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SPATIAL EQUITY ANALYSIS OF EDUCATIONAL SERVICE. METHODOLOGICAL PROPOSAL BASED ON A TRANSPORT SUPPLY MODEL

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Abstract: This study evaluates the spatial equity of the educational service provided in the urban areas of Manizales and Villamaría based on the hypothesis that there is inequity in the provision of this service. Methodology involves GIS-based territorial accessibility analysis using average travel times from a network of transport infrastructures as well as the geographical location of all formal education establishments. This methodology is designed to be applied on different locations around the world. As the main results, the areas with mixed values concerning educational provision are in the lower strata, which directly correlates with low spatial educational equity rates.

Key words: accessibility, education, equity, geo-statistics, public transport

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INTRODUCTION

Education is an essential component for all types of regions, influencing the progress and development of modern societies, essential for all inhabitants to a basic degree to live comfortably, advancing towards better economic and social standards. Global experience shows that there is a close correlation between the country's level of development and the strength of its education and scientific and technological research systems. According to studies by the Organization for Economic Co-operation and Development (OECD), an additional year of schooling increases a country's gross domestic product per capita by 4-7% (OECD, 2010). Education has come to be called a basic need by the United Nations (ONU, 2018), which gives it an important role, especially when talking about developing countries such as those in Latin America. Colombia is an unequal country (Sánchez, 2016), heavily damaged and fragmented by the violence of the 20th century, currently in a period of overall growth and development, facing significant challenges to reach all its regions with the need to close gaps (Sánchez, 2016), for which education plays a key role.

Manizales, capital of Caldas department, located in the Colombian coffee region, with geographical coordinates 5° 03' 58" north latitude and 75° 29' 5" west longitude (Figure 1), has an abrupt topography with an average elevation of 2150 meters above sea level (m.a.s.l.), limiting the processes of urban expansion and intervention (Robledo, 1996). The population registered in the 2018 national census is 400,436 inhabitants (National Administrative Department of Statistics - DANE, 2019). The municipality has a total surface area of 57184 hectares, of which 3818.58 hectares correspond to its urban area (Alcaldía de Manizales, 2019); however, in this research, an area of 5429 hectares is used, considering sectors with transport and public services influence. The transport infrastructure network, the inventory of institutions, and in general, the whole analysis is extended to the neighboring municipality of Villamaría in its urban area to obtain more accurate results in terms of educational coverage. Villamaría is incorporated due to its conurbation with Manizales, sharing economic conditions and connectivity, acting as an additional neighborhood to the capital of the department. It is located on one side of the central mountain range at 5° 02' 44" North latitude and 75° 30' 55" West longitude, with a total area of 46100 hectares, of which only 438.3 belong to the grouping of its urban environment together with the expanding sector of La Florida (Alcaldía de Villamaría, 2018). The total population of the municipality is 62,831 inhabitants as of 2018 (DANE, 2019).

Manizales and its metropolitan area have ranked first in Colombia in the provision of university education services. However, its performance at other educational levels (pre-school, kindergarten, primary, secondary and high school) has not been the best (Consejo Privado de Competitividad and Universidad del Rosario, 2020), ranking 18th among the capitals

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of the 32 departments of the country, with special shortcomings in the area of educational coverage, in which it ranked 22nd, 25th, 22nd and 15th, for pre-school, primary, secondary and high school education respectively among the 32 departmental capitals. It is, therefore, necessary to strengthen the conditions of equity and access to this service, not only as a means of building capacities and social mobility but also as a source of economic development. The analysis includes 209 educational establishments, divided into 25 for higher education and 184 for basic education, of which 70 provide early education services, 121 basic primary education, 84 basic secondary education, and 82 secondary education, many of which share several levels of education within the same infrastructure. In terms of higher education institutions, there are 13 of a technical-technological type and 12 professional ones, of which 4 correspond to faculties of the University of Caldas and 3 to the National University of Colombia, Manizales campus, leaving 8 universities altogether.

Nowadays, spatial equity refers to the equality that different residents have in accessing a particular service regardless of their social class, income, or ethnicity (Rahman and Rigar Neema, 2015). Measurements mainly include analyses based on geographical accessibility, the Gini coefficient, the Lorentz curve method, the coefficient of variation, and the Teil index (Hu et al., 2019). In terms of accessibility, Hansen (1959) defines it as the potential of opportunities for interaction, the first definition of the term in the geographical context. The potential for opportunities to interact that a particular group of people have in a particular area is then taken as a basis, supported by the argument that accessibility is a measure of spatial distribution from a point, adjusted for the ability and desire to overcome spatial separation. The concept has also been defined as the ease of getting to some activity from a location by a particular mode of transport (Dalvi and Martin, 1976), and taken together with mobility as influencing an individual's ability to travel in everyday life (Morris et al., 1979).

Years after Hansen defined it, some subdivisions of accessibility emerged, with Ingram making the first breakthroughs by defining relative accessibility as the distance or measure of interaction between two points and integral accessibility as the ease of access to a point from a set of nodes connected by a network (Ingram, 1971). Integral accessibility has gained considerable traction and different types of measures of accessibility have been proposed, such as gravity-based, cumulative opportunity-based, and topology- or distance-based measures (Handy and Niemeier, 1997; Pirie, 1979).

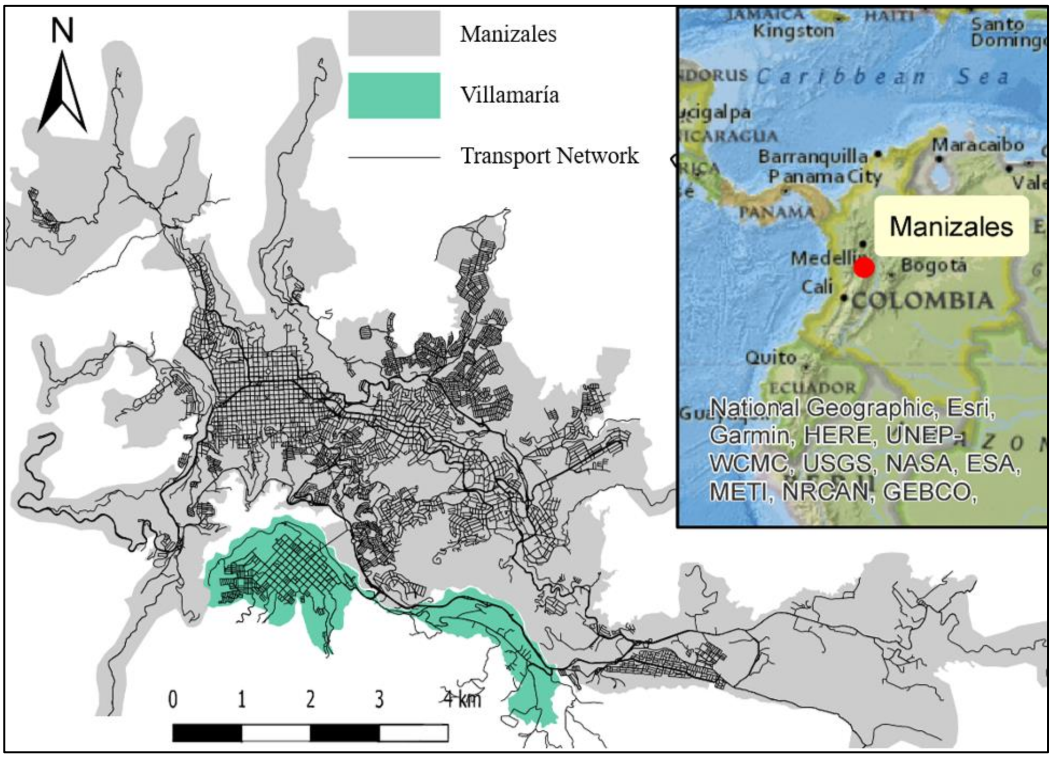

Figure 1. Geographical location of the study area (Source: authors)

Accessibility studies on the location and coverage of educational facilities have been carried out in different parts of the world, using a variety of methodologies to evaluate access to this service. For example, Ireland uses distance measures for its accessibility calculations (Walsh et al., 2015); Canada takes variables in addition to distance such as parental schooling and economic factors (Frenette, 2006); England uses the distance between home dwellings and universities (Gibbons and Vignoles, 2012); Portugal analyses the variables involved in decisions to study away from home (Sá et al., 2011). In addition, the Netherlands analyses the impact of geographical accessibility to higher education institutions and the influence of school background (Sá et al., 2006); Germany includes socio-economic variables (Spiess and Wrohlich, 2010); and Colombia conducts analyses of territorial accessibility to primary activity nodes (Escobar et al., 2016) and assessments of the spatial equity of educational service at the basic level (Avendaño, 2012).

In Manizales, the closest studies involve equity analyses of the university sector (Younes et al., 2016). Studies regarding the location of educational facilities and coverage have focused on single-level educational institutions, mostly on higher education. Additionally, few involve measures of spatial equity, highlighting the assessment of spatial disparities in access to primary and secondary schools in China (Gao et al., 2016); however, they point, generally, to other objectives being met, using accessibility measured through distance as the assessment value. In recent years, research has been developed around the world related to spatial equity and education, taking as an example the analysis of spatial equity in electric vehicle charging services in China (Li et al., 2022), analysis of spatial equity and access to urban parks in Iran (Fasihi and Parizadi, 2020) and analysis of accessibility to health care centers in China by different researchers (Yang et al., 2022; Liu et al., 2023) as clear examples of spatial equity analysis. While focused on education, Pizzol (Pizzol et al., 2021) published an investigation of accessibility to schools in Sao Paulo including the quality factor.

Studies involving the whole education service, spatial equity, and using travel time as the main variable in accessibility levels are so far non-existent. Therefore, this research aims to close the knowledge gap and proposes a methodology for calculating the Educational Equity Index (EEI), based on the analysis of social, economic, demographic, geographic, operational, spatial, and physical variables, by using measures of territorial accessibility and geostatistical models, through geographic information systems (GIS), assuming the existence of a strong inequity in educational service provision at all levels (initial, basic, middle and higher) in the study area, considering the geospatial configuration of the institutions and transport networks and the current conditions of the mentioned variables.

MATERIALS AND METHODS

The methodological procedure used in this study is shown in Figure 2, following six broadly defined steps subdivided into tasks that are more specific.

Phase 1 – Network update and validation: Investment in road infrastructure has been high over the past decades, changing travel conditions and making it necessary to update the digitized transport infrastructure network with the most recent works for a proper calculation of travel times and accessibility levels. New connections, turns, and reroutes are verified with online or field network viewers if necessary. The network for public and private transport is updated for the year 2021 based on an analysis network for public transport accessibility studies in the city, updated and optimized by Montoya (Montoya, 2019), based on the network previously built by the National University of Colombia, with speeds measured via GPS (Escobar and García, 2012; Younes et al., 2016) and excellent coverage of the study area. The updating process was carried out in the ArcMap program, using its network-editing tool, where it is possible to create and modify arcs or lines, as well as to calculate the real length of the new elements. Figure 3 shows the network used for the particular transport study, which has a total of 10,133 nodes and 12,766 arcs assigned for the different existing roads. On the other hand, the same updates were made to the public transport scenario, making similar changes and additions, but always maintaining the original differentiation and configuration of the network, which contains 19,838 arches and 15,380 nodes. The higher number is due to the existence of a pedestrian network base very similar to that of private transport, with some additional pedestrian-only crossings such as bridges and stairs, superimposed by the network composed of public transport routes, connected to each other at the location of the stops. As a basic input for the process, it is necessary to have the travel times calculated within the digitized network; these times are obtained by considering the length of the arches and the average speed assigned. Through equation 1, the travel times for the arcs are calculated within the ArcMap field calculator tool. Where: TV = Travel Time; Li= Length of the arc in km; Vi= Speed assigned to the arc in km/h.

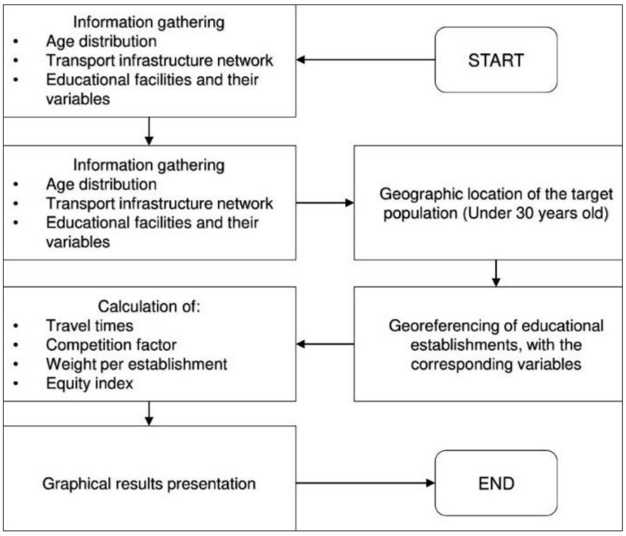

Figure 2. Research Methodology (Source: authors)

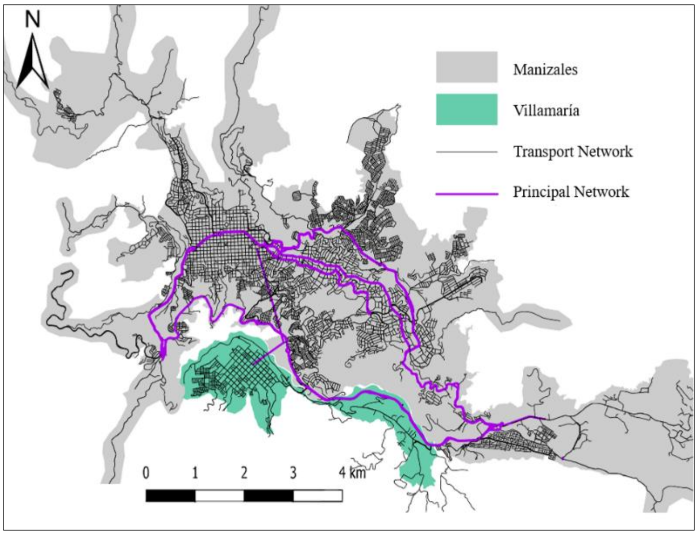

Figure 3. Private transport network (Source: authors)

$$TV = \frac{\text{Li}}{\text{Vi}} * 60 \tag{1}$$

Phase 2 – Target population: The population under consideration corresponds to people of school age, defined in our case as those inhabitants under 30 years of age since the study includes institutions from the first to the last stage of education. The age distribution is obtained from official databases (DANE, 2019) and is shown in Figure 4 with a graphical partitioning of natural breaks so that similar values are better grouped together and differences between classes are maximized.

Phase 3 – Facilities location: This is an important aspect in the development of the research, as the results will vary depending on the spatial distribution of the institutions. The geographical location was checked for all educational establishments so that there were no overlaps with other properties, they did not occupy part of the public space, or they were not at their real address; this last check is done with the help of Google Street View or in situ if necessary. Once the database had been optimized, the institutions were geo-spatially located in a new layer of polygons within the ArcMap program, using the tool to create new Shape-type entities, separating them by the educational level at which they provide. Figure 5 shows the geographical distribution of educational institutions in the study area.

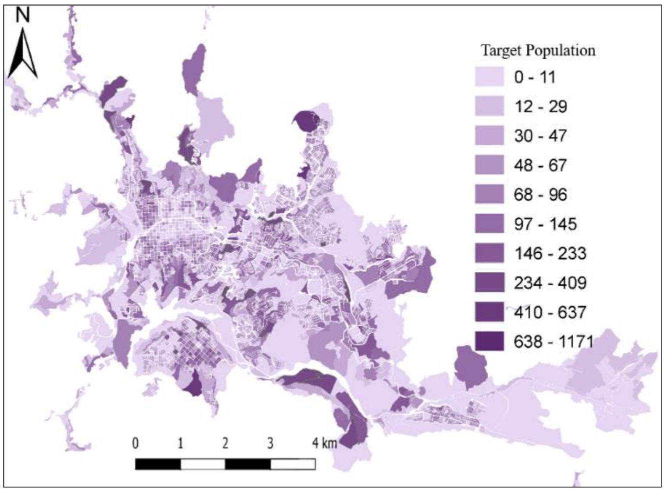

Figure 4. Student-aged population (Source: authors)

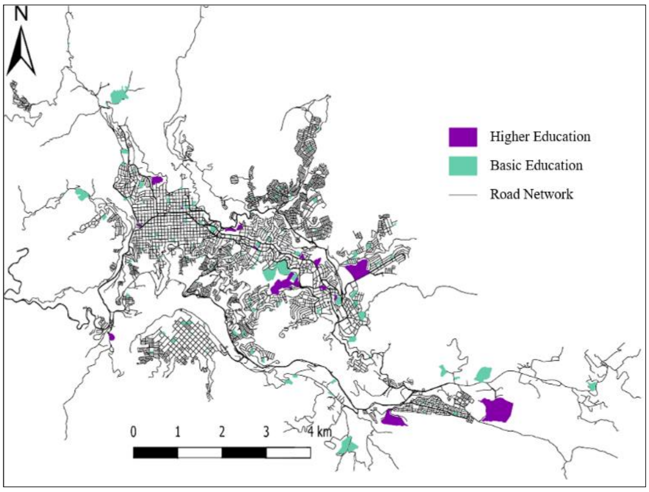

Figure 5. Location of educational institutions (Source: authors)

Phase 4 – Index calculation: First, external nodes to the network must be created, positioned at the location of the facilities to be analyzed, connecting to the nearest node of the network through a new arc with travel time equal to zero, so that it only generates a connection without increasing the distance or travel time. Then, travel time vectors are obtained under the different conditions of analysis, for which it is required to incorporate an additional computational tool -the TransCAD program- whose specific mathematical processing capacity for transport models is better optimized than ArcMap and does not require overly powerful hardware. Using the multiple paths extension of the TransCAD program, which involves the minimum paths algorithm born in 1959 (Dijkstra, 1959) and allows to obtain the travel times in matrix form between the desired points of the network, in our case from those created for the blocks, to the institutions initially and also between all the blocks.On the other hand, based on the general gravitational potential model, spatial equity models integrating different modes of transport have emerged (Chang and Liao, 2011), considering the mentioned results and the model developed on them by Hu to assess the spatial equity of elderly homes in Changchun (Hu et al., 2019), within which he incorporates the competition factor and the attractiveness factor of the assessed facilities. It is proposed to follow the line of development and use a similar equation, calculating the attractiveness factor based on the set of variables incorporated for educational establishments and the competition factor between blocks using travel times as the proximity value. The educational equity index is calculated from Equation 2, which condenses the procedure for obtaining the index as a ratio between the supply given by the educational establishments within the area of influence (20 minutes travel time) and the population competition (Equation 3) multiplied by the population-weighted average travel time for each mode of transport.

$$IE_i = \frac{\sum_{j=1}^{m} \mathrm{M_j} * S_j}{V_i * \left(\mathrm{a_{1i}} * \mathrm{p_i} * \mathrm{T_{i(pub)}}\right)} + \frac{\sum_{j=1}^{m} \mathrm{M_j} * S_j}{V_i * \left(\mathrm{a_{2i}} * \mathrm{p_i} * \mathrm{T_{i(priv)}}\right)} \quad (2)$$

$$V_i = \sum_{k=1}^{n} \frac{\mathrm{P_k}}{\mathrm{D_{ik}^{\beta}}} \quad (3)$$

Where, $\mathrm{IE_i}$ is the educational equity index of block i, $\mathrm{M_j}$ is the student capacity of educational institution j measured from registered enrolment. $\mathrm{S_j}$ is the attractiveness factor of each institution normalized by min-max normalization, which varies between 0 and 1, considering the academic level according to state tests, the number of educational levels served, the available area, and the monthly value of education; the latter aspect being evaluated inversely, i.e. the higher the cost, the lower the attractiveness. Institutions whose travel time exceeds the threshold range of 20 minutes automatically have an $\mathrm{S_j}$ =0, as they are not within the direct area of influence. $\mathrm{V_i}$ corresponds to the block's competition coefficient, $\mathrm{a_{1i}}$ and $\mathrm{a_{2i}}$ are the percentages of the block's population that make their study trips by private and public transport mode respectively, according to the TAZ (Traffic Analysis Zone) to which it belongs, based on the division and trip percentages recorded in the Manizales Mobility Plan 2017. pi is the school-age population of block i and $\mathbf{T_{i(pri)}}$ and $\mathbf{T_{i(pub)}}$ are the average travel times to reach educational institutions by private and public transport mode, respectively. In equation 3, $\mathrm{P_k}$ is the population under 30 years of age in block k corresponding to all other blocks other than i within a range of 1 minute, Dik is the separation between blocks measured in travel times, and β is the friction coefficient, taken as 2 for survey trips (Hansen, 1959). The value of $\mathrm{V_i}$ is uniform for both transport modes since in this section the spatial proximity is the same regardless of the mode.

The calculations of equations 2 and 3 are carried out through computational programming in Python, using the Pandas and Numpy libraries, which allow the handling of large databases and the performance of mathematical operations with them in a simple and fast way. The results are represented graphically in the ArcMap program, using the representation by quantities grouped in groups of colors corresponding to the quantiles considered necessary. In addition, the minimum, maximum, average, and standard deviation values of the public and private components are obtained separately, as well as the values for the result, so that a comparison of results internal to the index is possible. An analysis is also made by socio-economic stratum, finding the average value of the index for each stratum using Python.

Finally, Moran's spatial autocorrelation index is calculated, which evaluates how a phenomenon varies across geographical space. If the analyzed aspect tends to be grouped in uniform areas, forming clusters, then there is a positive autocorrelation. Conversely, if the variable measures in nearby units are different, i.e., if the phenomenon tends to be dispersed, then the spatial autocorrelation is negative; when the phenomenon behaves randomly, and no defined or structured behavior is identified, there is no spatial autocorrelation. Once again using the ArcMap program, the Moran index is calculated with the results per block of the IE, using the Spatial Autocorrelation (Moran I) tool, with the layer and field corresponding to the calculated value of IE as inputs, in its two components and in a grouped form, with a spatial relationship of inverse distance squared and using a Euclidean distance of 200 meters to designate the neighbouring entities. This tool outputs the Moran index, the z-value, and the p-value.

RESULTS AND DISCUSSION

The resulting value is made up of two parts, one corresponding to the section studied in public transport and the other in private transport, the sum of both of which makes up the final value. Bearing this in mind, the results are shown in three different ways, for each part and in aggregate, displayed in 10 quantiles so that the difference between values is visible. Polygons corresponding to zero index blocks are not shown on the maps, making the presentation cleaner. Figure 6 shows the spatial equity values for the public transport component, presenting a heterogeneous distribution on the map, but despite this, a concentration of the top quantiles along the main roads and in the city center, accompanied by some medium values next to the current overhead cable stations.The values in this section reach a limit of 737.39, with a mean of 2.14 and a standard deviation of 15, which indicates a very high concentration of very low values, less than 1, so it is necessary to show more than 2 decimal places, there are also singular points in high values. The Moran index in ArcMap resulted in 0.055, with a z-score of 7.31 and p-value = 0.00, indicating that the probability of the values being randomly distributed is very small, and the z-score being higher than 0 creates separate clusters of high and low values, i.e., the data are configured in a more spatially cohesive way than would be expected for a completely random distribution. The mean value of the equity index for stratum one is 0.94, for stratum two 0.80, for stratum three 3.72, for stratum four 3.99, for stratum five 4.24, and for stratum six 5.03, indicating a clear inequity for the lowest strata.

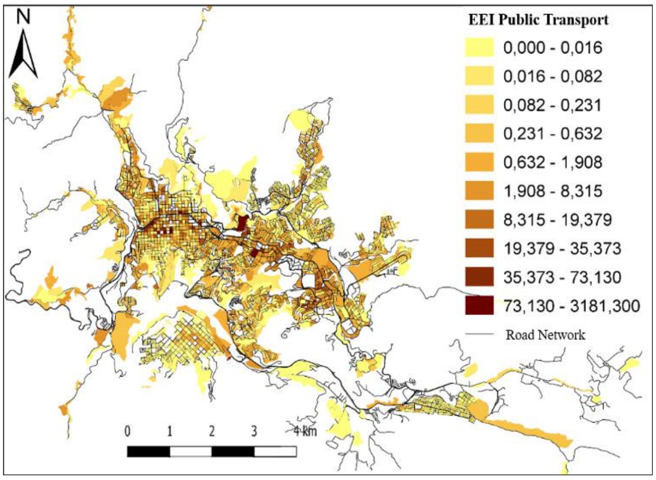

Figure 6. Spatial equity in public transport (Source: authors)

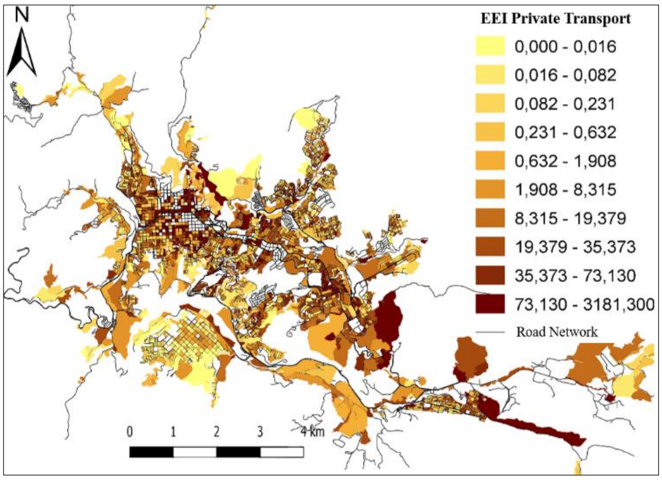

Figure 7. Spatial equity in private transport (Source: authors)

In the case of private transport, the results are shown in Figure 7, with a maximum value of 3162.21, a mean of 26.30, and a standard deviation of 116.46, indicating a low clustering of values. Levels of spatial equity are much higher than in public transport due to the ease with which this mode of transport can access institutions within the time limit. Differences in concentration are observed concerning the public transport map, with the strongest shades being found in the center of the analyzed sector, close to the El Cable area, while high values increase in the city's outskirts, especially in the eastern area. Moran's I. results give a value of 0.124, slightly higher than for private transport, together with a z-score of 13.88 and p-value of 0.00, which also represents a cluster-prone distribution. The mean values per stratum from one to six result in a mean of 21.09, 18.72, 40.03, 42.00, 24.98, and 45.69 respectively, indicating, once again, better conditions for the higher strata compared to the lower strata. The final result comprises the sum of opportunities offered by each mode of transport, integrating the variation of access based on the choice of transport mode declared in the 2017 mobility master plan surveys, is presented in Figure 8, reaching values of 3181.30 at its upper limit, with a mean of 28.44 and standard deviation of 121.86, equally high as in the two components that make up its value.

Moran's index results in 0.122, together with a z-score of 13.58 and p-value of 0.00, having a distribution with very low randomness, with a trend to clustering as mentioned above. These results indicate from a statistical point of view that the values obtained for the Educational Equity Index are not the product of coincidence or chance, but they are distributed in a concentrated sectorial manner within the geographical space. The maximum values are distributed in the area without a defined concentration but always surrounded by high and medium-high values, which can be seen in sectors with low student-age populations. For instance, in the historic center, where equity values are increased since the offer is the same for a few applicants, while blocks with a high concentration of young people have reduced values caused by a high level of competition. Areas located close to the main universities, such as Universidad Nacional or Universidad Autónoma, also stand out with medium-high concentrated values. The mean results per stratum are as follows: for stratum 1= 22.03; stratum 2= 19.53; stratum 3= 43.75; stratum 4= 46.00; stratum 5= 29.22 and stratum 6= 50.73, indicating that the highest stratum tends to obtain better results while the two lowest strata have the lowest values.

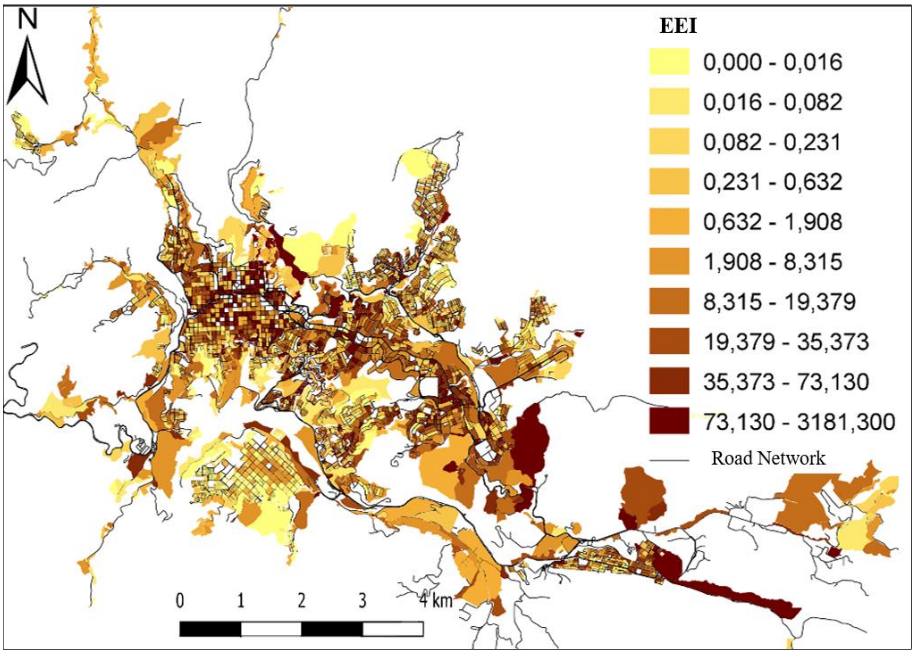

Figure 8. Total equity index Source: authors

CONCLUSION

The proposed model for measuring spatial equity in education can assess the coverage characteristics for each block individually, considering the institutions covered at a given time, its own and the neighborhood's student-age population, and recognizing the modal distribution for the purpose of study in its analysis. This methodology can be applied in any city as long as the basic information is properly organized. The results of the index have a low impact on small institutions such as kindergartens, where only one level of education is provided to a few students with a minimal area compared to large university campuses. This shows that although there are good levels of integral accessibility to early childhood or basic education institutions, the overall levels are not very good. The spatial equity values show the sectored concentration of values, with a partially homogeneous distribution on the map, so that there is a distribution with a little random tendency of the result. The spatial equity index is influenced by the location of the institutions, the density of the student population, and the travel mode of preference, where strata one and two represent the lowest average values of the index, indicating shortcomings in the access of this service by having high concentrations of the student population in small areas whose main mode of transport corresponds to collective public transport, which is in unequal conditions compared to private transport in terms of the number of opportunities reached in a given time.

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

REFERENCES

Alcaldía de Manizales. (2019). *Información General [General information]*. (In Spanish). https://manizales.gov.co/informacion-general/

Alcaldía Municipal de Villamaría en Caldas. (2018). (In Spanish). http://www.villamaria-caldas.gov.co/

Avendaño Rodríguez, N.R. (2012). *La equidad espacial en la distribución del servicio educativo (1999-2009) [Spatial equity in the distribution of educational services (1999-2009)]*. 102. (In Spanish).

Chang, H.S., & Liao, C.H. (2011). Exploring an integrated method for measuring the relative spatial equity in public facilities in the context of urban parks. *Cities* 28, 361–371. https://doi.org/10.1016/j.cities.2011.04.002

Consejo Privado De Competitividad & Universidad Del Rosario. (2020). *Índice De Competitividad De Ciudades 2020 [Cities Competitiveness Index 2020]*, (In Spanish).

Dalvi, M.Q., & Martin, K.M. (1976). The measurement of accessibility: Some preliminary results. *Transportation (Amst)*. 5, 17–42. https://doi.org/10.1007/BF00165245

Departamento Administrativo Nacional de Estadística – DANE. (2019). Censo Nacional de Población y Vivienda [National Population and Housing Census]. (In Spanish). http://microdatos.dane.gov.co/index.php/catalog/643/get_microdata

Dijkstra, E.W. (1959). A note on two problems in connexion with graphs. *Numerische Mathematik*. 1, 269–271. https://doi.org/10.1007/BF01386390

Escobar, D., & Garcia, F. (2012). Territorial Accessibility Analysis as a Key Variable for Diagnosis of Urban Mobility: A Case Study Manizales (Colombia). *Procedia - Soc. Behav. Sci*. 48, 1385–1394. https://doi.org/10.1016/j.sbspro.2012.06.1114

Escobar, D.A., Holguin, J.M., & Zuluaga, J.D. (2016). *Accesibilidad de los centros de ambulancias y hospitales prestadores de servicio de urgencias y su relacion con la inequidad especial [Accessibility of ambulance centers and hospitals providing emergency services and its relationship with special inequality]*. Espacios 37, 429–431, (In Spanish).

Fasihi, H., & Parizadi, T. (2020). Analysis of spatial equity and access to urban parks in Ilam, Iran. *Journal of environmental management*, *260*, 110122.

Frenette, M. (2006). Too far to go on? Distance to school and university participation. *Educ. Econ*. 14, 31–58. https://doi.org/10.1080/09645290500481865

Gao, Y., He, Q., Liu, Y., Zhang, L., Wang, H., & Cai, E. (2016). Imbalance in spatial accessibility to primary and secondary schools in China: Guidance for education sustainability. *Sustain*. 8. https://doi.org/10.3390/su8121236

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

Handy, S.L., & Niemeier, D.A. (1997). Measuring accessibility: An exploration of issues and alternatives. *Environ. Plan. A* 29, 1175–1194. https://doi.org/10.1068/a291175

Hansen, W.G. (1959). How Accessibility Shapes Land Use. *J. Am. Plan. Assoc*. 25, 73–76. https://doi.org/10.1080/01944365908978307

Hu, S., Song, W., Li, C., & Lu, J. (2019). The spatial equity of nursing homes in Changchun: A multi-trip modes analysis. *ISPRS Int. J. Geo-Information* 8. https://doi.org/10.3390/ijgi8050223

Ingram, D.R. (1971). The Concept of Accessibility: A Search for an Operational Form. *Reg. Stud.* 5, 101–107. https://doi.org/10.1080/09595237100185131

Montoya Goméz, J.A. (2019). *Análisis De Cobertura, Mediante Accesibilidad Geográfica, Para Sistemas De Paraderos De Transporte Público Colectivo Urbano [Coverage Analysis, Through Geographical Accessibility, For Urban Public Transportation Stop Systems]*. (In Spanish).

Li, G., Luo, T., & Song, Y. (2022). Spatial equity analysis of urban public services for electric vehicle charging - Implications of Chinese cities. *Sustainable Cities and Society*, *76*, 103519.

Morris, J.M., Dumble, P.L., & Wigan, M.R. (1979). Accessibility indicators for transport planning. *Transp. Res. Part A Gen*. 13, 91–109. https://doi.org/10.1016/0191-2607(79)90012-8

Liu, L., Zhao, Y., Lyu, H., Chen, S., Tu, Y., & Huang, S. (2023). Spatial Accessibility and Equity Evaluation of Medical Facilities Based on Improved 2SFCA: A Case Study in Xi'an, China. *International Journal of Environmental Research and Public Health*, *20*(3), 2076.

OECD. (2010). *Educación Hoy: La perspectiva de la OCDE, Educación Hoy [Education Today: The OECD Perspective, Education Today]*. (In Spanish). https://doi.org/10.1787/9789264252486-es

Organización de las Naciones Unidas – ONU. (2018). *Objetivos de Desarrollo Sostenible [Sustainable Development Goals]*. (In Spanish). http://www.undp.org/content/undp/es/home/sustainable-development-goals.html.

Pirie, G.H. (1979). Measuring Accessibility: A Review and Proposal. *Environ. Plan. A Econ. Sp.* 11, 299–312. https://doi.org/10.1068/a110299

Pizzol, B., Giannotti, M., & Tomasiello, D.B. (2021). Qualifying accessibility to education to investigate spatial equity. *Journal of Transport Geography*, *96*, 103199.

Rahman, M., & Nigar Neema, M. (2015). A GIS Based Integrated Approach to Measure the Spatial Equity of Community Facilities of Bangladesh. *AIMS Geosci*. 1, 21–40. https://doi.org/10.3934/geosci.2015.1.21

Robledo, J.E. (1996). *La ciudad en la colonización antioqueña: Manizales [The city in the Antioquia colonization: Manizales]*. (In Spanish).

Sá, C., Amado Tavares, D., Justino, E., & Amaral, A. (2011). Higher education (related) choices in Portugal: Joint decisions on institution type and leaving home. *Stud. High. Educ*. 36, 689–703. https://doi.org/10.1080/03075071003725343

Sá, C., Florax, R.J.G.M., & Rietveld, P. (2006). Does Accessibility to Higher Education Matter? Choice Behaviour of High School Graduates in the Netherlands. *Spat. Econ. Anal*. 1, 155–174. https://doi.org/10.1080/17421770601009791

Sánchez, C.F. (2016). *Colombia en el post-acuerdo y el rol de la infraestructura de transporte [Colombia in the post-agreement and the role of transportation infrastructure]*. Rev. Ing. 0, 28, (In Spanish). https://doi.org/10.16924/riua.v0i44.918

Spiess, C.K., & Wrohlich, K. (2010). Does distance determine who attends a university in Germany? *Econ. Educ. Rev*. 29, 470–479. https://doi.org/10.1016/j.econedurev.2009.10.009

Walsh, S., Flannery, D., & Cullinan, J. (2015). Geographic accessibility to higher education on the island of Ireland. *Irish Educ. Stud*. 34, 5–23. https://doi.org/10.1080/03323315.2015.1010302

Yang, Y., He, R., Tian, G., Shi, Z., Wang, X., & Fekete, A. (2022). Equity Study on Urban Park Accessibility Based on Improved 2SFCA Method in Zhengzhou, China. *Land*, *11*(11), 2045.

Younes, C., Escobar, D.A., & Holguín, J.M. (2016). *Equidad, accesibilidad y transporte. Aplicación explicativa mediante un análisis de accesibilidad al sector universitario de manizales (Colombia) [Equity, accessibility and transportation. Explanatory application through an analysis of accessibility to the university sector of Manizales (Colombia)]*. (In Spanish). Inf. Tecnológica 27, 107–118. https://doi.org/10.4067/S0718-07642016000300010

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