

MEASURING RURAL ACCESSIBILITY IN THE GIS ENVIRONMENT: CASE STUDY OF ARMENIA

Artak Piloyan, Aram Gevorgyan

Artak Piloyan

Yerevan State University; Faculty of Geography and Geology

Alex Manoogian 1, 0025 Yerevan, Armenia

+37491885003, artakpiloyan@ysu.am

Aram Gevorgyan

Yerevan State University; Faculty of Biology

Alex Manoogian 1, 0025 Yerevan, Armenia

+37477497266, aram_gevorgyan@yahoo.com

Abstract

In rural areas of the developing world, where the majority of the poor live, good transport connectivity through road infrastructure and transport services is an essential part of the enabling environment for sustainable growth. Access to markets and social services is a major determinant of economic status and welfare. Measurement of access is therefore of great importance for policy analysis and planning of interventions. The resulting Rural Access Index (RAI) may serve as a useful and cost effective tool for governments planning their rural transport programs and as an indicator of progress towards the achievement of several of the UN Sustainable Development Goal (SDG) targets. The purpose of this paper is the presentation of the results of the first country-wide road survey ever conducted in Armenia, the results of which were used to measure rural accessibility.

Keywords: Rural Accessibility Index, Accessibility Analysis, Armenia

INTRODUCTION

Transport connectivity is an essential part of the enabling environment for inclusive and sustained growth. In many developing countries the vast majority of farmers are still disconnected from local, regional, and global markets. To reduce poverty and support inclusive economic growth, rural access is key. The Sustainable Development Goals (SDGs) aim to build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation (Goal 9), for which Target 9.1 is to develop quality, reliable, sustainable and resilient infrastructure...to support economic development and human well-being, with a focus on affordable and equitable access for all. The Rural Access Index (RAI) is proposed as an indicator to measure this target. The role of transport infrastructure in reducing poverty through better access to opportunities and services has been widely studied, but not clearly understood (Gannon and Liu 1997; Booth et al. 2000). Shared prosperity and poverty reduction require making the transport network accessible to everyone, particularly the poor and bottom 40 percent.

Improved access to social services, infrastructure and markets is an important element of rural development and poverty alleviation. Poor access, especially in rural areas is associated with a range of development problems – children face difficulties in reaching educational facilities; residents have severe problems in getting to health facilities for both emergency and non-acute treatment; farmers have less incentive to exploit the full agro-ecological potential of remote farming areas due to problems in reaching markets; or they face low farm gate prices offered by traders. From a policy analysis perspective, it then becomes important to devise ways of measuring access – across space and over time. New ways of collecting and analyzing geographically explicit data have also given rise to new ways of measuring and visualizing accessibility (Yoshida and Deichmann 2009).

The potential accessibility index is constructed based on the assumption that the benefit of access to an urban center increases with the population size of the center, and declines with distance, travel time or cost. Improvements in geographic information systems (GIS) have opened up new ways to measure accessibility. A typical way to assess accessibility has traditionally been to conduct a household survey and ask each household (typically the household head) in the sample how far urban centers are from the household. An alternative and modern approach is to measure accessibility directly from geo-referenced databases. In many developing countries, an increasing number of road

networks and locations of cities and villages are digitized and referenced according to the location code system (Gibson and McKenzie 2008). Using these databases, a standard commercial GIS packages (like ArcGIS, QGIS) can easily calculate the shortest route between an origin site and a destination such as a large city or the closest major road. Estimates of feasible travel speed, taking into account the road conditions, can then convert distances into estimates of travel time.

The latter approach based on GIS databases is more objective than the traditional approach in that it leaves little room for subjective judgement. Another attractive feature of this approach is related to how the results are shown. A table with 10,000 villages' access indicators is almost incomprehensible. Instead, the GIS-based accessibility index is presented in a map that identifies geographical patterns of villages suffering from lack of access to infrastructure.

Potential accessibility indexes are becoming increasingly popular in the empirical literature that tests the impact of market access to regional economic growth and poverty reduction. For example, potential accessibility indexes have been used to test hypotheses from "New Economic Geography" on externalities from urban agglomeration, such as whether access to urban agglomeration helps local firms improve their productivity. Also, along with recent developments in poverty mapping, the indexes are used to examine the spatial relationship between poverty and market access (Yoshida and Deichmann 2009).

COUNTRY OVERVIEW

Armenia is a lower-middle-income country with a gross national income (GNI) per capita (Atlas method) of US\$ 3,760 in 2016. Armenia's economy has grown by 3 percent per year on average since it gained independence in 1991, but the average masks large fluctuations. The country's growth episode can be distinguished into five phases: (a) the period after independence (1991-1993) in which the economy contracted by half; (b) the transition phase (1999-2003) in which growth was driven by high productivity growth and rising exports; (c) the construction boom period (2003-2008), facilitated by the government's campaign to actively encourage investments from Armenians living abroad into real estate in Armenia; (d) the period of a sharp economic contraction and post-crisis recovery (2009-2011), when the government responded to the collapse in economic activity by increasing public spending for the construction sector; and (e) the current phase, in which solid export growth and weak domestic demand, in combination with a recession in the Russian Federation, only allows for sluggish economic growth (World Bank 2017).

Armenia has a relatively well-developed road network, serving all areas of its economy, but road quality is still a matter of concern, particularly in rural areas. With an underdeveloped railway network, principally due to its difficult terrain, the road system is of vital importance for the development of the country. Most of the road network was built in the 1960s and 1970s. Most republican and local roads have deteriorated since independence. The roads linking villages to the main highways are often called "lifeline roads" in Armenia. They are vital for communities' located dozens as well as hundreds of kilometers away from urban areas. With a significant part of them last rehabilitated in the Soviet era, the lifeline roads are in desperately poor conditions, effectively cutting off rural communities from the nearby towns and big cities (World Bank 2017).

Most of freight and passenger transport is conducted by road. The classified road network is 7,700 km long with 1,400 km of interstate roads, 2,520 km of regional roads, and 3,780 km of local roads. Surface conditions of these roads vary from good to fair, and up to 84 percent of roads are paved.

Armenia is subdivided into eleven administrative divisions. Of these, ten are provinces, known as marzes or in the singular form marz in Armenian. Yerevan is treated separately and granted special administrative status as the country's capital.

METHODOLOGY

Where poverty is predominantly a result of isolation from markets and services, it is not surprising to see a close correlation. It is hence useful to construct indices to better understand the spatial relationship between poverty incidence and market and service accessibility. Three indices are proposed: (a) Rural Accessibility Index (RAI), (b) Market Accessibility Index (MAI), and (c) Service Accessibility Index (SAI).

Methodology for Calculating Rural Accessibility Index

The RAI developed by Roberts et al. (2006) is one of the most important global development indicators in the transport sector. The RAI measures the proportion of the rural population within 2 km or a 25-minute walk to an all-weather road. An all-weather road in this context is considered as one in fair condition or better. The proposed RAI method proposed here requires three data: (i) Population distribution, (ii) Road network, and (iii) Road condition. Geospatial

techniques are used to combine all of them in the same format (Figure 1). The use of this spatial data has various advantages: It can help ensure consistency across countries. The level of spatial resolution is broadly the same regardless of the size of countries or subnational boundaries. Any given norm of connectivity (e.g., 2 km distance from a road) is uniquely and unambiguously applied for all countries. Global population distribution data are highly disaggregated to enable an assessment of how many people live at any given locality. In addition, global population distribution data are regularly updated and provided mostly free of charge, which greatly helps ensure the sustainability of the index.

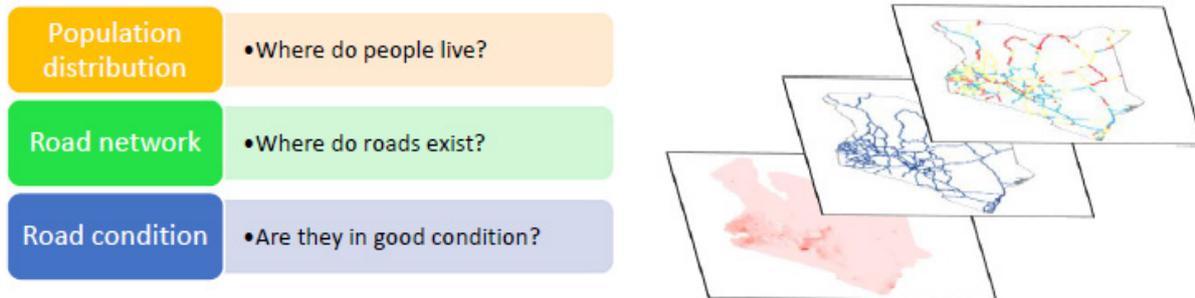


Figure 1. Data requirements for the Proposed RAI (Source: World Bank 2016)

Data requirement (1): Population distribution data

Quality population distribution data are essential to correctly measure rural access. However, detailed and contemporary census data is only available in Armenia for 2011 and cannot be easily accessed due to prevailing confidentiality laws. The proposed method relies on available global population distribution data. In addition, detailed, contemporary census data may not be available in developing countries. In recent years, highly disaggregated global population data, such as LandScan and WorldPop, have been developed by the international research community. Although it remains subject to available data, modeling and assumptions, these datasets distribute subnational data at the more detailed, subnational level, using a number of spatial data and techniques. While all available population datasets are derived from population census data, each dataset has advantages and disadvantages. While LandScan, for instance, provides population distribution at approximately a 1 km resolution, WorldPop is available at a 100 m resolution (<http://www.worldpop.org.uk/>).

Data requirement (2): Road network data and Road Condition data

The RAI aims at taking advantage of georeferenced road network data. The use of spatial data has the particular advantage of locating roads accurately and objectively. In the RAI calculation, client government data are used whenever available. They are consistent with the road network for which road agencies are responsible and are relatively easily merged with other operational databases, such as road asset management systems, and traffic count data. From a sustainability point of view, it is also important to foster ownership by and partnership with client governments, and will encourage them to collect condition data and use the resultant RAI outcomes directly in their operations.

The most difficult challenge in the new RAI calculation lies in collecting road condition data at the individual road segment level. Some road condition data may already have been georeferenced but are often fragmented and in different data formats. Thus, it is necessary to collect reasonably accurate road condition data and integrate them into the above-mentioned georeferenced road network data.

In recent years, smartphone applications for road condition assessment have been developed. These are becoming increasingly attractive because of their cost-effectiveness and objectivity. There are both commercial and open applications. While the former may allow for a better maintenance and update of collected data, with some additional assessment tools provided, the latter is more cost-effective. It is essentially free software. For instance, the RoadLab app can record roughness estimates for every 100 meters, as well as average speed and GPS coordinates of both starting and ending points, while a user is driving with the app running on a smartphone or tablet. This is a relatively cost-effective option, although labor costs are still required for surveyors or drivers. But if this is used in the open data context to which everyone can contribute, the cost of data collection could be nearly zero, creating significant potential for sustainability in data collection as well as citizen engagement in road asset management more broadly.

In the case of Armenia the road survey was carried out between April and May of 2017 to avoid icy and snowy conditions and obtain a more accurate measure of the International Roughness Index (IRI). Because of inadequate

snow-removal efforts in rural areas, accessibility is seriously curtailed in the winter. For road survey RoadLabPro smartphone application was used to capture georeferenced road condition data of the entire road network of Armenia.

Computing the RAI

As mentioned above, the RAI is defined as the share of the population who live within 2 kilometers of the nearest road in “good or fair condition” in rural areas. A road in good condition refers to:

- Paved road with IRI less than 6 m/km and unpaved road with IRI less than 13 m/km, when IRI data are available; and
- Paved road in excellent, good or fair condition and unpaved road in excellent and good condition, when IRI data are not available but other road condition data, such as Pavement Condition Index (PCI) or visual assessment by class value, are available.

The road condition data in Armenia were determined based on the IRI value of the road according to the following matrix (Table 1):

Table 1. Road condition taken into account in RAI calculation

Condition	Minimum Roughness (IRI)	Maximum Roughness (IRI)
Very Good	1.0	2.0
Good	2.0	4.0
Fair	4.0	6.0
Poor	6.0	10.0
Very Poor	10.0	16.0

Methodology for Calculating Accessibility Indicators

The MAI is defined as the travel time required for the population in a given area to reach a town, city, or any other high-density population center. The MAI as defined in this study is driven only by time and distance. It does not take into account important factors such as affordability, availability, and reliability of transport; availability of transport services on the supply side; and household income and purchasing power on the demand side.

The simplest formula for an accessibility index (I_i) is depicted below:

$$I_i = \sum_j \frac{S_j}{T_{ij}^\alpha}$$

where, S_j is a size indicator at target j (for example, population of large cities/towns), and T_{ij} is the distance (or travel time) between origin i and target j . By varying α , the functional form of the impact of travel time on the potential accessibility can be changed. A high α implies that the influence of nearby cities diminishes very quickly, while a low α means that even cities and towns far away exert an influence on a location (Yoshida and Deichmann 2009).

RESULTS

Rural Accessibility Index

Given Armenia’s current road conditions, it is estimated that 66 percent of the rural population, or 1,190,000 people, are within 2 km of a road in good condition, while an additional 610,000 people do not have access to an all-weather road. The analysis demonstrated that Kotayk and Armavir Marz have the highest RAI and Gegharkunik Marz has the lowest RAI as illustrated in Figure 2.

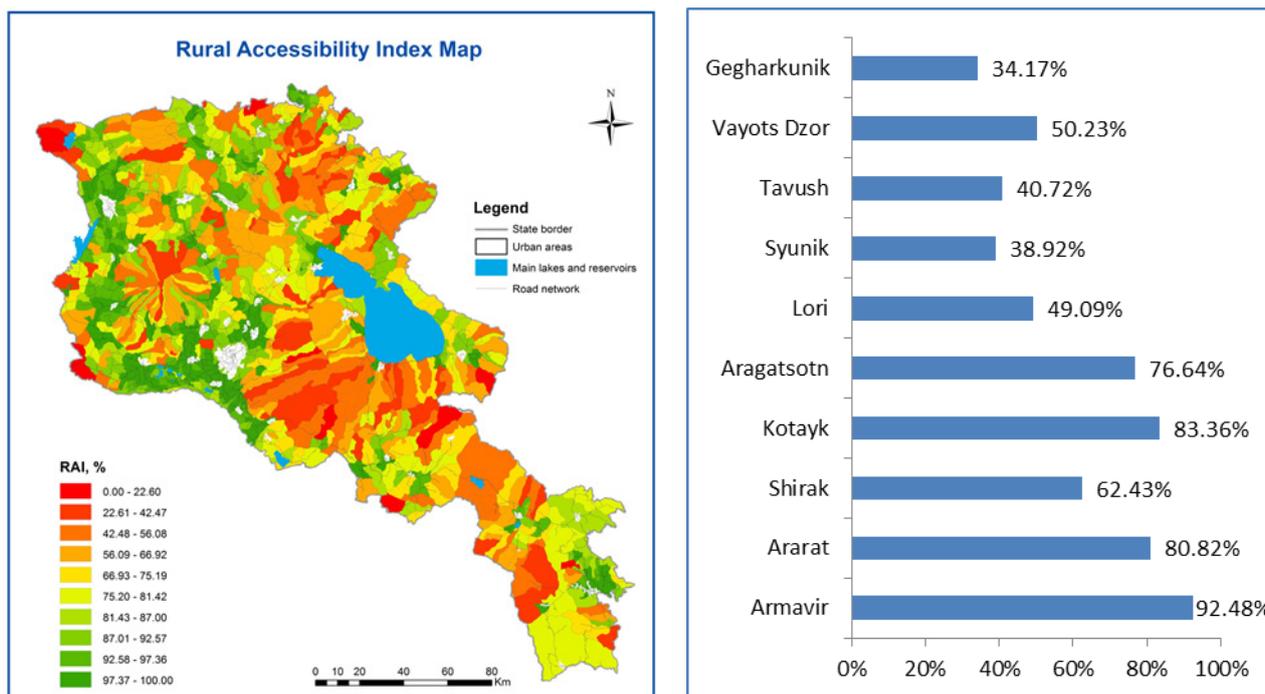


Figure 2. RAI Map for Armenia and RAI by Marz 2017

This finding implies that there is a high degree of physical isolation for a nontrivial number of rural households in Armenia. The RAI provides a consistent basis for estimating the proportion of the rural population that has adequate access to the transport system (Roberts et al. 2006). While the country-wide RAI is high compared to other low- and middle-income countries, it is still lower than the 2003 estimate of 80 percent. This may be due to structural changes in the demographic distribution of Armenia and the way in which the RAI has been calculated for the selected period. It is important to mention that the RAI by itself does not fully capture people's access to opportunities and services. To this end, another set of indicators was constructed to illustrate the essential goal of transport and mobility, and the ease with which households can access markets, education, and health's facilities.

Market Accessibility Index

Drawing on the methodology developed by Yoshida and Deichman (2009), an index is constructed to gauge connectivity-specific locations within the country in the larger cities in Armenia (Yerevan, Gyumri, and Vanadzor) and other smaller urban centers, while considering the population of the cities or other destinations of interest and the transportation facilities to reach them. In the absence of household surveys to measure countrywide access to urban centers, open source demographic data are used to assess the distribution of the population in Armenia (WorldPop 2015) and linked to the data from the community database, which is available until 2015, and the geo-referenced database that was assembled through the 2017 road survey to derive the MAI. For the purposes of this study, this index calculates total population in all the communities and towns of Armenia within a given threshold distance, inversely weighted by travel time from the origin. The index assumes that the benefit of access to an urban center increases with the population size of the center and declines with distance, travel time, or cost.

The GIS played a key role in constructing the MAI for Armenia. The index was calculated considering time intervals needed to reach the nearest town hall/city hall. A statistical analysis was performed using the zonal statistical tools and with the use of GIS. The actual speed values recorded during the road survey for each 100-m interval of the roads are used for calculations since they provide for more detailed and realistic assessment than using the constant speed values for each level of the roads.

Using the approach, the MAI was computed for the following:

- Time intervals needed to reach the nearest city hall of the three main cities in Armenia (Yerevan, Gyumri, and Vanadzor). These are cities with a population of over 50,000 (Figure 3).
- Time intervals needed to reach the nearest city hall/town hall of the cities/towns with population over 15,000. There are 19 such towns in Armenia (Figure 4).

- Time intervals needed to reach the nearest city hall/town hall of the 30 largest cities/towns in Armenia (cities of approximately 10,000 people or more).

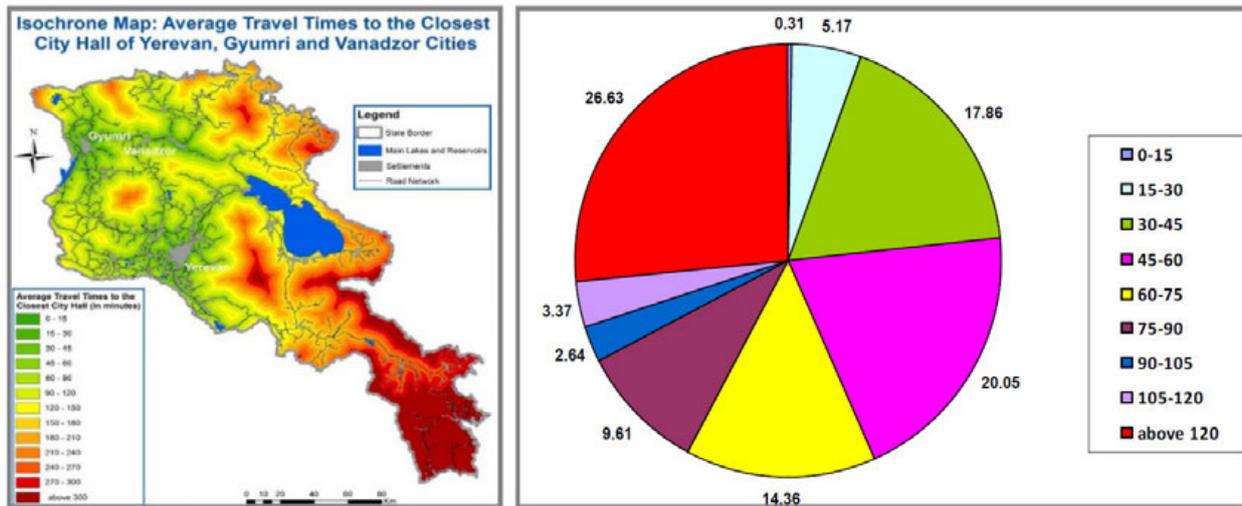


Figure 3. Travel Times to Yerevan, Gyumri, and Vanadzor Cities and Distribution of the Rural Population from the Point of Interest (Source: World Bank 2017)

As can be seen from Figure 3, close to half of Armenia's rural population lives in settlements situated within one hour of the country's largest cities, indicating the economic reliance on the dominant cities and the country's relatively compact size and dense demographic distribution. For over 25 percent of the population, a journey to the main cities takes over two hours, particularly in the southernmost marzes of Syunik and Vayots Dzor, where rural accessibility is unsurprisingly low compared to other marzes (World Bank 2017).

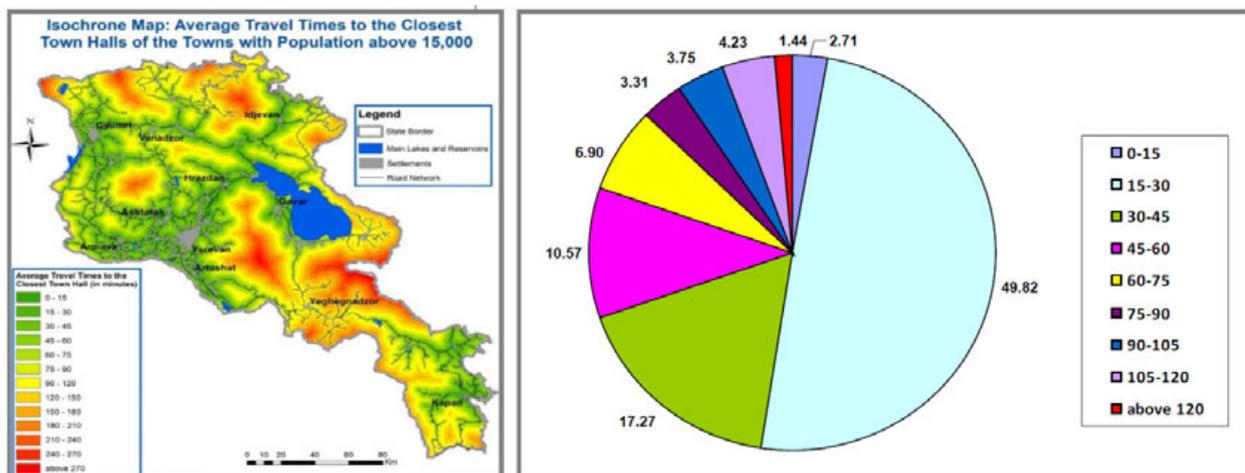


Figure 4. Average Travel Time to Towns with Population of over 15,000 and Distribution of Rural Population from the Point of Interest (Source: World Bank 2017)

Figure 4 shows that more than half of Armenia's rural population is located within a 30-minute drive from a town of 15,000 people, demonstrating that the rural population is relatively well connected to the immediate towns where they are likely to sell their produce and buy inputs for production and consumer goods.

Service Accessibility Indices

One final step of the analysis was to measure the average time it takes for the population to reach social services. To this end, the average travel time to health facilities and schools in the whole territory of Armenia was measured.

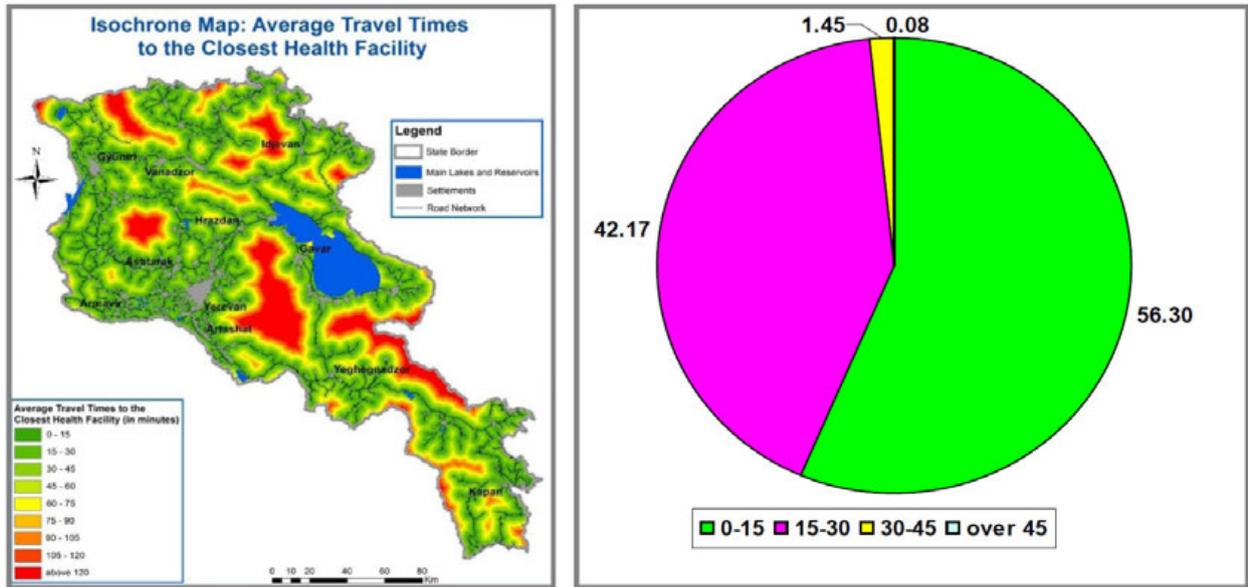


Figure 5. Average Travel Times to the Closest Health Facilities and Distribution of the Population within Time Thresholds (Source: World Bank 2017)

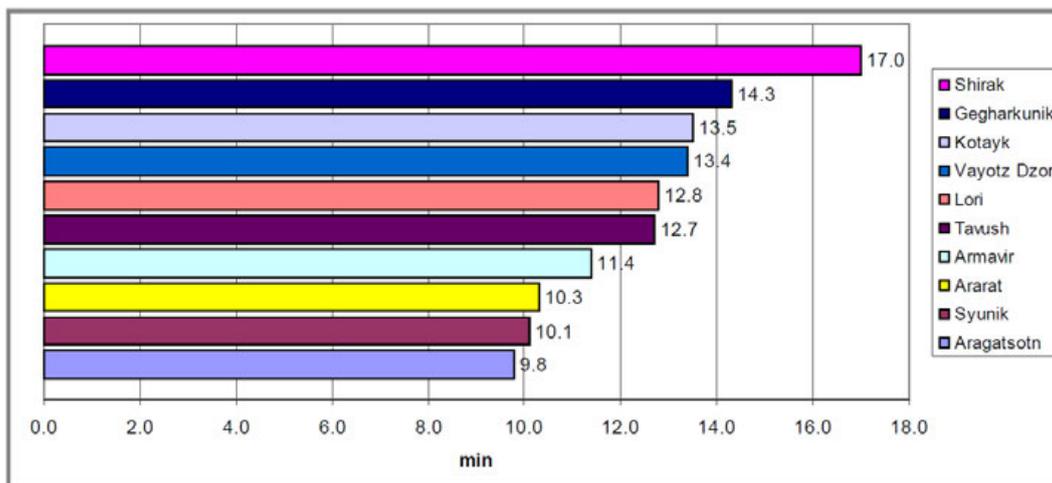


Figure 6. Average Travel Times to the Closest Health Facility, by Marz

Figure 5 and Figure 6 show that geographic coverage of health facilities is almost universal in Armenia with at least one health post in almost every community. Shirak is the marz with the least health service availability, but even there, it takes on average 17 minutes to reach a primary health post.

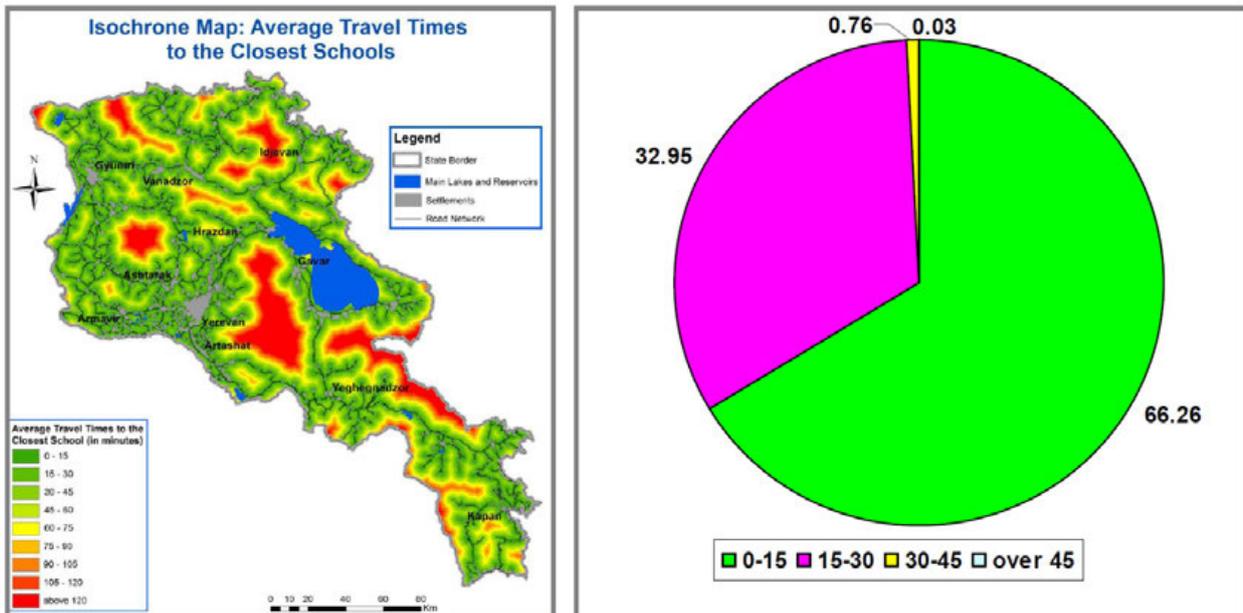


Figure 7. Average Travel Times to the Closest School (Source: World Bank 2017)

Figure 7 and Figure 8 show that geographic coverage of schools is almost universal in Armenia with at least one elementary school in almost every community. Gegharkunik Marz has the highest average travel time to reach a school, but again, it takes on average less than 15 minutes to reach a primary school in that marz.

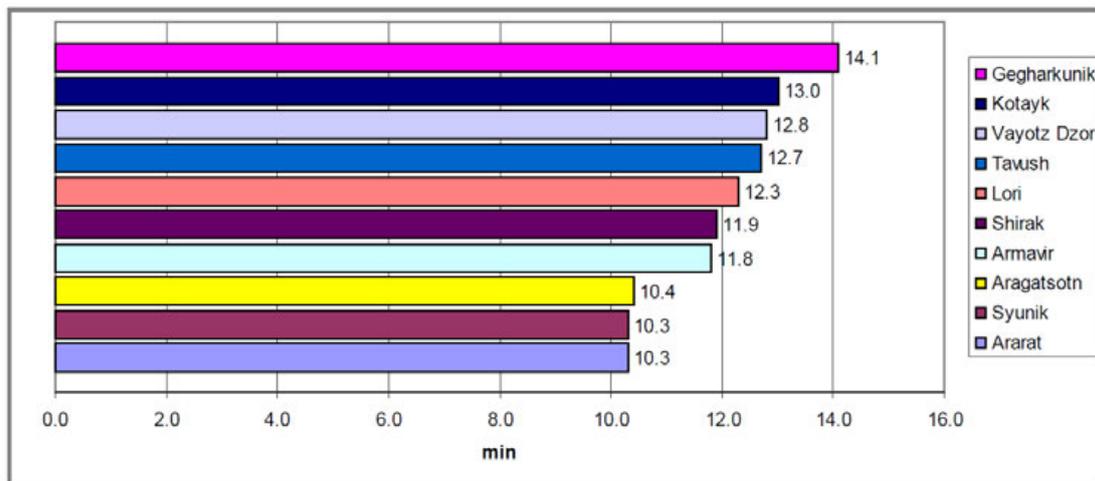


Figure 6. Average Travel Times to the Closest School, by Marz

DISSCUSSION

For the first time, geo-referenced data of the road network in Armenia was used to measure accessibility indices. The countrywide accessibility analysis provides some insight into the extent to which the rural population is constrained in terms of physical access to opportunities. The results suggest that despite the relatively poor condition of rural roads in several regions of the country, most inhabitants have relatively good access to services and markets. This implies that while the quality of rural roads in Armenia is still a matter of concern, there does not seem to be a lack of market and service concentration as evidenced by a high degree of accessibility to high-density population centers, health posts, and schools.

The results presented cannot be taken for year-round accessibility. As mentioned earlier, the road survey took place in spring when most of the road network was accessible. Accessibility can be seriously curtailed in winter, particularly in rural communities that depend on the lifeline road network, which does not get proper snow removal equipment. For instance, during winter, the roads in the north (Shirak and Lori Marzes) and in the south (Syunik) are closed for short

periods due to insufficient snow cleaning machinery. Heavy snow and fog are common from the end of January to the beginning of February. The same applies to some mountainous regions such as Tavush and Syunik that are subject to landslides in the rainy seasons blocking access to some of the poorest communities (World Bank 2017).

ACKNOWLEDGEMENTS

This research was carried out within the framework of the Project “Impact of Roads on Poverty and Access (Connecting Transport to Social Inclusion) (ID: P161376). Component II: Market/service accessibility index and characterization of rural connectivity” The project was financed by the World Bank.

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BIOGRAPHY



Artak Piloyan is a lecturer and PhD candidate at Yerevan State University, Faculty of Geography. With the complete Master’s degree in Cartography and GIS he has more than 8 years of experience in Geomorphological, Environmental, Cartographic and Geospatial studies, particularly in thematic mapping for management of water resources, natural hazards and risks assessment and mapping, LULC mapping, landform classification. Over 8 years of experience in commercial environment and working on donor-funded international projects (UNDP, EU, USAID, GIZ, OSCE, SDC), 6 + years of experience working in a scientific environment.



Aram Gevorgyan is an experienced professional in data management, GIS, building information systems and using remote sensing technologies for environmental decision-making and management. He has more than 16 years working experience in various national, regional and international projects as an expert on data management / GIS / information systems, practicing in the field of water resources management, disaster risk reduction and biodiversity conservation. Specific activities include development of information systems in the field of environment and water resources management in the South Caucasus, Kyrgyzstan and Tajikistan, classification of land cover/use based on remote sensing data, as well as construction of biodiversity clearing-house mechanism during one-year international experience at UNEP-WCMC office in Cambridge, UK.