UNIVERSIDAD NACIONAL DE COLOMBIA
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A gas stations location and their relationship with the operational characteristics of a road network

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Received: February 5th, 2014. Received in revised form: October 31th, 2014. Accepted: November 26th, 2014.

Abstract
This research proposal applies geostatistical techniques to discover the relationship between the geographic locations of different gas stations and the operational characteristics offered by the transport network of the city of Manizales. This research is supported by basic information gathered for more than a year using GPS equipment (more than 18 million records). The time needed to get to gas stations is calculated as well as the spatial coverage in terms of population and area. Graphical results are obtained and these explain the time needed to get to a particular gas station. Quantitative comparisons are made among the different types of gas stations and the sectors of the city lacking gas stations coverage are established.

Keywords: Accessibility, coverage, geostatistics, gas stations, GPS.

Localización de estaciones de servicio y su relación con las características operacionales de la red viaria

Resumen
En esta investigación se aplican técnicas geoestadísticas con el fin de descubrir la relación existente entre la ubicación geográfica de las “Estaciones de Servicio” y las características operativas ofrecidas por la red de transporte de la ciudad de Manizales. La investigación se soporta en la toma de información primaria por un período superior a un año, con equipos GPS (más de 18 millones de datos). Se calculan los tiempos de desplazamiento que deben ser invertidos para alcanzar las estaciones de servicio, así como las coberturas espaciales en términos de población y área. Se obtienen resultados gráficos que explican el tiempo que se debe invertir para llegar a una determinada estación de servicio, así como comparaciones cuantitativas entre los diferentes tipos de estaciones de servicio estudiadas. Se establecen qué sectores de la ciudad presentan una deficiencia respecto a la cobertura de este tipo de nodos de actividad.

Palabras clave: Accesibilidad, cobertura, geoestadística, estaciones de servicio, GPS.

1. Introduction

Manizales is a city located in the central western region of Colombia, on the Andean mountain chain prolongation (2150 m.a.s.l.) with latitude between 5.4 degrees north and 75.3 ° Greenwich. The city has approximately 370,000 inhabitants.

The concept of "accessibility” is very important in urban and regional planning. Its origins date back to the 20s when this concept was applied in areas such as location theory and regional economic planning [1]. This research proposal focuses on an accessibility analysis that relates the geospatial location of Gas Stations (GS) and the operational characteristics of the road network. TransCAD ® and Surfer ® software were used to process the information.

The following chapters introduce a literature review, the research methodology and a discussion of the main results.

2. Literature review

Accessibility is a measure rarely used in Colombia, but is so representative that it should be recognized as a not perceived secondary need [2]. Accessibility is a means to reach priority events for the interest of the people (health care, education, employment, among others).

Currently, fuel can be considered a basic need item in

Colombia and therefore it should be accessible and affordable. The transport goals in many countries seek to eliminate class differences through increased access to services and basic need items. [3].

Accessibility is defined as a measurement of the ease of communication between activities and human settlements using a particular transport mode [4,5]. However, there are many other definitions of the term, and the most classic is: "... the potential of Opportunities for interaction. "[6]. There are different types of accessibility analyzes that tackle different applications in various fields of knowledge, such as: sustainability [7,8], economic development [9-11], demography [12], coverage analysis [13], social cohesion [14,15], transport modes operations [16, 17], studies of localization and services rendering [18-20], social networks [21], and tourism [22].

Classical models of accessibility are in terms of distance and attraction nodes [23], however, this ease is nowadays less related to the distance between two different places and more related to the distance to transport infrastructures and the reduction in connection times between regions [24]. Accessibility then becomes a key element of economic development, social welfare and land use planning [25]. Factors affecting accessibility [26] have been defined and categorized and these are: location of the nodes of activity (alpha factor), number of nodes (beta factor), transportation networks (gamma factor) and population distribution (delta factor.). It is emphasized that accessibility analyses are becoming very important in the evaluation of plans and infrastructure projects [27]. The improvement in accessibility levels is, in many cases, is one of the criteria used in these evaluations.

The GIS store large amounts of information that allow a more detailed understanding of the accessibility features offered by a particular mode of transport. One of the advantages in using the GIS is that facilitate the understanding of the behavior of the networks, which might be analyzed using algorithms (eg shortest paths) [28] providing researchers with tools to simulate such behavior.

In Colombia we have not yet implemented localization methods that include an territorial accessibility analysis, despite not find examples of GS localization if there are examples of location analysis and ethanol biofuel plants [29].

3. Methodology

The methodology of this research consists of four stages.

The first stage is related to the set up of the entire transport infrastructure network, which in turn included several sub-stages such as information acquisition and the upgrade of the georeferenced network.

The second stage is related to the calculation of the average operating speeds in the links.

The third stage is related to the calculation of the global media accessibility offered by the infrastructure network in different transport modes.

And the fourth stage is related to the calculation of the percentage of area, population and number of houses covered by the curves of average travel time obtained from the accessibility analysis and its relationship with the GS geospatial location.

3.1. Information acquisition

GPS devices were installed in different types of vehicles (cars, taxis, motorcycles, trucks and Urban Public Transport), in order to gather satellite positioning data according to a predetermined time interval (one second).

Basic information was obtained from vehicles and the calculation of average travel time was done on each of the links that make up the system. A field study was carried out to identify the GS, categorizing the type of fuel offered and verifying their geospatial location.

3.2. Upgrade of the georeferenced network

The road network provided by the Municipal Administration was analyzed and the information was supplemented with data provided by the fieldwork using GPS equipment, which allowed the correction and validation of the geographic information. The city of Manizales has a network of more than 12,000 links and around 9,000 nodes.

3.3. Calculation of operating speeds and instantaneous speed

Operating speeds are calculated from real data and show the true operational characteristics of the links in the network. This is important because in accessibility analysis the operating speeds are usually assumed according to the category of the road [29]. However, recent research on accessibility takes into account the actual speeds of vehicles [30].

Different calculation algorithms were required to process all the information to carry out the project. The operating speed is calculated in each link of the network using the data of time constantly obtained by the GPS.

Three parameters were examined: (1) the speed of the vehicle each data interval reading along the i-th link, (2) the average operating speed of the ith link, and (3) the operating speed in each link i of a specific route.

3.3.1. Calculation of instantaneous speed

The operating speed per time interval between points 1 and 2 was obtained using eq. (1).

$$v_i = \frac{3.6}{t}\sqrt{(y_2 - y_1)^2 + (x_2 - x_1)^2} \quad (1)$$

Where:

v_i = Speed in Km/h

x_1, y_1 = Coordinates in meters of point 1.

x_2, y_2 = Coordinates in meters of point 2.

t = Time interval in seconds between datum and datum

This parameter is used to identify speed variations in a link, to determine the number of stops when values equal zero, and also to establish the durations of these stops.

3.3.2. Calculation of the average speed of a trip in the link

The average travel speed in a link was obtained using the relation between the link length and the difference in the traveling times between the initial node and the end node (see eq. 2).

$$v_i^a = 3.6 \frac{l_a}{t_2 - t_1} \quad (2)$$

Where:
v_i^a = Speed i in link a (km/h),
l_a = Link a length in meters,
t_1 = Travel time in the initial node,
t_2 = Travel time in the end node.

3.3.3. Calculation of the average speed in the link in a time period

The speed average in the link in a period of time is calculated by the application of eq. 3. This speed is calculated in each link of the road network and is used to set the impedances through this matrix of minimum times.

$$\overline{v_a} = \frac{\sum_{i=1}^{n} v_i^a}{n} \quad (3)$$

Where:
$\overline{v_a}$ = Average operating speed in link a,
n = Number of speed data recorded in link a in a period of time.

3.4. Calculation of Global Media Accessibility

Global Media Accessibility is analyzed beginning at the vector of average travel time, which represents the average travel time from node i to the other nodes of the road network.

The indicator tends to favor the nodes located at the center of a network, because its geographical location makes travel times shorter from these nodes to the others. The unimodal matrix of distances must be obtained to get the vector of average travel time. Then, the matrix of minimum average travel times is designed using the average operating speed in each link, in which the average travel time between all the nodes in the network is minimized.

The vector of average travel time obtained (nx1) is related to the geographic coordinates (latitude and longitude) in each of the nodes, resulting in a matrix of order (nx3) which in turn generates isochronous curves of average travel time.

Four scenarios were analyzed:

- Scenario 1 takes into account all the GS without classifying the type of fuel;
- Scenario 2 takes into account only GS distributing premium gasoline;
- Scenario 3 takes into account GS distributing regular gasoline and diesel fuel;

Figure 1. Location of the GS in the city of Manizales.
Source: Author's design.

- Scenario 4 takes into account GS distributing natural vehicular gas -CNG.

4. Results and discussion

4.1. Scenario 1 (All the GS)

Initially, the geospatial location of all the GS were studied together, without considering the type of fuel distributed. Citywide there were 31 GS. Fig. 1 shows the spatial location of the GS in the city of Manizales.

The results show the relationship between the location of the GS and the operational characteristics of the road network. The area reporting greater accessibility to GS nodes refers an average travel time of 4 minutes, covering a wide sector of downtown and expanding on both sides of main roads such as Avenida Centenario and Avenida Kevin Angel.

Fig. 2 shows the area of the city covered by the curve of shorter average travel time. An analysis of the entire urban area shows that it is possible to reach a GS operating at an average travel times between 4 and 22 min. approx.

The analysis of coverage of area, population and housing, regarding time curve, provide a better diagnosis of the geospatial location of the GS.

Table 1 shows the results of coverage percentages. The curve of 6 minutes has the highest coverage percentage for the variables area and number of houses. This differs from the variable population where the curve of 10 minutes covers the largest amount of people.

Fig. 3 shows the cumulative percentage of area, population and number of houses covered by isochronous curves. The three variables show quite similar behavior in terms of slope and coverage percentages.

It is concluded in the first scenario that 50% of the population would get to a GS in 7.7 minutes of average travel time. This value decreases to 7.4 minutes with regards to the variable number of houses. Northwest, northeast and south sectors show the longest coverage times making them areas with greater difficulties in getting to GS.

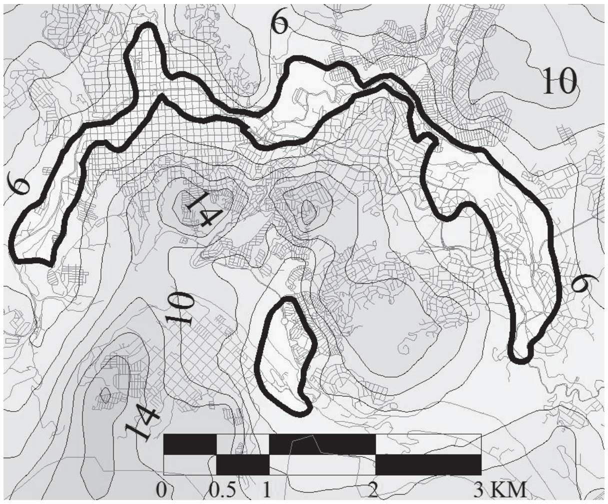

Figure 2. Curve of shorter average travel time, scenario 1.
Source: Author's calculations.

Table 1.
Coverage percentage according to the time curve. Scenario 1.

Isochrone curve	Area		Population		Housing	
	Km^2	%	N° People	%	N° Housing	%
4	3,6	9%	43.006	11%	11.875	13%
6	9,7	24%	79.903	20%	20.226	22%
8	8,0	20%	87.534	22%	19.243	21%
10	8,1	20%	93.141	23%	19.949	22%
12	5,8	14%	60.553	15%	13.398	15%
14	3,1	8%	23.420	6%	5.190	6%
16	1,1	3%	6.642	2%	1.306	1%
18	0,7	2%	2.469	1%	531	1%
20	0,1	0%	356	0%	69	0%
22	0,0	0%	171	0%	32	0%
Total	40,2	100%	397.194	100%	91.817	100%

Source: Author's calculations.

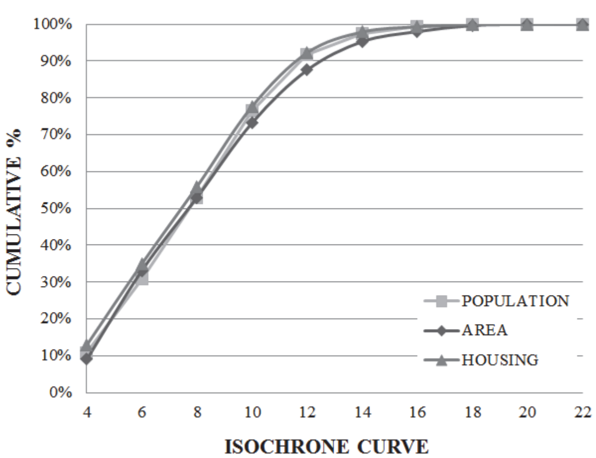

Figure 3. Cumulative Percentage Vs average travel time, isochrone curve. Stage 1.
Source: Author's calculations.

4.2. Scenario 2 (premium gasoline)

18 out of 31 GS (58%) in the city of Manizales distribute premium gasoline. Fig. 4 shows a zoom of the sector of the city to be reached by the shortest average travel time; 4 minutes. This curve is located along the Avenida Kevin Angel (eastern sector).

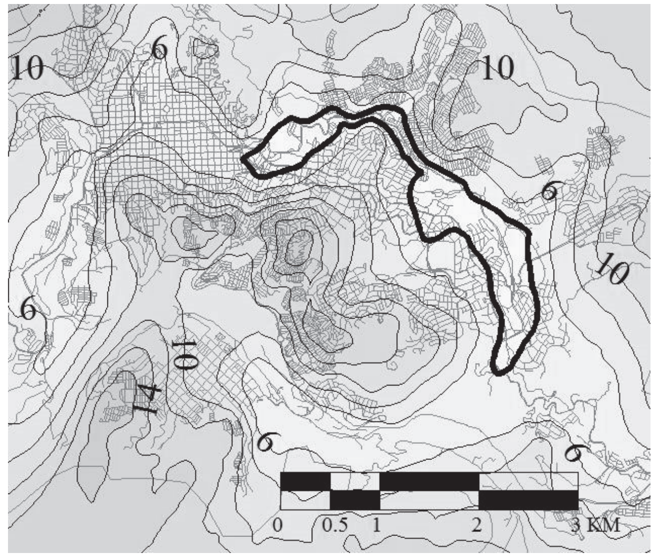

Figure 4. Curve of shortest average travel time. Scenario 2.
Source: Author's calculations.

Table 2. Coverage percentage according to the time curve, scenario 1.

Isochrone curve	Area		Population		Housing	
	Km^2	%	N° People	%	N° Housing	%
4	1,8	5%	19.859	5%	6.527	7%
6	7,7	19%	69.735	18%	18.301	20%
8	7,0	17%	81.720	21%	18.603	20%
10	8,5	21%	90.089	23%	19.304	21%
12	6,0	15%	63.320	16%	13.057	14%
14	4,1	10%	40.071	10%	8.500	9%
16	1,8	4%	19.510	5%	4.171	5%
18	1,1	3%	6.368	2%	1.729	2%
20	0,5	1%	1.561	0%	559	1%
22	0,5	1%	1.131	0%	307	0%
24	0,5	2%	989	0%	218	0%
26	0,4	1%	785	0%	145	0%
28	0,1	0%	629	0%	128	0%
30	0,1	0%	426	0%	112	0%
32	0,1	0%	535	0%	92	0%
34	0,1	0%	466	0%	65	0%
Total	40,2	100%	397.194	100%	91.817	100%

Source: Author's design.

It is easily identified in Fig. 2 that the western area of the city is not covered by this time curve.

Table 2 shows the coverage percentages obtained in the GS distributing premium gasoline. The city is covered by curves of average travel time between 4 and 34 minutes.

The curve of 10 minutes has the highest percentage regarding the three variables (area, population and number of houses).

Comparing the above results to those obtained in Scenario 1, and analyzing the variable population, it is observed that 100% of the population in scenario 1 is covered in 18 minutes of average travel time, whereas, 98% of the population in scenario 2 is covered by the same time curve; a difference of approximately 7,950 inhabitants.

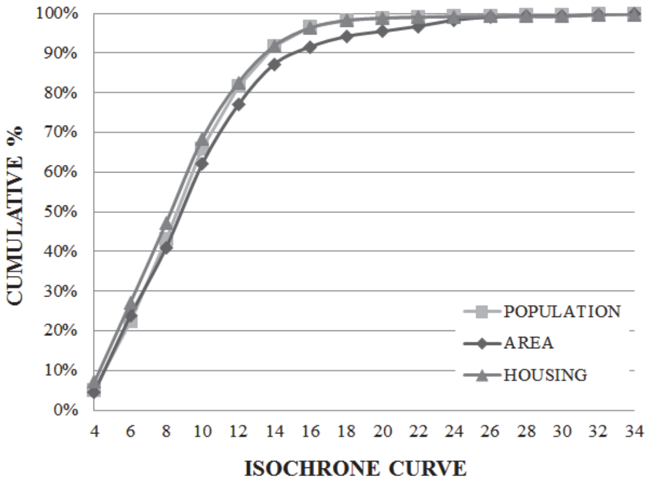

Figure 5. Cumulative Percentage Vs average travel time, isochrone curve. Stage 2.
Source: Author's calculations.

However, scenario 2 refers a coverage difference of 23,150 inhabitants regarding scenario 1 in the time curve of 4 minutes.

Fig. 5 shows the cumulative percentage of area, population and number of houses covered by isochronous curves.

It is concluded that 50% of the population would get to a GS in about 8.6 minutes of average travel time in scenario 2. Compared to scenario 1, and regarding the variable number of houses, this value decreases to 8.3 minutes; it takes extra time to get to a GS that distributes premium gasoline.

It was found that the central and western sectors of the city have higher operational limitations to get to a GS that distribute premium gasoline; situation not present in the eastern sector. A large percentage of upper class houses sit in the eastern part of the city.

4.3. Scenario 3 (regular gasoline and diesel)

30 out of the 31 GS distribute regular gasoline, and 29 distribute diesel. The results are quite similar to those obtained in scenario 1, finding only some differences in the percentages of coverage of some curves of average travel time.

It is concluded that in scenario 3, 50% of the population would get to a GS in 7.7 minutes of average travel time. This value decreases to 7.5 minutes in the variable number of houses.

As in scenario 1, the northwest, northeast and south areas show the greatest coverage times, making them areas with greater difficulties in getting to a GS that distribute regular gasoline or diesel fuel.

4.4. Scenario 4 (Vehicular Natural Gas - CNG)

12 out of 31 GS distribute CNG, this is 39%. Fig. 6 shows a zoom of the area covered by the shortest average travel time curve (4 minutes). This curve expands along Avenida Kevin Angel and towards an important sector of the center of the city. It also shows a small covered area around the Intermunicipal Transport Terminal.

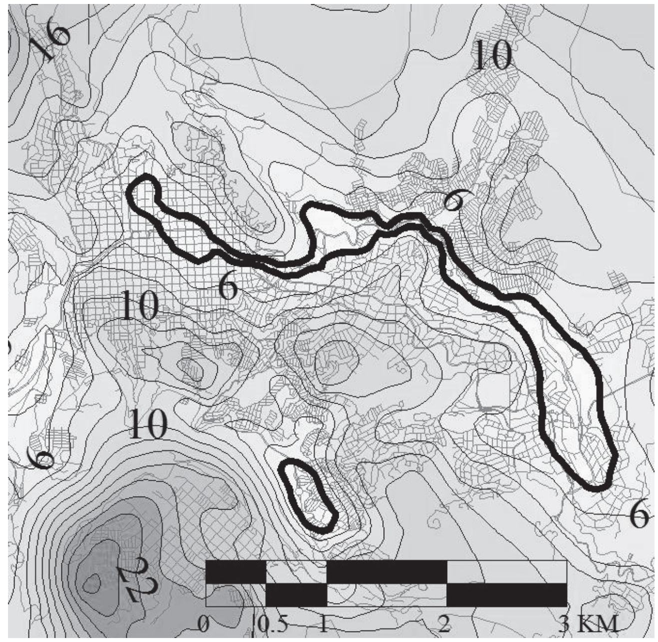

Figure 6: Shortest average travel time curve, scenario 4.
Source: Author's calculations.

Compared to the curve obtained for premium gasoline (see Fig. 4), there is more coverage of GS that distribute CNG towards the west sector of the city.

Table 3 shows the coverage percentages obtained for GS that distribute CNG. The city is covered by average travel time curves between 4 and 40 minutes. That is to say that the longest time to get to a GS that distribute CNG is 40 minutes. The curve of 8 minutes refers the highest percentage in the variables population and number of houses.

Comparing these results with those obtained in previous scenarios, and analyzing the variable population it is observed that 100% of the population is covered in 18 minutes of average travel time in scenarios 1 and 3. The same time curve covers 98% of the population in scenario 2, while 93% of the population is covered in scenario 4.

The percentage ogive shown in Fig. 7 shows the relationship between the isochronous curve and the coverage percentage for the three variables studied. It is important to highlight that 90% of the population might get to a GS that distributes CNG in a maximum of 16 minutes of average travel time.

It is concluded that 50% of the population would get to a GS in 8.9 minutes of average travel time in scenario 4. This value decreases to 8.6 minutes for the variable number of houses. This means that it takes longer to get to a GS that distributes CNG than to one distributing premium gasoline.

An additional result is that most of the GS that distribute CNG are located along the main vehicular corridor in western direction - east and west, and are conspicuously absent in the corridor south - north and north-south.

Table 3: Coverage percentage according to the time curve, scenario 4.

Isochrone curve	Area		Population		Housing	
	Km^2	%	N° People	%	N° Housing	%
4	2,0	5%	22.190	6%	6.311	7%
6	3,9	10%	54.298	14%	14.022	15%
8	7,6	19%	83.817	21%	19.647	21%
10	7,7	19%	83.179	21%	18.185	20%
12	6,0	15%	62.921	16%	12.652	14%
14	5,1	13%	36.708	9%	7.842	9%
16	2,7	7%	16.222	4%	4.414	5%
18	1,0	3%	8.637	2%	2.229	2%
20	1,0	2%	8.617	2%	2.036	2%
22	0,9	2%	6.322	2%	1.416	2%
24	1,0	2%	6.152	2%	1.375	1%
26	0,8	2%	2.838	1%	637	1%
28	0,4	1%	2.737	1%	568	1%
30	0,1	0%	981	0%	191	0%
32	0,0	0%	418	0%	77	0%
34	0,0	0%	343	0%	64	0%
36	0,0	0%	415	0%	77	0%
38	0,0	0%	301	0%	56	0%
40	0,0	0%	99	0%	18	0%
Total	40,2	100%	397.194	100%	91.817	100%

Source: Author's calculations

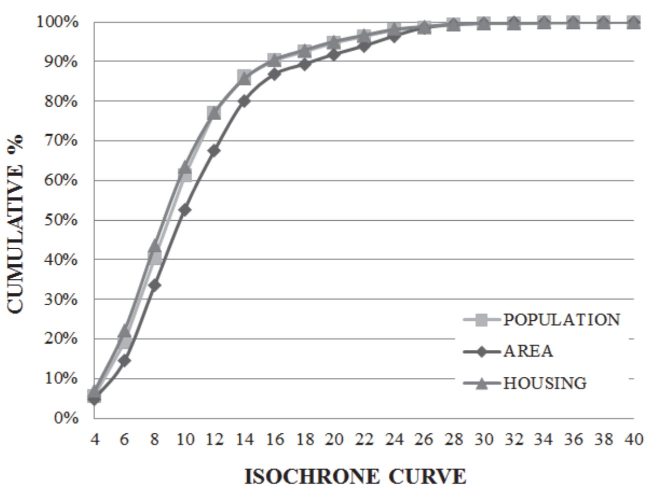

Figure 7: Cumulative Percentage Vs average travel time, isochrone curve. Stage 4.
Source: Author's calculations.

5. Conclusions

It is possible to get to a GS in the city of Manizales in an average travel time of 4 and 22 minutes.

The worst scenario is regarding GS that distribute CNG as it might take between 4 and 40 minutes to get to these GS. The importance of location has been recognized for years as one of the influencing factors in the economic development of a country, region or city [31].

The coverage percentages were calculated taking into account the variables area, population and number of houses in each GS of the city. This was done to determine the GS reporting greater coverage and thus referring a better relationship between geospatial location and the operational characteristics of the road network of the city.

Fig. 8 shows the geographical location of the GS that refer greater coverage of the isochronous curve of 5 minutes. It was found that GS presenting greater coverage are located towards the eastern sector of the city (green fill), with a value of 3.5% of the covered urban area. Regarding the variable population (red fill), GS of greater coverage are located in the downtown area, with a value of 4.5% of the urban population.

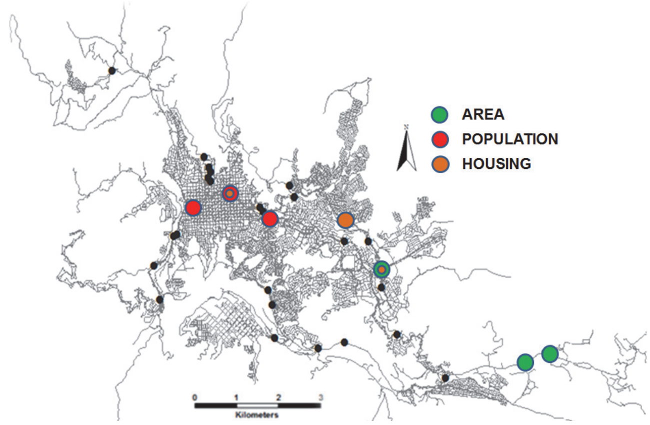

Figure 8. Location of the GS of greater geospatial coverage. 5 min. isochrone curve.
Source: Author's calculations.

Regarding the variable number of houses (orange fill), the GS of greater coverage is located further est (GS Laureles). The GS with the greatest population coverage is located further west (GS Carrera 18). The third GS of higher coverage of number of houses is located among the above mentioned on Avenida Kevin Angel (GS La Carola).

Fig. 9 shows the geographic location of the GS referring the greatest coverage of the isochrone curve of 15 minutes. Regarding the variables of population and number of houses, the three GS of greater coverage are located towards downtown, two on Avenida Santander (Cervantes and Caldas GS) and one on Avenida Kevin Angel (Los Cedros GS). These GS cover 46% of the population and 47% of the number of houses in 15 minutes of average travel time.

Regarding the variable area, the GS of greatest coverage in the curve of 15 minutes is located towards east. Researchers need to design tools based on maps to show the

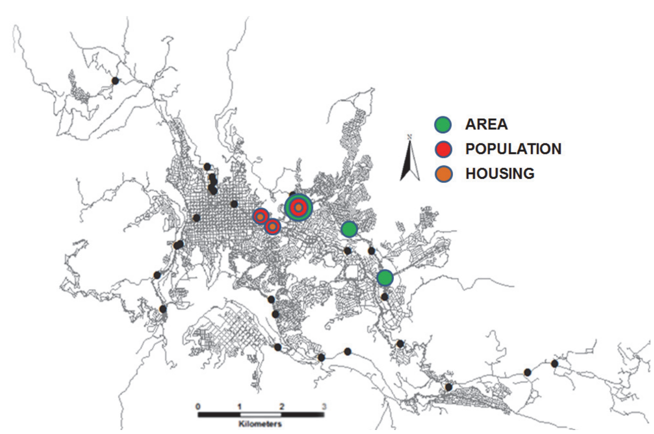

Figure 9. Location of GS of greater geospatial coverage. 15 min. isochrone curve.
Source: Author's calculations.

specific effects of changes in accessibility [32], especially when the aim is to study the location of new activity nodes.

The results obtained show that the Northwestern sector, the sector on the Pan-American Highway towards east, and the southern sector of the city (Villamaría) are three areas in the city that would benefit from a new GS.

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