Human Geographies – Journal of Studies and Research in Human Geography
Vol. 20, No. 1, May 2026 | www.humangeographies.org.ro
ISSN–print: 1843–6587 | ISSN–online: 2067–2284

Geographic accessibility and quality of life in a rural population of the department of Ayacucho (Peru)

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Abstract: Geographic accessibility in rural areas is a determining factor in rural development and a key element in improving the quality of life of the population. This article aims to quantify travel time, both on foot and by motor vehicle, from homes to the main basic services in Ayacucho, Peru. To do so, Geographic Information Systems (GIS) were used as a methodological tool to analyse accessibility networks, thereby allowing the identification of access difficulties for certain populations. Using the geographic locations of homes and services, and GIS data processing, the distances and travel times required to access health centres, municipalities, markets, pharmacies, banks, medical posts, and primary and secondary education institutions were evaluated. The results showed that 12% of homes require more than 6 hours round-trip to access the main services on foot, a time that far exceeds acceptable standards and constitutes a clear sign of isolation and inequality in rural contexts. On the other hand, it was found that 13% of households record an average time of 40 minutes by car, which, although higher than the standard of 30 minutes, is considered relatively normal in the given rural environment.

Keywords: *rural population; quality of life; basic services; network analysis; cost of time*

Article Info: Received: *October 17, 2024*; Revised: *December 15, 2025*; Accepted: *April 13, 2026*; Online: *May 31, 2026*.

Introduction

The difficulty rural populations have in accessing basic services leads to social isolation due to poor communication and service distribution. Deficiencies in rural road networks contribute to poverty and hinder economic development, depriving rural communities of basic goods and services due to poor maintenance or the non-existence of infrastructure (Nyawo & Mashau, 2019). In addition, limited access to roads not only impedes the provision of basic services but also affects the sustainability and growth of villages. It also

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prevents the circulation of vehicles, discouraging the little trade in agricultural products (Soto et al., 2021).

Geographic accessibility is a key factor for community development, especially in rural contexts where distances and travel times to basic services determine the quality of life of the population. In this sense, the physical distance and travel time required to access essential goods and services are fundamental indicators of a community's level of integration and the degree of social isolation it faces. In addition, the cost of time invested in these trips, both on foot and by motor vehicle, directly affects the economic, educational and health opportunities of rural residents (Bravo, 2002).

In rural areas, the role of the road network is crucial in determining connectivity and the efficiency of access to services. The existence, condition, and maintenance of these roads are determining factors in travel times, especially in mountainous areas such as Ayacucho, where rugged terrain and adverse weather conditions make mobility difficult. Poor road infrastructure not only increases the time needed to access services but also raises the economic and social costs of the most remote communities (Jayasree, 2022).

Basic services, on the other hand, are essential for human well-being and development, such as health centres, which are necessary to guarantee access to medical care and preventive services, and municipalities, which manage essential administrative procedures and services. Markets are essential for the supply of food and necessities. Pharmacies ensure the availability of medicines and provide pharmaceutical care. Banks are key to facilitating financial operations, such as savings and access to credit. Medical posts provide primary health care in remote communities. Primary and secondary education institutions are necessary to guarantee the right to education and to develop the capacities of the young population.

The road infrastructure, especially the surface type, road quality, and vehicle accessibility, has proven crucial in driving rural economic transformation (Palacios, 2017). Improving rural access to facilities, services and employment opportunities is an essential element in combating poverty. A meticulously planned road system in rural areas is critical to improving rural accessibility and, consequently, boosting overall rural development (Kumar, 2010).

In mobility and transport studies, road accessibility refers to the degree to which people can reach the products and services of a given place through a specific transport system (Levine et al., 2019; Levine, 2020; Gutiérrez & García, 2020) and at the same time, it is the guarantee to enhance opportunities for interaction (Hansen, 1959). Road networks are a fundamental pillar of rural development and social well-being, so it is essential to consider multiple factors when planning rural road connectivity (Bautista, 2018), as they directly impact mobility. These not only ensure efficient road communication, but also contribute significantly to sustainable rural development, poverty alleviation and job creation. They therefore become an invaluable tool for planners and decision-making in the field of rural development (Jayasree, 2022). The road network enables people to ensure their basic needs for education, work, food, and health. These needs are the main activities of a country; for this reason, it is strategic to develop its road system under adequate conditions to satisfy not only the obligation to travel but also the essential needs of the population (Rivera, 2015).

There is a relationship between distance to services, quality of life and mobility. Women, children, and the elderly with low levels of education or income are most affected by mobility difficulties in rural areas, which in turn affect their well-being (Andrea & Estela, 2017). Road networks have a significant impact on gender relations in the Peruvian Andes. Although road rehabilitation has enhanced mobility and access to services, improvements in livelihoods have not been uniform across all groups, with greater gains for men than for women, reflecting factors such as social norms and/or household burdens. The degree of connectivity of a people depends on the structure of the network and the level of development, since it

ensures a good articulation of its social and commercial flows within its territory (Suel, 2008). Infrastructure must improve connectivity, the main factor in ensuring quality of life by facilitating access to housing, health services, education, and electrification, among other things (Gaudin, 2019; Giner et al., 2013).

Network analysis is a process that evaluates and optimises the efficiency of transportation networks, accounting for constraints such as speed limits and the condition of the road network. It includes point-to-point analysis to determine the optimal route between two locations and the accessible areas within a given time (Ministry of Communications and Transportation, 2021). The economic transformation is not limited to improving the road network; it is also affected by other factors, such as access to services, electricity coverage, market presence, equipped health posts, educational centres in adequate conditions, the topography of the plains, and the availability of water for consumption and irrigation. For effective and sustainable rural economic transformation, it is essential to consider a comprehensive approach that encompasses all these aspects. In this sense, accessibility in terms of distance cost significantly influences agricultural development in rural areas (Kamaludin & Qibthiyyah, 2022; Hendra, 2020) and, at the same time, shapes household income structures.

Accessibility enables people to move, fosters high connectivity, and improves social integration, thereby enhancing economic opportunities and cultural links (Palacio, 2008). A key element in road connectivity is the system of nodes that connect towns or cities through which flows of people, goods, information, among others, move (Cardozo et al., 2009). Road networks link territories by enabling the movement of goods, services, information, and people between different points (Rozas & Figueroa, 2006). In this sense, distance and time serve as indicators that allow us to identify groups of homes that are distant.

Network analysis is a methodology used to assess mobility and accessibility. It is based on studies that use aggregated and disaggregated population data to examine commuting patterns and public transport accessibility. Although the application of this methodology in the context of dispersed urbanisation remains limited, some studies have used mathematical formulas and network analysis tools to calculate various centrality measures in urban networks. However, these studies have focused mainly on large cities and on pedestrian feasibility, leaving room for exploring their application in areas of dispersed urbanisation (Mezzetti, 2021).

Rural villages in the Peruvian Andes are very poorly connected to road networks, which impacts the precariousness of the population's livelihoods, including access to health, education, and commerce services (Bravo, 2002). It mainly affects vulnerable people (MTC, 2022).

The starting hypothesis is that in the district of Los Morochos, the cost of the time required to access basic services for most homes is too high and prevents essential needs from being met in a way that guarantees the quality of life of the population. To respond to this hypothesis, the objective is to analyse and understand the importance of road infrastructure in rural areas, and to reflect on how its improvement can contribute to poverty reduction and the economic development of these communities.

Methodology

Study area

The selected study area was the district of Los Morochucos in the province of Cangallo in the department of Ayacucho. This area was selected because of a few social and economic

opportunities, where good territorial planning based on road networks can help increase the quality of life of this population. In addition, few references quantify the time-distance record in a rural environment with the characteristics of Los Morochucos. It has a population of 8,323 inhabitants as of December 2020 (INEI, 2023), distributed across the five population centres of Juscaymarca, Huallchancca, Satica, Chanquil, and Pampa Cangallo, the latter being the district capital (Figure 1). The population centres are located between 2900 and 3600 meters above sea level, on the western slope of the Andes in Peru.

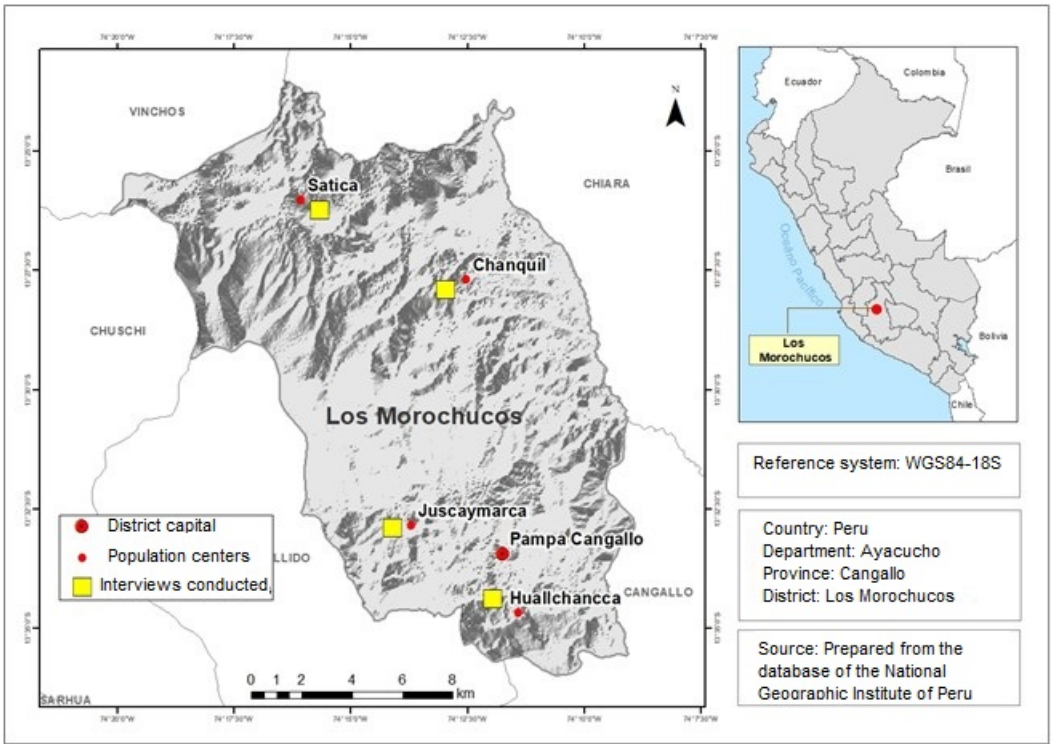

Figure 1. Location of the study area

Source: Author's elaboration

In 2020, the district of Los Morochucos comprises five populated centres with 146 hamlets or small towns, also known as villages. Only one of these hamlets is classified as urban, with 2,875 residents, representing 35% of the total population. The remaining 145 hamlets are classified as rural, where 5,448 people live, that is, 65% of the population (INEI, 2023). It should be noted that 99% of the hamlets are classified as rural and exhibit high dwelling dispersion. There are even hamlets that have only 10 inhabitants.

Network analysis

To model the cost of time for a type of service, Network Analyst in ArcGIS 10.8 was used in the UTM - WGS84 coordinate system. This analysis requires georeferenced data for all dwellings and services in the investigated area, represented as point-type vectors, and for the roads, represented as polyline-type vectors, in the UTM - WGS84 coordinate system (Figure 2).

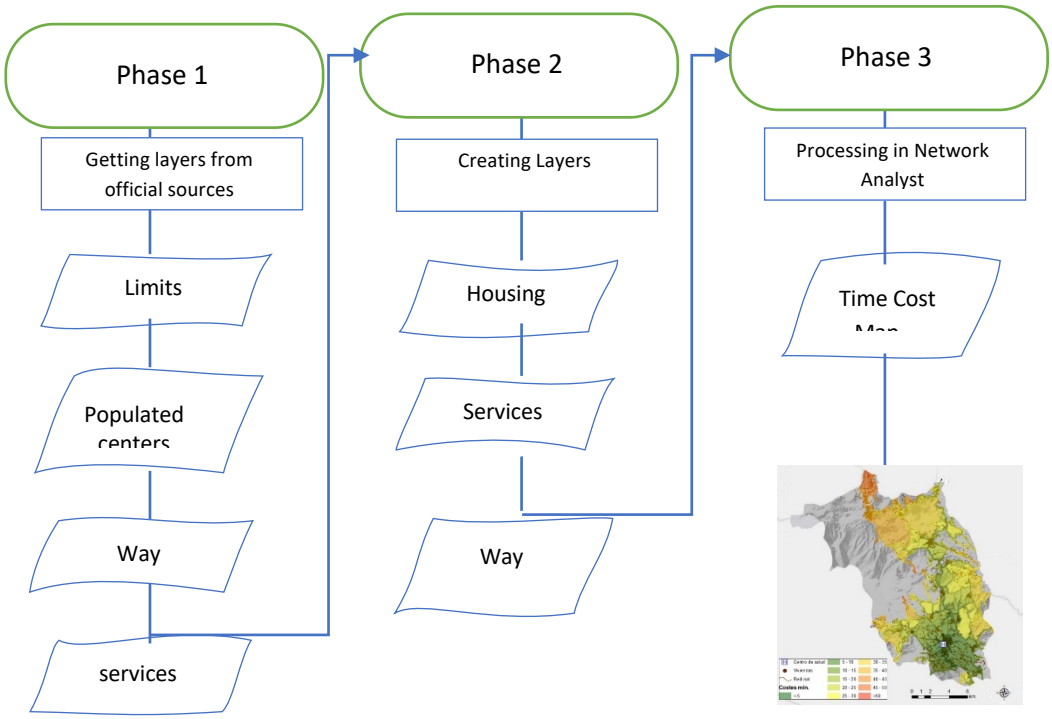

Figure 2. Network Analysis Process Outline

Source: Author's elaboration

Data source & methodology

The information has been obtained through official databases of the Peruvian State, such as ministries and other entities with competence in the subject (Table 1).

Another source of data was the creation of the time cost cartography in three phases: a) Georeferencing of the houses within the study area. Since there are no georeferenced houses at the village scale, the Google Earth base map was used for digitisation from photointerpretation. As a result, 3,785 homes were digitised in a dot-type shapefile. b) Identification and georeferencing of the services that are most in demand among the rural population: the nearest health centre, a municipality, a market, a pharmacy, a bank, 4 posts, 4 colleges and 34 schools (Figure 3). Due to the non-availability of linear layers with the road network, streets, paths, asphalt roads, unpaved roads and trails, digitisation was carried out using Google Earth satellite images. As a result, a total of 370 km was mapped (Figure 2).

Table 1. Official Database Sources

Institution	Link
National Geographic Institute - IGN	https://www.idep.gob.pe/geovisor/descarga/visor.html
National Institute of Statistics and Informatics - INEI	https://metadatogis.inei.gob.pe/geonetwork/srv/spa/catalog.search;jsessionid=833BADB409DA538114DD8A30B0F1F5EA?fbclid=IwAR3OY4l5iy7v7xIUlzSYGkswRV-nr_V6LcNeCVJtfDONutHawl9dWVCFbwI#/metadata/857d9c69-117f-41d3-9762-a592a8256e1b
Ministry of Education	http://sigmed.minedu.gob.pe/descargas/
Ministry of Transport and Communications	https://portal.mtc.gob.pe/estadisticas/descarga.html
Ministry of Health	https://www.datosabiertos.gob.pe/dataset/establecimientos-de-salud
Presidency of the Council of Ministers	https://visor.geoperu.gob.pe/
Ministry of Education - Escale	http://sigmed.minedu.gob.pe/mapaeducativo/

Source: Author's elaboration

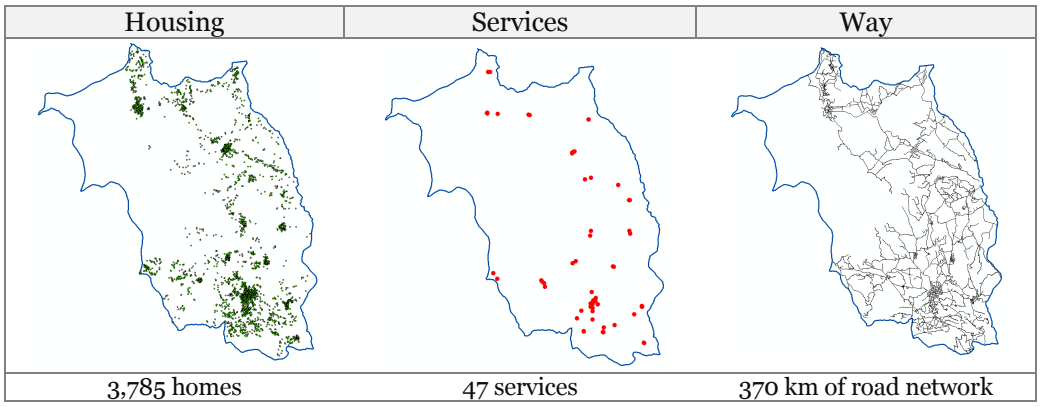

Figure 3. Preliminary processes for time-cost mapping

Source: Author's elaboration

To calculate the time cost (the time it takes a person to reach a service from their home, either on foot or by vehicle), a table was generated with five fields (Table 2).

Length (m) represents the distance of the category in meters (m)

*Speed (km*h)* are the speeds that a car takes depending on the category of the roads (street = 30 km/h, road = 10 km/h, asphalt road = 60 km/h, unpaved road = 40 km/h and track = 20 km//h). These speeds are considered based on the standards established by the Ministry of Transport and Communications of Peru.

m_min_C is the car's journey (C) in meters per minute (m/min), converted from Speed (km/h). For example, the formula for the first category in Table 2 is used, where the street speed is 30km/h.

Table 2. Example of costs in a vehicle and walking

Category*	Length (m)	Speed (km*h)	m_min_C (m*min)	Coste_C (min)	Coste_P (min)	Oneway
Street	72.13	30	500.00	0.14	0.97	0
Road	256.12	10	166.00	1.54	3.46	0
Asphalt road	36.47	60	1000.00	0.04	0.49	0
Unpaved road	71.14	40	666.67	0.11	0.96	0
Trail	1927.44	20	333.33	5.78	26.02	0

Source: Author's elaboration

$$m/min = kph * 16.66667$$
$$m/min = 30 * 16.66667$$
$$m/min = 500.0000$$

Coste_C is the cost per car, representing the time it takes a person to travel from their home to a service type, based on road category (street, road, asphalt road, unpaved road, trail). The formula is:

$$\text{Coste\_C} = \frac{\text{Lenght (m)}}{\text{m\_min\_C}}$$

Coste_P is the cost on foot (P) that represents the time it takes for a person to travel from their home to a type of service (health centre, municipality, market, pharmacy, bank, post, primary and secondary education), considering the average speed travelled by a person, which is 13.5 min in 1 km or 1000 m. The formula is (Gencat, 2023):

$$\text{Coste\_P} = \frac{\text{Lenght (m)} * 13.5 \text{ min}}{1000 \text{ (m)}}$$

Oneway indicates whether the road has a single or two directions; for this study, all roads have two directions, which was represented by a zero.

Results

The results, presented as a map, reveal the time required to access services from rural homes and how road infrastructure and accessibility affect quality of life. Figure 4 (a) shows the travel time by car from homes to five essential services: health centre, municipality, market, pharmacy and bank, measured in minutes of travel cost. Of a total of 3,840 homes, 13% (477 homes) are located 30 to 50 minutes away, indicating that these homes are farther from services under normal conditions. It is important to note that this time can increase due to factors such as rainfall or road conditions. On the other hand, Figure 4 (b) shows the time it takes people to reach these services on foot under normal conditions, without accounting for climatic factors. They reflect a worrying reality regarding accessibility to essential services, such as health centres, municipalities, markets, pharmacies, and banks, both by car and on foot. Figure 4(b) shows that 12% of dwellings (449) require 6-7 hours of walking to access essential services, indicating a critical situation for the most isolated populations. This prolonged time reflects the isolation of rural areas, mainly affecting vulnerable groups such as the elderly, people with reduced mobility or children. In addition, in cases of medical emergencies or urgent care needs, these distances put residents' health and lives at risk. On the other hand, the cost in terms of time and

productivity is high, as long hours spent walking to access services limit the time available for work, education, and personal activities, thereby perpetuating poverty and social marginalisation.

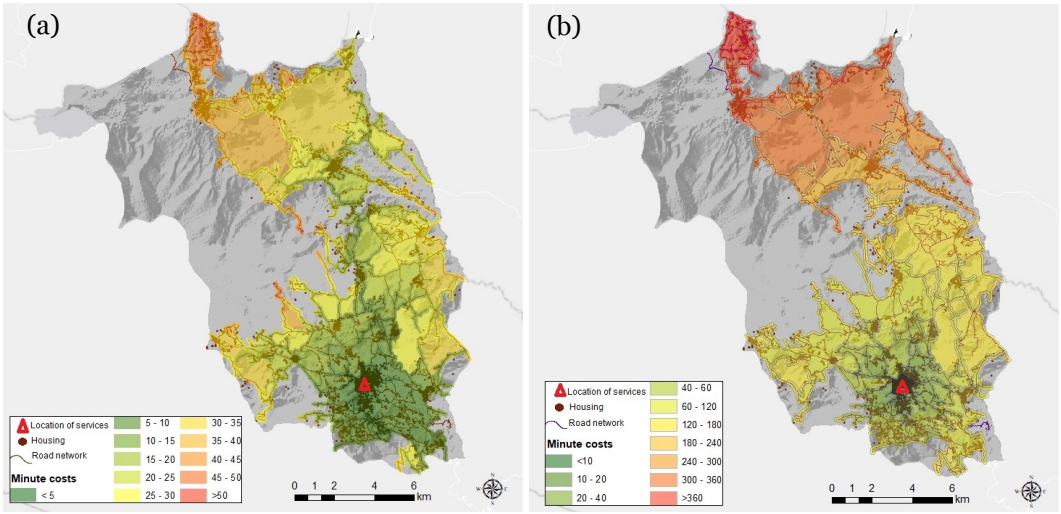

Figure 4. Time costs from homes to the five services by car (a) and on foot (b)

Source: Author's elaboration

The implications for the population reflect territorial inequality: the most remote dwellings, which represent approximately 12-13% of the population, have an unequal distribution of services, whereas in urban areas these are located minutes away. Figure 5 (a) illustrates the time required to travel by car from homes to a post office, while Figure 5 (b) shows the time required to make the same journey on foot. It is observed that 68% of the homes are within 5 to 15 minutes of a post. 28% of the homes are within a 10 to 30 minute walk of a post office.

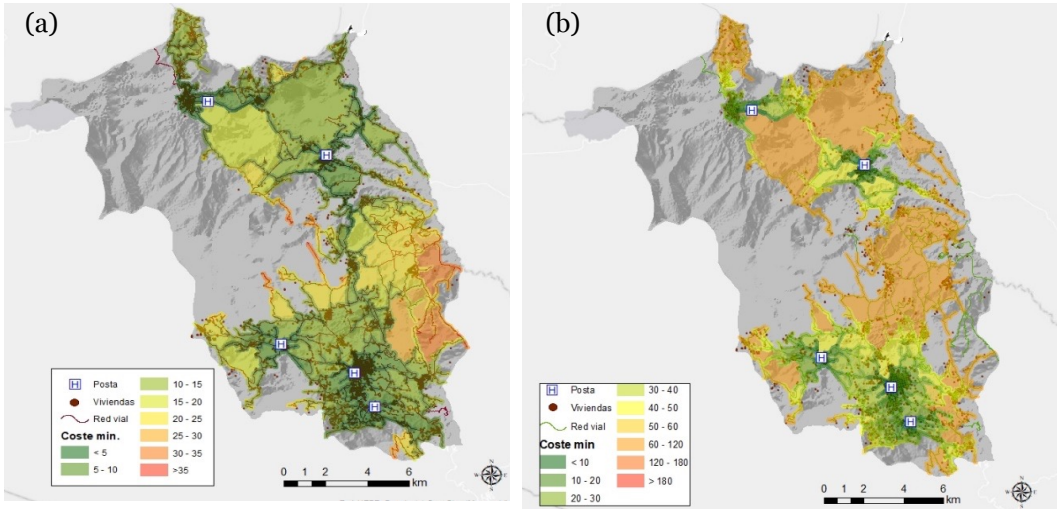

Figure 5. Time costs from the dwellings to the post by car (a) and on foot (b)

Source: Author's elaboration

It is observed that 88% of the homes are within a 5- to 15-minute drive of at least one educational institution. The fact that 86% of dwellings are within a 30-minute walk of at least one primary educational institution is a positive indicator of educational accessibility in this area (Figure 6 (b)). This relatively close access can facilitate regular school attendance for children and reduce logistical barriers to education. However, even this travel time can present challenges, as a 30-minute walk can be exhausting for younger children.

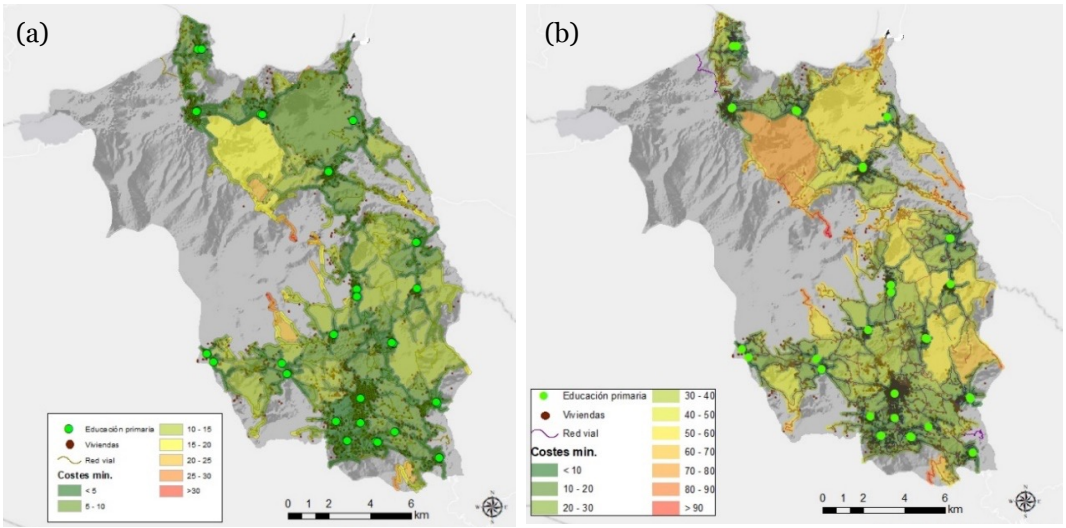

Figure 6. Time costs from housing to primary education by car and on foot

Source: Author's elaboration

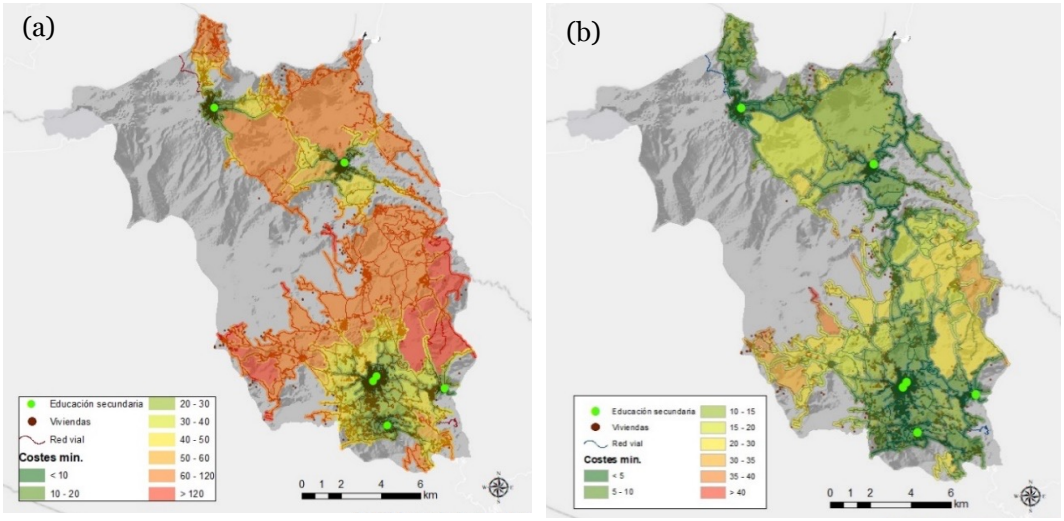

Figure 7. Costs of time from housing to secondary education by car

Source: Author's elaboration

Figure 7 (a) shows the time required to travel by car from homes to a secondary school, while Figure 7 (b) shows the time required to make the same journey on foot. It is observed that 72% of the dwellings are within a 5-15 minute drive of at least one secondary school. Access to education can influence children's future opportunities, while access to health facilities can affect the community's overall health and well-being.

Figure 8 shows the distribution of dwellings by travel time (in minutes) to a service type. It can be seen that the highest concentration of homes is in the 20 to 40-minute range. This indicates that, both by car and on foot, most homes are located within 20 to 40 minutes of accessing a given service. Figure 8 shows moderate access to essential services. That is, a majority of the population is not completely isolated, but neither does it enjoy immediate access, indicating an intermediate situation in terms of infrastructure and connectivity. This time is acceptable in urban or semi-urban contexts where private and public transport are available, but in rural areas it represents a significant challenge, especially if travel must be on foot.

On the other hand, the range of 20 to 40 minutes indicates possible accessibility gaps, since not all homes are equally close to services. Those at the upper end of the range (40 minutes) face additional difficulties due to factors such as road conditions, inadequate transport, or economic limitations on access to transport. This situation mainly affects rural populations, where physical or climatic obstacles can extend travel time.

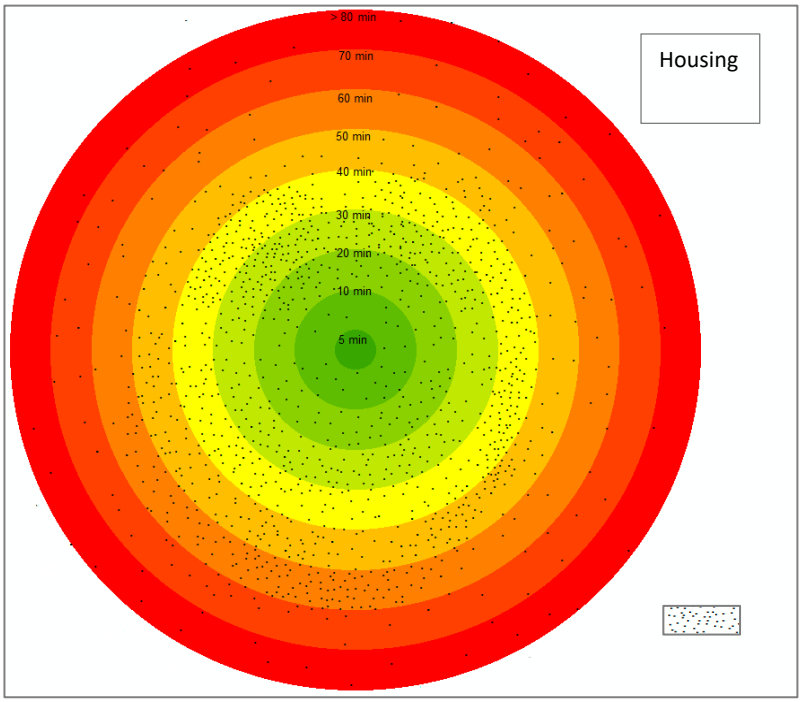

Figure 8. Average distribution of dwellings according to travel time in minutes, towards a type of service by car and on foot

Source: Author's elaboration

Concentration also implies a pattern of territorial planning where services are not sufficiently decentralised to reach all communities equitably. Although most homes are within an accessible distance, some people must travel farther, creating inequality in access to basic rights such as health, education, and essential goods.

Although the distribution shows a favourable trend in terms of general accessibility (20 to 40 minutes), it is necessary to further analyse the specific conditions of these homes, including the types of services they have access to, the quality of communication routes, and the transport options available. This analysis will enable the identification of areas where improvements in infrastructure or greater decentralisation of services are required to ensure equitable, efficient access for the entire population.

Discussion

Vehicle accessibility depends on external factors, such as rainfall and poor road conditions, which can increase travel times and make access to basic services even more difficult. In addition, dependence on private transport puts families without their own vehicles or the financial resources to afford alternative transport at a disadvantage, deepening the inequality of opportunity in these communities.

For residents of rural areas, access to the health centre takes longer. The barrier to accessing health care is not only distance but also the difficulty of obtaining transportation and its associated cost, which especially affects pregnant women, people with newborns, and the elderly. Those who reside in the areas marked red in Figures 4 and 5 challenges in getting there on time. This means that if they can't get a motor vehicle, they must walk a quarter of the day to get medical attention. Health and education are priority areas of the UN SDGs; however, it has been shown that, using OpenStreetMap road data and land cover, accessibility to hospitals and schools in poor areas costs twice as much as in non-poor areas (Hu et al., 2023).

Strategies to improve access to health services for these populations, such as improving transport infrastructure, implementing mobile health services, or promoting telemedicine, are crucial (Hazarika & Yadav, 2023). These measures could help ensure that all residents have timely access to health care, regardless of their location. Rodríguez et al. (2014). They indicate that not only distance is a limitation in rural towns for access to a health centre, but also the difficulty of getting a transport vehicle and covering the cost, which are barriers to access and cause non-attendance among pregnant mothers and older adults, as well as among newborns. To corroborate this, a transportation subsidy was implemented, and with it, absences decreased by 87% (Tariverdi et al., 2023).

They point out that in order to reach a service such as health from distant places, it is necessary to consider the components of infrastructure systems, thus guaranteeing mobility and access to public services, but situations such as the state of the road, disasters, floods, earthquakes, among others, can extend the car's arrival time.

Willberg et al. (2023) indicate that people tend to prefer walking if a service is less than a 15-minute walk away. However, this preference can vary depending on the season and the condition of the roads or paths. Therefore, planners must consider accessibility by age groups when developing their plans to mitigate social and spatial inequalities. Walking 15 minutes may not be the same for a young person as for an older adult, and this challenge is intensified in rural areas, where distances may require hours of walking.

The transport system plays a crucial role in access to services, being an essential operation in the social economy of both cities and rural areas (Hazarika & Yadav, 2023). Tools such as GIS-based Network Analyst enable identification of access gaps and

monitoring of the transportation system, network conditions, the shortest or most efficient route to the destination, and the nearest services. According to the World Health Organisation (WHO) and sustainable development studies, essential services should be located within an accessible distance, with travel times not exceeding 30 minutes in urban areas and around 1 hour in rural areas. A round-trip time of 6 hours far exceeds these standards and is considered a clear sign of isolation and inequality.

Pharmacy accessibility is a significant challenge for rural populations, especially older adults. The lack of transportation and the costs of travelling to the district capital are limiting. Padeiro (2018) agrees that community pharmacies are vital in ageing societies, providing medicines, advice and specific services. However, geographic accessibility is a major concern, especially for older adults with mobility issues. Although 76.9% of adults in urban areas live within 15 minutes of a pharmacy, this figure is not comparable to rural areas, where pharmacies are scarce or nonexistent.

Studies such as those by Lam et al. (2019) and Homann et al. (2021) highlight the importance of proximity to pharmacies. Up to 11% of people discharged from a hospital do not complete their prescriptions due to the distance to pharmacies. Older adults, who are the main consumers of prescription drugs, often have difficulty accessing pharmacies in rural areas due to distance and lack of transportation. In the district of Los Morochucos, where 9% of the population is 65 years of age or older (INEI, 2018), those living in rural areas have difficulty accessing pharmacies. These challenges underscore the need for effective strategies to improve access to pharmacies in rural areas, especially for older adults.

Workman & McPherson (2021) highlight the importance of the rural access index, a measure developed by the World Bank that has been incorporated into the Sustainable Development Goals (SDGs) as indicator 9.1.1. This index measures the proportion of the rural population living within 2 km of a road, reflecting the accessibility of transport infrastructure. Therefore, proximity to roads and the quality of the road network are crucial factors for access to banking services in rural areas. These challenges underscore the need to improve transportation infrastructure and banking services in rural areas to facilitate access to loans for economic activities such as agriculture and livestock.

During the COVID-19 pandemic, Khazi et al. (2022) identified vulnerable populations who, due to their geographic location, lacked access to a health facility for testing and vaccination. These communities face difficulties due to inadequate road access to health facilities. Although there may be a functioning post in a population centre, people living at considerable distances may encounter obstacles to accessing it promptly. These obstacles may include poor road conditions or the lack of a motor vehicle to transport the sick person.

Conclusions

Mapping analysis of road networks in rural areas provides valuable insight into the quality of life in these regions. This analysis allows us to understand the distances and travel times, both by car and on foot, to essential services such as health centres, municipalities, markets, pharmacies, banks, post offices, and primary and secondary education centres. These services are the ones that people use the most and therefore require special attention. It is particularly important to guarantee access to these services for groups in vulnerable situations, such as children, pregnant women, the elderly and people with disabilities.

The results allow us to validate the initial hypothesis and affirm that, in the district of Los Morochos, the cost of distance in time to access the basic services of most dwellings is

too high and does not allow satisfying the essential needs of the population, thereby compromising the quality of life. By quantifying the time-consuming cost of accessing basic services, this research offers a valuable tool for planners in decision-making about service management in rural areas. In addition, this study represents an important novelty, as there is no previous research that quantifies the time cost of accessing basic services in a rural population with the characteristics of Los Morochucos.

This research has provided methodological and practical advances in the understanding of accessibility and quality of life in rural communities in Ayacucho and offers a basis for future research in this field, such as age-group differences. Likewise, one of the main contributions of this article is the application of network analysis in rural areas with dispersed populations. That is, the use of tools such as the GIS-based Network Analyst made it possible to identify the time of access to services, either by car or on foot, and to evaluate the transport system, the network conditions, and the shortest or most efficient route to the destination. It is hoped to complement these results with research already conducted on the perceptions of the populations in these rural areas. This combination of quantitative and qualitative approaches will allow for a more complete understanding of accessibility and quality of life in rural communities in Ayacucho.

Financing: The fieldwork was funded by the Andean Rural Geographic Research Institute.

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