google Earth, are excluded; thus, when making the population allocation to the set of blocks, a more accurate approximation of the distribution of inhabitants is achieved. Likewise, the allocation process contemplates the population distribution based on the area percentage of each polygon, with respect to the total urban strip of the municipality (equation 4).

$$Pob_{kij} = \frac{Area_{kij}}{\sum Area_{ij}} * Pob_{ij} \quad (4)$$

Where Pob_{kij} is the population of block k with respect to its contribution in the total area of i and class j. Likewise, Table-1 shows the meaning of each sub index, with respect to the base document used. It is important to remember that, since this study is part of a larger proportion analysis, the population allocation is made on a regional scale, which is subsequently trimmed to make the urban analysis presented in the document.

Table-1. Indicative sub-index. Source: self-made.

Sub-index	Variable in Document	Meaning
i	CDG_MPO	Municipality code
j	CLASE	Block class: 1(urban), 2(rural)

RESULTS AND DISCUSSIONS

As a result of the analysis of territorial accessibility to the Primary Activity Nodes in the municipality of San Andrés de Tumaco, Figures 5 to 9 are constructed, in which the isochronous curves for each analyzed component are shown, as well as their respective coverage curves population and area.

In Figure-5, the behavior associated with secondary education facilities can be seen. A high concentration of educational institutions is observed in the central sector of the municipality, as well as some significant presence in the airport area and the citadel, thus allowing users to gain access in a maximum travel time of 10 minutes. On the other hand, the lower area of figure 5 shows the behavior of the population and area coverage associated with the travel time obtained. It is observed that, close to 50% of the population requires a travel time of less than 3 minutes to travel to an institution. Similarly, coverage in the area requires a travel time of just over 3 minutes to achieve the same percentage of coverage. This discrepancy in time can be assumed as an equitable distribution of institutions between population and area, which allows efficient coverage with respect to populated areas and possible expansion sectors.

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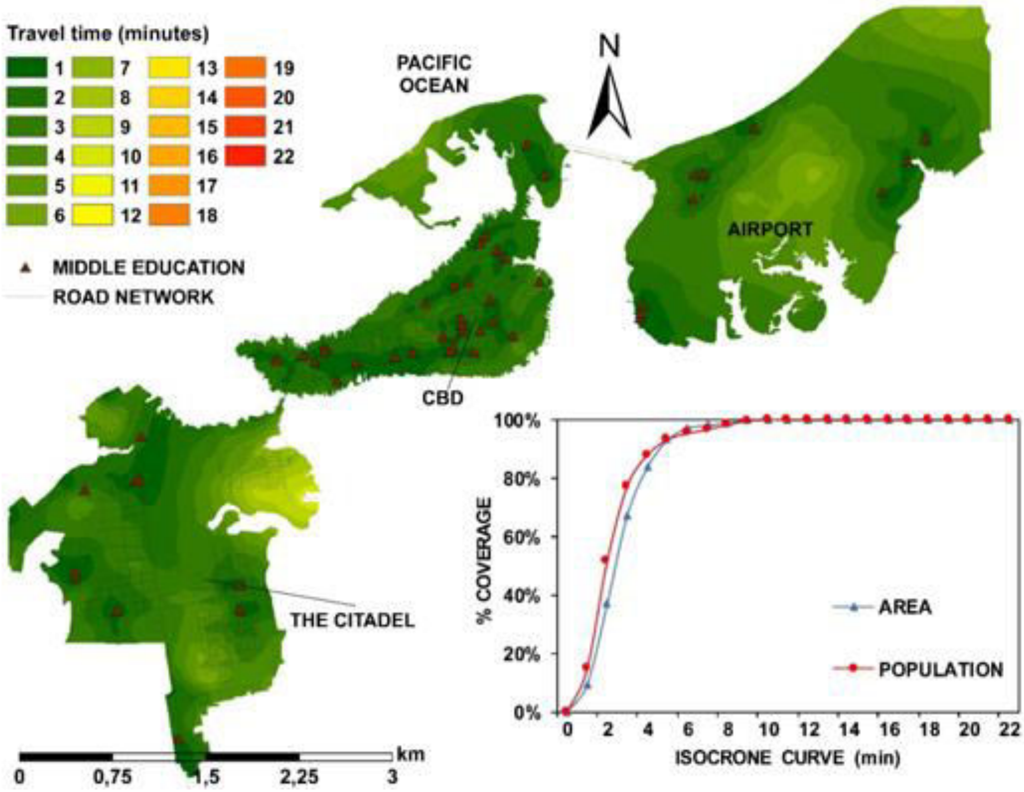

Figure-5. Accessibility and coverage curves for the set of secondary education equipment.
Source: self-made.

Continuing with the analysis of the educational NAPs, the territorial accessibility curves of the set of higher education institutions are presented. In Figure-6, it is possible to observe a maximum travel time of 21 minutes over the airport area. Likewise, there are foci with registration of up to 12 minutes in the citadel area. However, these average travel times are not exaggerated when compared to some studies from other cities, where a longer travel time is required (Escobar *et al.*, 2015; Escobar *et al*., 2017). Respectively, the population and area coverage curves show linear cumulative growth, with a slope close to 0.05, despite certain differences between curves. Regarding the percentage of coverage, a travel time of 8 minutes is required to cover 50% of the population, while for the area; it takes just over 11 minutes. This behavior refers to a higher priority in the distribution of institutions over areas of higher population density, which, despite being important, limits the processes of expansion of institutions since these regularly require extensive campuses to supply their needs.

Figure-7 presents the results obtained for health equipment. It is observed that the center sector and the citadel, report the shortest travel times with up to 11 minutes; however, the airport sector requires 7 and 18 minutes time to meet the needs of residents in this area, which implies that it would allow the inclusion of new equipment in this sector to facilitate user access.

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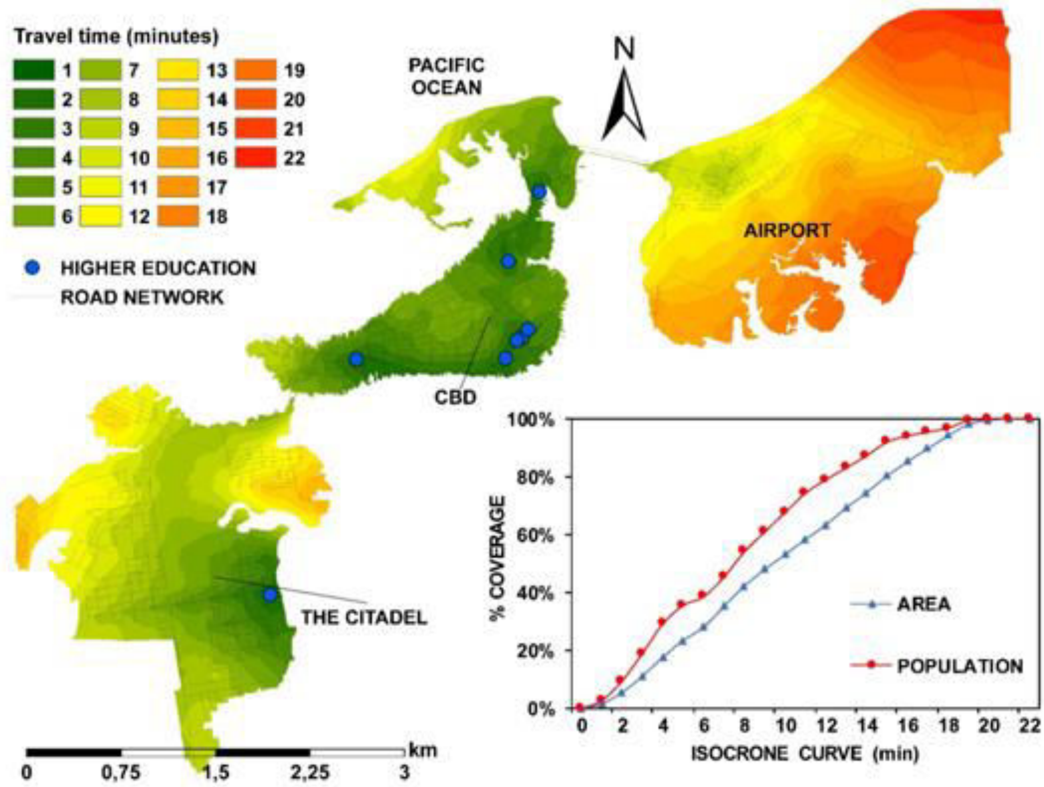

Figure-6. Accessibility and coverage curves for the set of higher education equipment. Source: self-made.

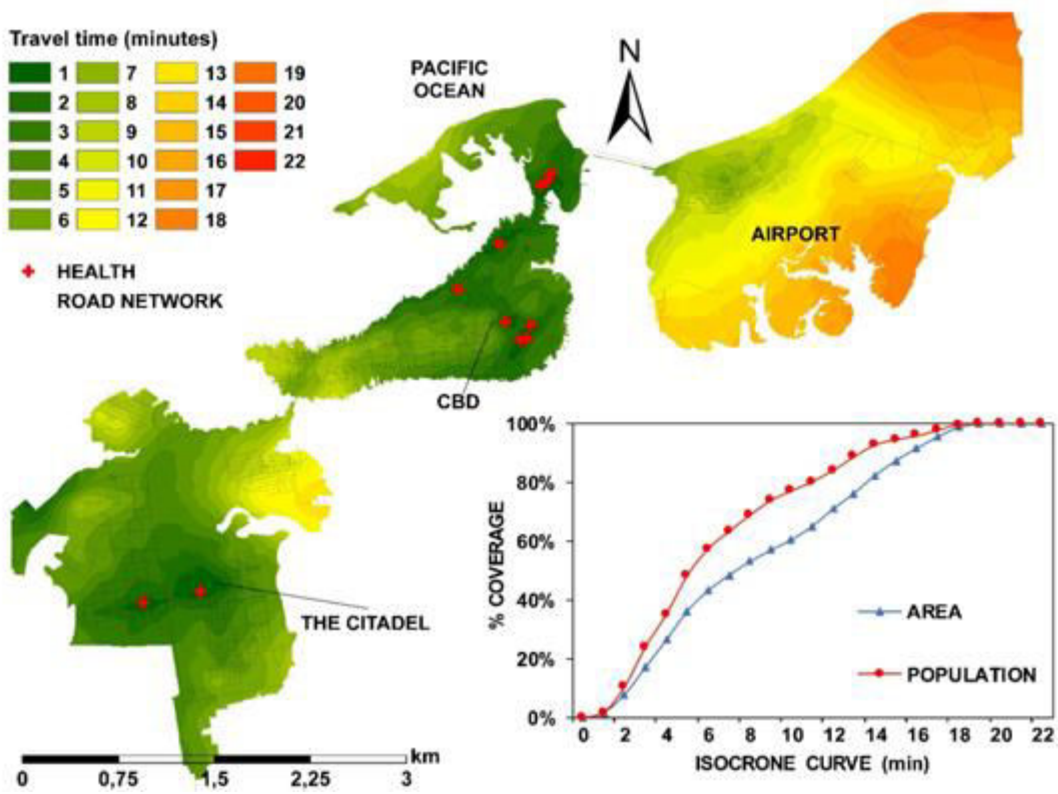

Figure-7. Accessibility and coverage curves for the set of health equipment. Source: self-made.

In the coverage section, associated to population and area for health facilities, as in higher education facilities, it is observed a prevalence towards areas with higher population density. However, the growth of the

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curves varies with respect to the slope, presenting a pronounced growth up to 4 minutes, covering about 50% of the population and 40% of the area. After this time, the growth structure decreases, reaching up to 18 minutes to supply 100% of both variables.

In Figure-8, the accessibility curves of the set of security equipment in the municipality are appreciated, as well as their respective coverage graphs. It is clearly seen that the citadel sector has the least capacity to respond to security. In this sense, the citadel sector has the longest travel time (22 minutes), anticipating the need to include a community attention point, be it CAI (Immediate Attention Center), checkpoint, or any another entity associated with the security component. On the other hand, the airport area has the best accessibility, with a maximum time of 6 minutes.

Complementing the analysis, the results of the population and area coverage are presented, according to the travel time. It is observed that the curve associated with the area obtains a greater coverage with respect to the population curve. This is due to the location of the equipment, in which they are in a less populated area. Likewise, the behavior of both curves refers to a variation in their slope, requiring about 6 minutes to supply 50% and 40% of the area and population respectively. However, the growth trend varies its slope; flattening the curve of both variables, until 100% coverage is achieved in the total time of 22 minutes.

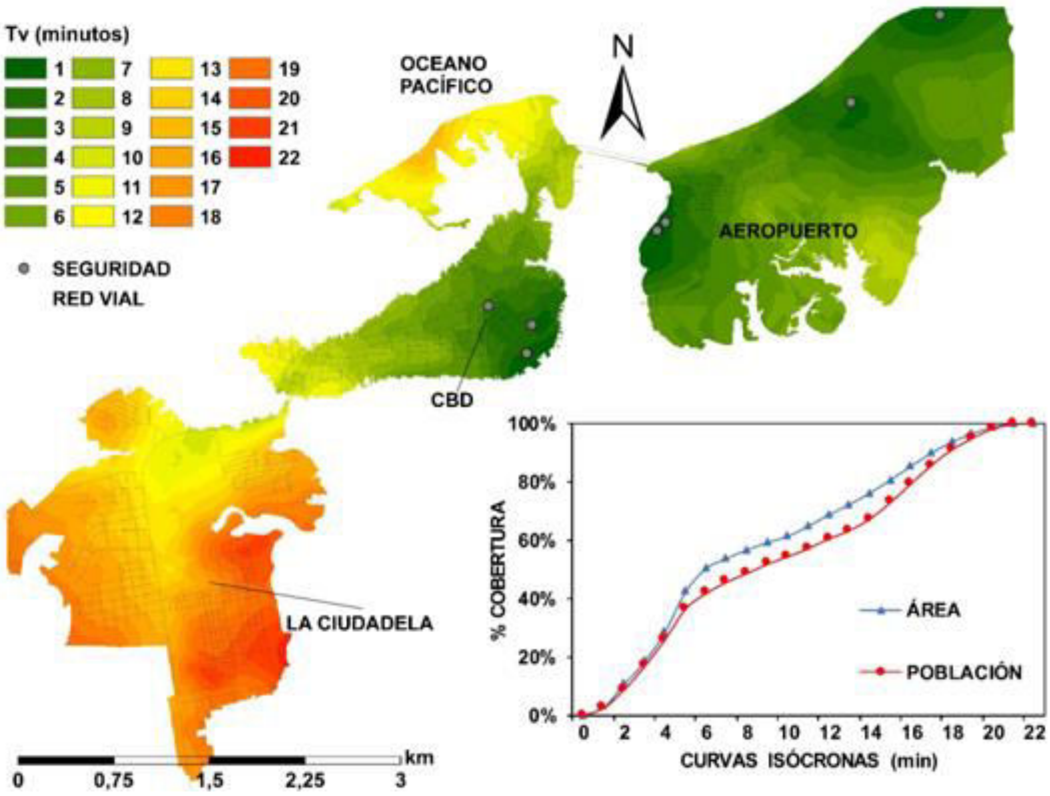

Figure-8. Accessibility and coverage curves for the set of safety equipment. Source: self-made.

Finally, in Figure-9, the comprehensive average accessibility map of the recreational facilities of the municipality of San Andrés de Tumaco is presented. an adequate distribution is appreciated, achieving coverage in less than 12 minutes, in addition to preserving the best coverage over the center area, as in the previous equipment.

In its lower part, the behavior in coverage generated by the equipment for the considered variables is shown. A joint growth between curves is appreciated, which infers an equitable distribution of the equipment. Likewise, a pronounced growth in coverage is observed, in which travel time of less than 6 minutes is required to supply 50% of the coverage in both variables.

In order to make a comparison between the coverage offered by each type of equipment, Figures 10 and 11 are presented. In the first of these, the comparison in population coverage is presented, showing that the safety equipment is the one in which the time requirement needs to meet the needs of the population; meanwhile, middle and educational facilities refer to the shortest travel times to cover their population, travel time between 8 and 10 minutes for both facilities. Likewise, higher education and health facilities also have intermediate time requirements, with respect to the ranges observed, without being as significant as in the case of safety equipment. In Figure-11, the comparison in coverage for the equipment is presented, with respect to the area. As in the population comparison, recreational and secondary education facilities report the shortest travel times. Likewise, safety equipment maintains a similar behavior to the previous graph; however, for health and education higher facilities,

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a greater time requirement is observed to supply 100% of its area, being the higher education equipment, the one with the least coverage.

Considering the comparisons presented in Figures 10 and 11, it is possible to affirm that safety, higher education and health equipment should be prioritized in order to balance their coverage models. This does not directly imply the linking of new equipment, since it is possible to attend to the areas with deficiencies with improvements in the road infrastructure, with which the operational speed could be increased. Likewise, some equipment could be relocated without affecting the areas with efficient current coverage. Additionally, it would be recommended to carry out an analysis of demand by institution; this, in order to define the number of possible institutions to include, without overselling the coverage and generating operational imbalances.

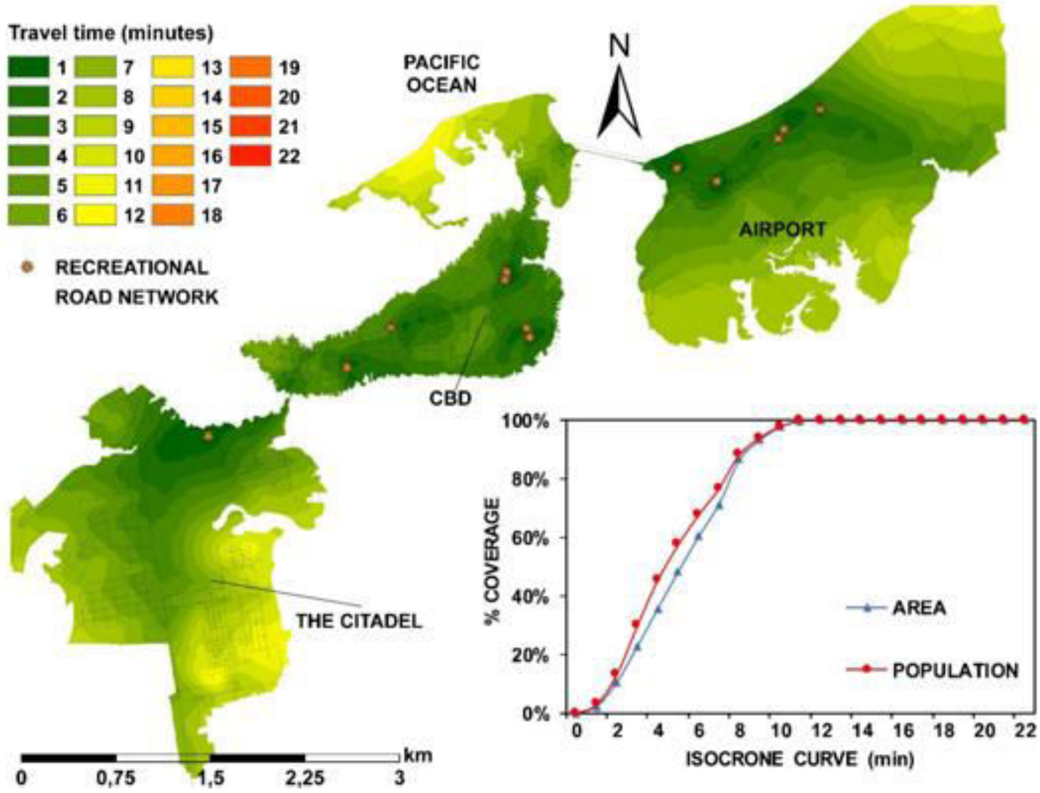

Figure-9. Accessibility and coverage curves for the set of recreational facilities. Source: self-made.

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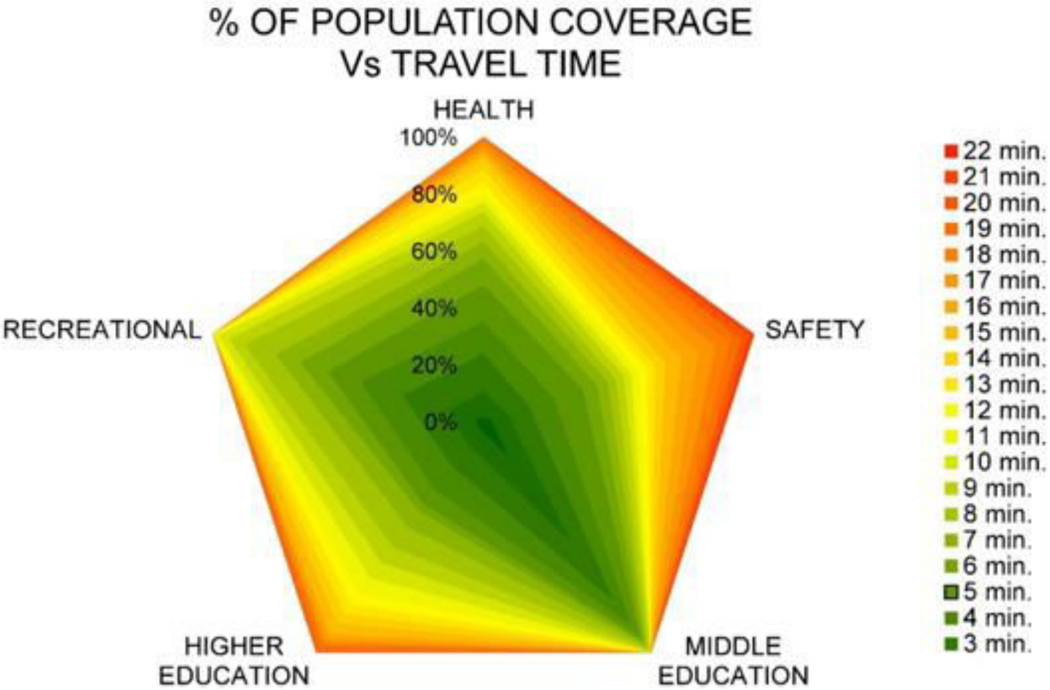

Figure-10. Comparison in population coverage for the set of facilities in the municipality of San Andrés de Tumaco. Source: self-made.

Finally, in Figures 12 and 13, the average analysis of accessibility to the set of nodes of primary activity is presented. This analysis allows to visualize the areas of the municipality with greater or lesser difficulty of access to facilities.

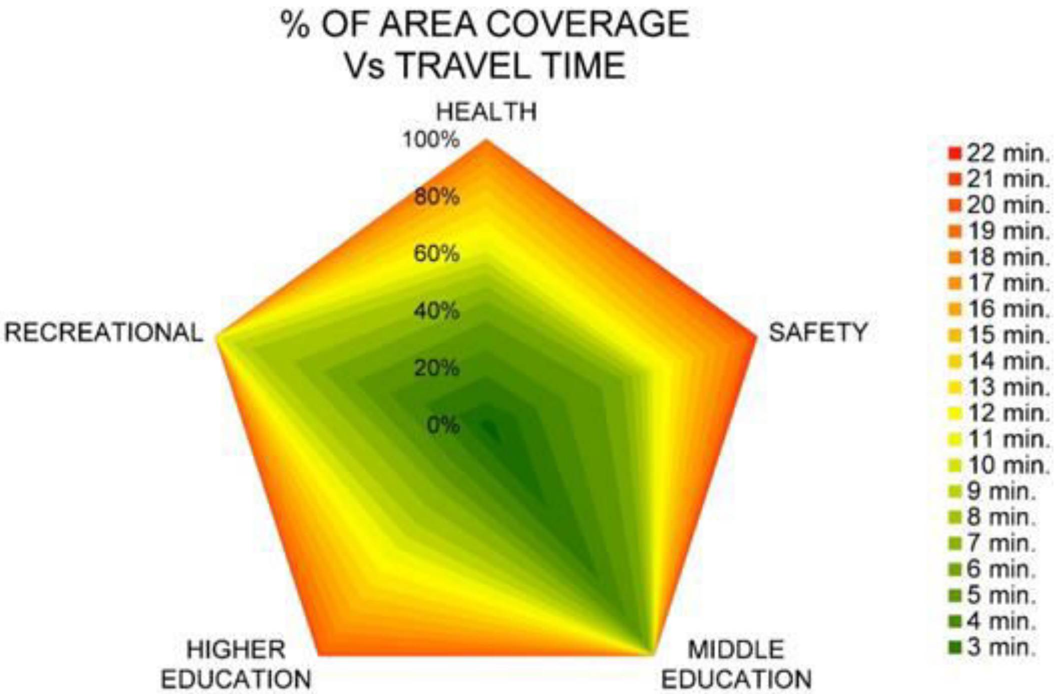

Figure-11. Comparison in area coverage for the set of facilities in the municipality of San Andrés de Tumaco. Source: self-made.

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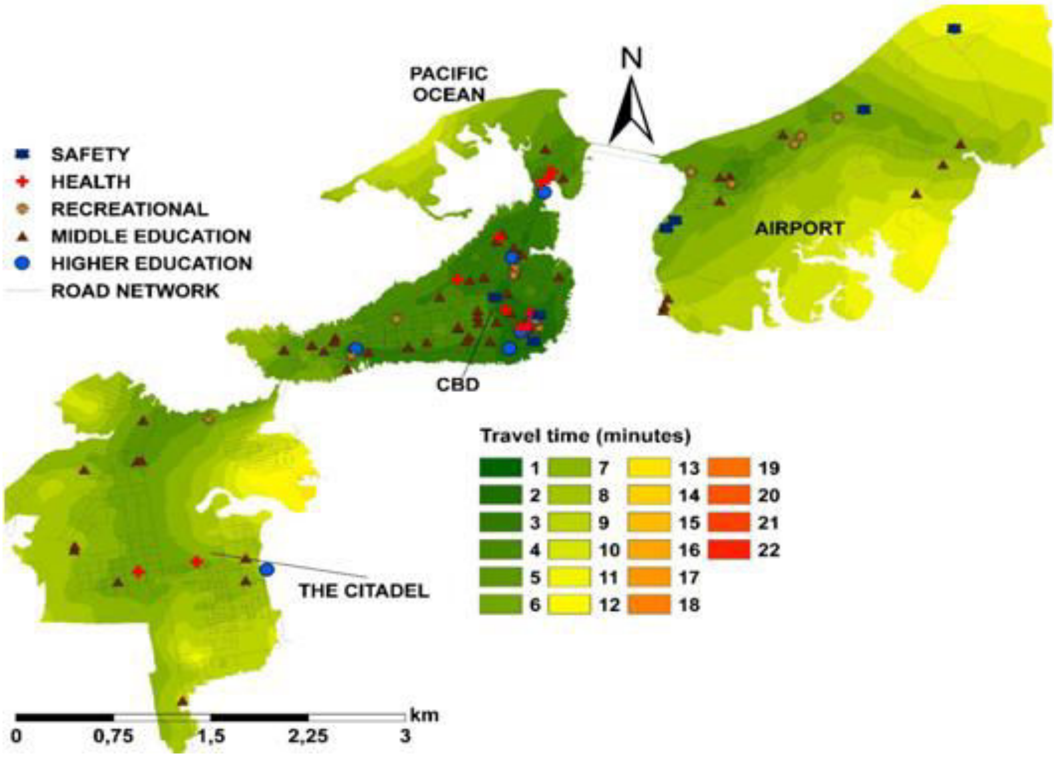

Figure-12. Average accessibility curves for the set of facilities in the municipality of San Andrés de Tumaco. Source: self-made.

Thus, the center area refers to the best accessibility with respect to the set of facilities, with a maximum average time of 6 minutes, followed by the citadel sector, which links an average accessibility of between 6 and 11 minutes, with its maximum requirement towards the eastern part of the sector. On the other hand, the airport sector reports the highest average accessibility time to the set of equipment, with its defined range of action between 7 and 12 minutes, it has a greater tendency towards 12 minutes in the southern and north-eastern part. The coverage values presented in Figure-12 show a similar behavior between curves, with a travel time between 6 and 7 minutes for 50% of the population and area.

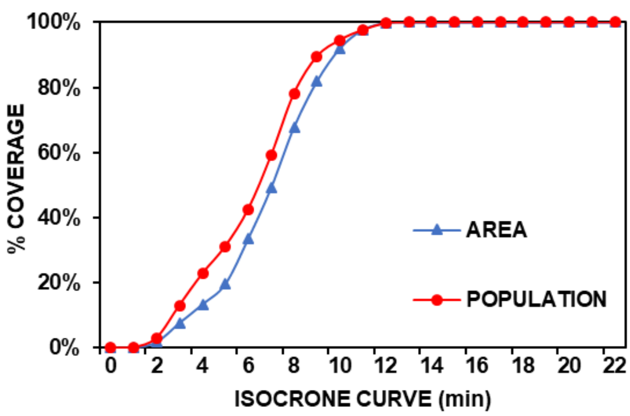

Figure-13. Population and area coverage curves for the average coverage time of facilities in the municipality of San Andrés de Tumaco. Source: self-made.

CONCLUSIONS

From the obtained results, it is possible to propose some conclusions and reflections regarding the analysis.

A good territorial accessibility of each set of equipment associated with the nodes of primary activity is appreciated, bearing in mind that the travel time observed for the municipality of San Andrés de Tumaco is less than the times present in other cities. This behavior guarantees that the population can easily access the required institutions; however, it is important to carry out a demand evaluation, in order to define if the capacity of each equipment manages to supply the population's requirements.

Regarding the individual analysis, it can be seen that the safety equipment has the lowest coverage. This implies that some attention is required regarding the inclusion of new equipment, or the improvement in the road infrastructure that allows access in less time the areas with difficulties.

In general, it is appreciated that the average access time to the set of equipment manages to supply the population demand in less than 12 minutes; an acceptable travel time if critical attention time intervals such as emergencies are considered, in which a minimum time of 10 minutes increases the survival probabilities of a user (Holguín *et al.,* 2018).

Finally, it is possible to assume that the use of geo-statistical models as evaluation tools, allow observing from a broader perspective the operation of certain activities within a city. This assessment facilitates decision-making by government entities, generating greater social and economic impact, in addition to prioritizing the sectors with the greatest shortcomings.

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