Measuring Rural Access
Using new technologies

UKaid
from the British people

ReCAP
Research for Community Access Partnership

WORLD BANK GROUP

MEASURING RURAL ACCESS: USING NEW TECHNOLOGIES

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Annexes

LIST OF ABBREVIATIONS

CDRs	call detail records
DFID	Department for International Development (United Kingdom)
GIS	geographic information system
GPS	Global Positioning System
GPW	Gridded Population of the World
GRUMP	Global Rural-Urban Mapping Project
IGAD	Intergovernmental Authority on Development
IRI	International Roughness Index
km	kilometer
m	meter
PCI	Pavement Condition Index
PDO	project development objective
RAI	Rural Access Index
SDGs	Sustainable Development Goals
SRN	Strategic Road Network
UAV	unmanned aerial vehicle
UNEP	United Nations Environment Programme

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EXECUTIVE SUMMARY

Background

Transport connectivity is an essential part of the enabling environment for inclusive and sustained growth. In many developing countries, particularly in Africa, 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 RAI, which was developed by Roberts, Shyam, and Rastogi (2006), is one of the most important global development indicators in the transport sector. The RAI measures the proportion of people who have access to an all-season road within an approximate walking distance of 2 kilometers (km). There is a common understanding that the 2 km threshold is a reasonable extent for people's normal economic and social purposes. The definition is also simple enough to understand and use not only in transport, but also in the broader development context, such as poverty alleviation. In the initial study, the RAI was estimated at 68.3 percent based on household surveys, leaving a rural population of about one billion unconnected to a good quality road network (map 1).

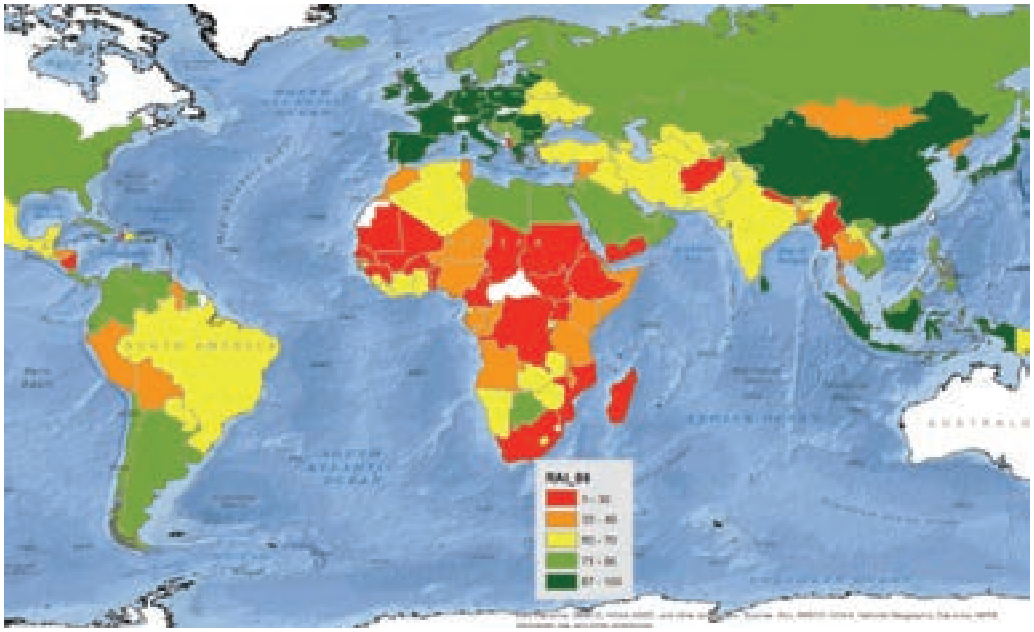
It is important to update the RAI in a timely manner and use it in actual operations. Unfortunately, however, the previous methodology has several disadvantages, such as inconsistency across countries, lack of sustainability of regular updates, and weak operational relevance and client ownership. In particular, it is generally costly to rely on a household survey, which limits the sustainability of the index. In addition, the household-based approach cannot be spatially representative enough, limiting operational usefulness. With different tools and innovative technologies, it is now becoming easier and very possible to collect data, update the condition of the road network, and revise the RAI more regularly.

Proposed New Method

The World Bank has partnered with the Department for International Development (DFID) of the United Kingdom and the Research for Community Access Partnership to develop a new methodology to measure rural access, which is sustainable, consistent, simple, and operationally relevant. Conceptually, the proposed new methodology is still focused on access to an all-weather road. Technically, it measures the share of the population that lives within 2 km of the nearest road in "good condition" in rural areas. The condition of roads is assessed in transport engineering terms.

The proposed methodology is not new, but it takes advantage of spatial techniques and data collected using innovative technologies. In recent years, several new technologies and data sets have been developed. The proposed method uses some of them, although not all. For instance, high-resolution population distribution data have been developed by the international research community. The WorldPop data have the highest resolution (100 meters). Therefore, it is more or less known

Map 1: Rural Access Index, 2006



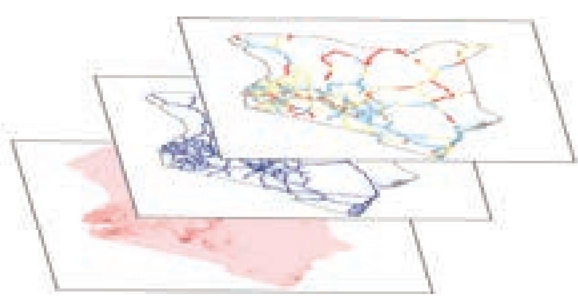
where people live. Digitized road network data, including road conditions, are also often available at road agencies.

Of course, some data may be missing, in particular road condition data are the most challenging in developing countries. Road asset management systems may not be updated. Data on rural road condition may also be fragmented. But there are many ways to collect such data, for example by traditional road inventory surveys or a smartphone application that assesses road roughness while driving. Some other technologies, such as high-resolution satellite imagery, have potential to assess road conditions remotely and consistently. Crowdsourced or open data also have potential, especially from a sustainable data source point of view, although the proposed method does not fully rely on it yet.

By spatially combining the above-mentioned various spatial data (figure 1), the RAI is virtually computed without counting households on the ground. This helps to make the index more sustainable as well as consistent across countries. The new method also allows for estimation of rural accessibility at any disaggregated subnational level (such as districts or villages). Therefore, it is expected to be highly relevant to road sector operations, such as rural road prioritization and monitoring.

The spatial approach is more cost-effective and sustainable than the previous RAI method based on household surveys. In addition, the proposed approach to collaborate with road agencies or governments has the advan-

Figure 1: Spatial Technique for the New Rural Access Index Method

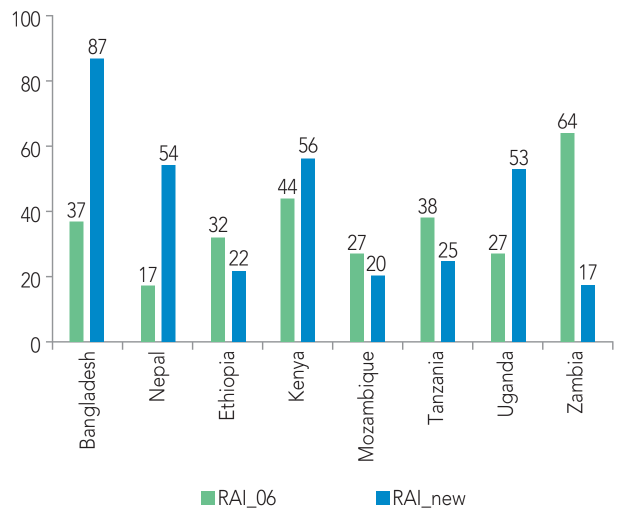


tage that it motivates them to collect and update their road condition data sets by themselves, since these data are required for their operational needs anyway.

Results from the Eight Pilot Countries

The new method was applied to eight pilot counties: Ethiopia, Kenya, Mozambique, Tanzania, Uganda, and Zambia in Africa, and Bangladesh and Nepal in South Asia. Rural access varies significantly across these countries, from 17 percent in Zambia to 56 percent in Kenya (figure 2). In total, it is estimated that about 34 percent of the rural population is connected, with roughly seven million people left disconnected.

Figure 2: Comparison of Original and New RAI Results



The new RAIs are somewhat different from the original estimates, because the methodology and data are fundamentally different from the original work. Of particular note, the coverage of the data is different. In the original RAI estimation, for instance, the household survey that was used in Tanzania covered 3,917 households nationwide in 409 villages. This has limited representativeness of the country's vast land area of 950,000 square kilometers. The new RAI measures the accessibility of every single local place (technically, every area of 100 x 100 meters).

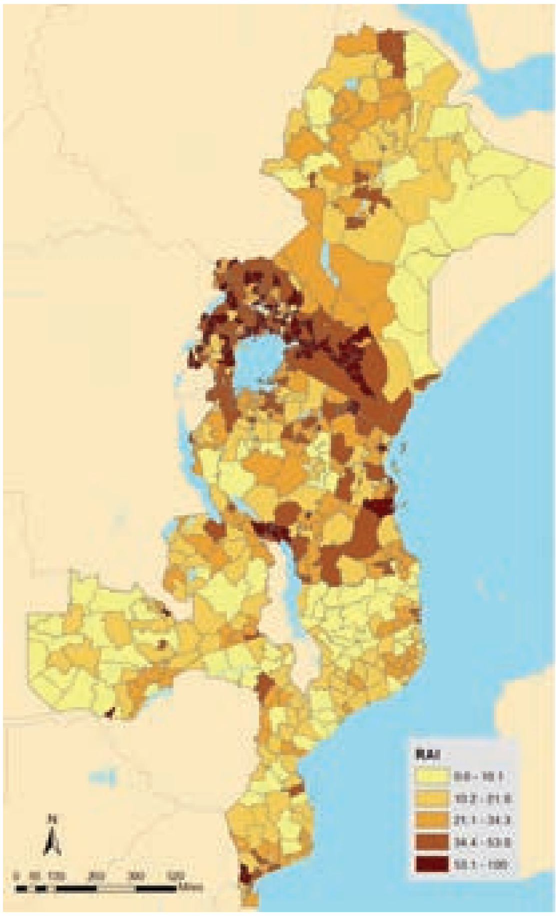
All the indications are that there exists a significant infrastructure gap in rural access. In the eight pilot countries, it is estimated that there are about 174 million people without access. In the six African countries, about 148 million people are estimated to have no access, which translates to an RAI of 32 percent, which is down 3 percentage points from the original estimate in 2006. Although the two estimates are not directly comparable, the comparison may indicate that infrastructure efforts might not catch up with the increasing rural populations in absolute terms.

A significant amount of resources would likely be required to meet the existing gaps. Based on the new RAI estimates, for instance, it is estimated that Kenya would need about US$2 billion to rehabilitate and improve the entire road network. The new methodology also clearly suggests that universal rural road access is a challenge in some of the countries where the current official road networks are narrowly defined. In Mozambique and Zambia, for instance, universal access could not be achieved even if all the roads in the current classified networks were improved. People live beyond the current road networks. Significant efforts are therefore required not only in rehabilitating or maintaining the current network, but also extending the network (through the reclassification of existing unclassified roads or new construction).

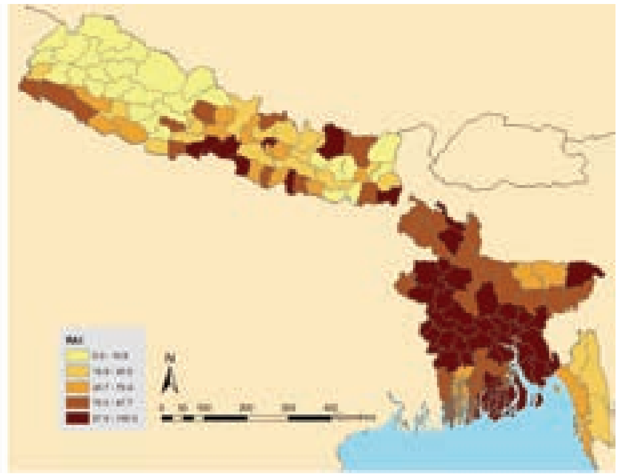
Therefore, given available resources, strategic prioritization is a must. The new RAI can provide insight into where to invest, because it is now available not only at the national level, but also at the subnational level. In a given country, some areas often have better road access than others (map 2). The provision of access in areas with low population density, where poverty often coexists, is a particular challenge. It is also suggestive of potential synergies between rural access improvement and regional integration. In Africa, for instance, there are several regional road or rail corridors that coexist with high rural accessibility. Rural communities may be able to be connected not only to the road network, but also the global market through regional corridors.

Map 2: New Rural Access Index at the Subnational Level

a. East Africa



b. South Asia



Source: World Bank calculations.

Relevance to Broader Development Objectives

The results confirm that rural access is essential to boost agricultural growth and reduce poverty in Africa. An advantage of using spatial data and techniques is that it is easy to overlay different themes in the same format. For instance, the new RAI is highly correlated to poverty incidence, although causality remains debatable. In Mozambique, the RAI is systematically low where poverty is high (map 3). In Kenya, the correlation is estimated at –0.729 (figure 3). Measured rural accessibility is also found to be relevant to agricultural production (figure 4).

Not surprisingly, the measured RAI is also related to other types of access, such as access to markets or social facilities. In Mozambique, for instance, the RAI is significantly correlated with market access—measured by the share of population living within a distance of four hours to a large city (figure 5). The RAI is also correlated, although less significantly, with access to social facilities, such as schools and hospitals (figure 6). Therefore, as usually expected in rural road development projects, improved rural access is likely to contribute to bringing more economic opportunities to local communities and providing better access to social services.

Map 3: Mozambique: Rural Access Index and Poverty Rate

a. Rural Access Index | **b. Poverty rate**

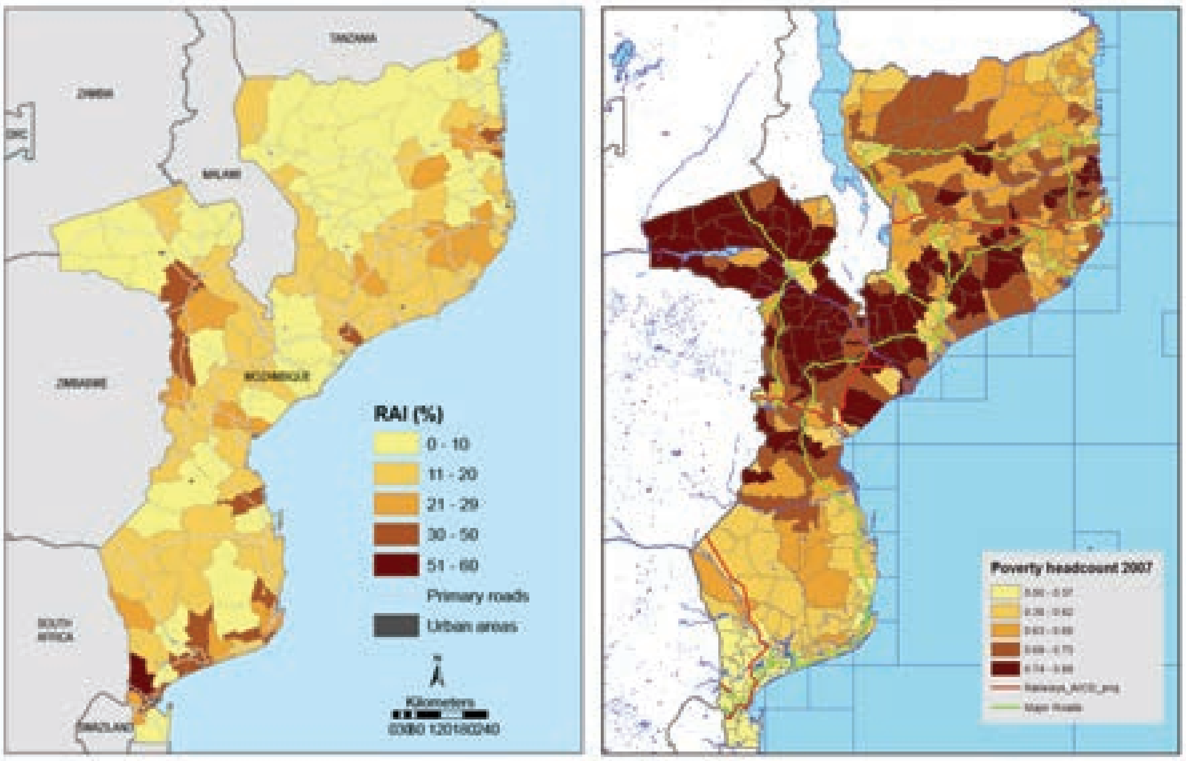


Figure 3: Kenya: Rural Access Index and Poverty Rate

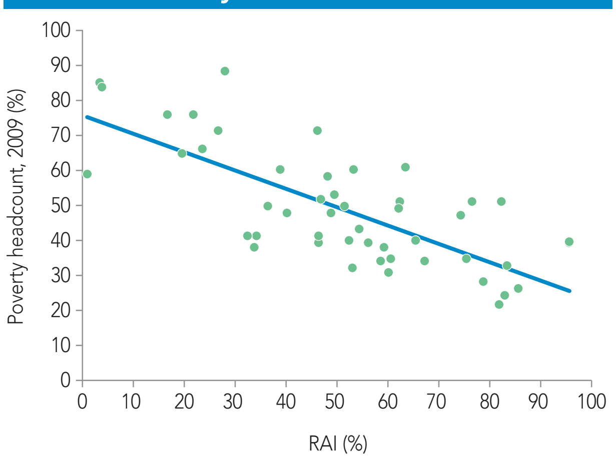


Figure 4: Kenya: Rural Access Index and Agricultural Production

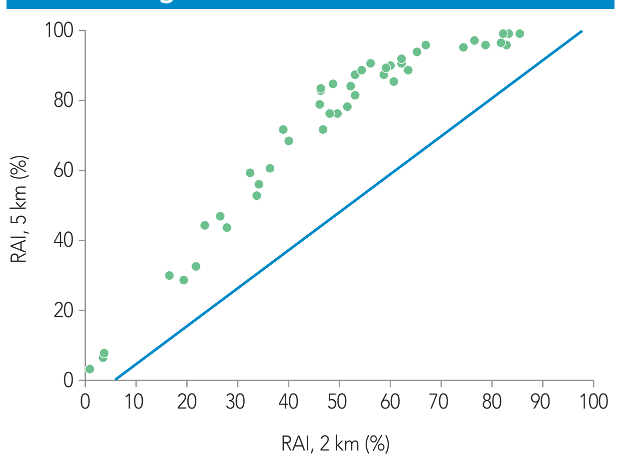


Figure 5: Mozambique: Rural Access Index and Market Access

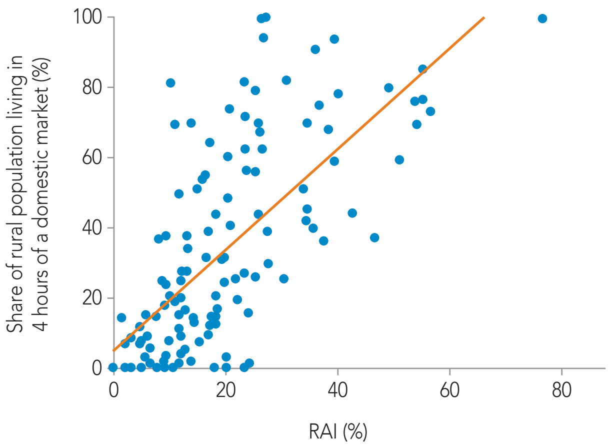
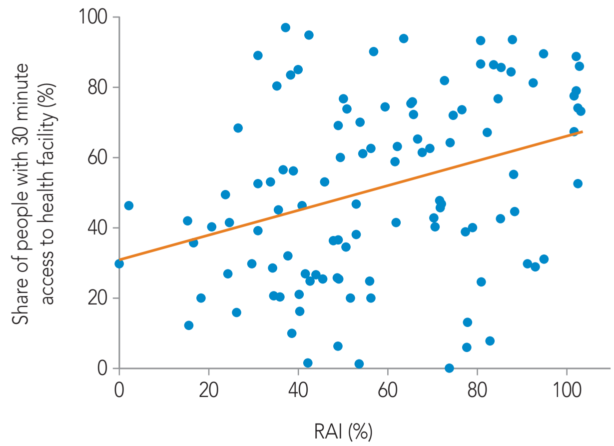


Figure 6: Uganda: Rural Access Index and Access to a Health Facility



Finally, it cannot be overemphasized that the accuracy of the new RAI estimates depends on the quality of the underlying spatial data. Among others, road data density (road density in a given data set) is important for a correct RAI estimate. In developing countries, road classification may not have been completed, and existing road inventory data may lack some or all of the feeder roads. In such cases, efforts need to be made to improve the underlying data sets. In this regard, having a wide variety of new data sources and innovative technologies to generate data is very encouraging.

Road agencies play a critical role. Regardless of the RAI, they must have accurate and detailed road condition information for effective road asset management. This can be challenging, as different institutions are often responsible for management as well as data collection for different classes of roads in a country. Thus, the proposed method is designed to encourage developing countries to update the data themselves and use the resultant RAI outcomes in their own operations.

1

INTRODUCTION

Among other factors, transport connectivity is an essential part of the enabling environment for inclusive and sustained growth. In developing countries, particularly in Africa, the vast majority of agricultural production remains smallholder farming with limited access to local, regional, or global markets. Isolated manufacturing and other local businesses (except for those related to mining) often lag behind in the global market.[1] Limited transport connectivity is also a critical constraint to accessing social and administrative services, especially in rural areas where the majority of the poor live.

Rural access is key to unleashing untapped economic potentials and eradicating poverty in many developing countries. The literature is strongly supportive of this. In the short term, transport costs and travel time can be reduced by improved road conditions (Lokshin and Yemtsov 2005; Danida 2010). Over the longer term, agricultural productivity will be increased (Khandker, Bakht, and Koolwal 2009; Bell and van Dillen 2012) and firms will become more profitable with the creation of more jobs (Mu and van de Walle 2011). Poverty will then be alleviated (Dercon, Hoddinott, and Woldehanna 2008; Khandker and Koolwal 2011).[2]

To make good investments, quality data are required. Since resources are limited, it is essential to understand where the most critical unmet needs exist, and monitor efforts made over time. In the transport sector, there are few global indicators. The World Bank's World Development Indicators used to include the percentage of paved roads in the total road network at the national level, with data sourced from the International Road Federation. However, these data are no longer available, and do not provide information on the granularity of local connectivity. The quality of roads is often unknown and a matter of concern in developing countries. In Africa, the Road Management Initiative, started by the Africa Transport Policy Program in the late 1990s, developed a road sector database, which includes road network condition data such as the share of roads in good or bad condition. But this database is largely outdated and insufficient.[3]

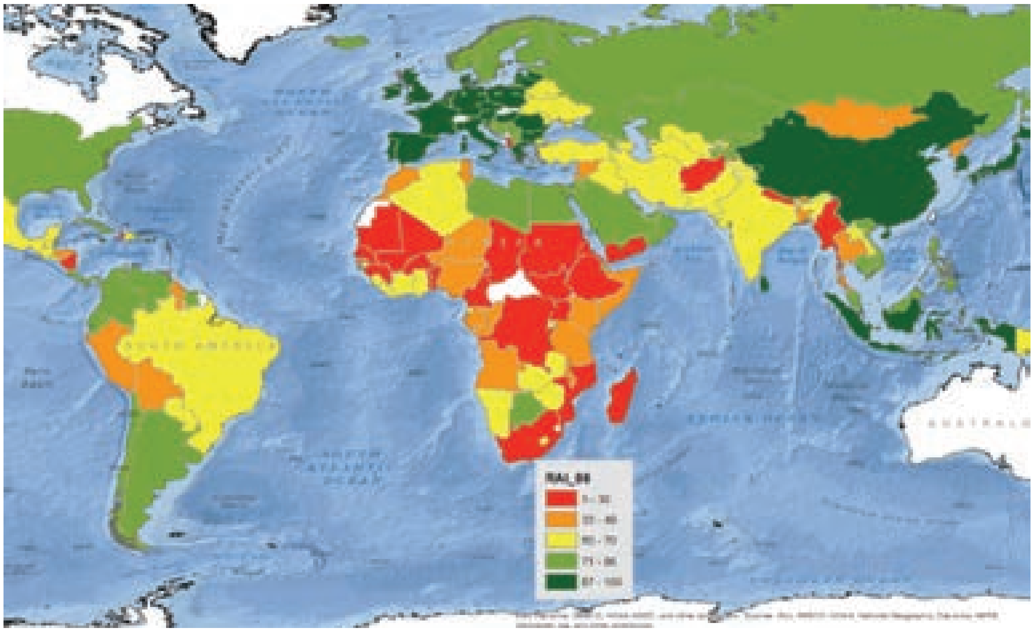
The Rural Access Index (RAI), developed by Roberts, Shyam, and Rastogi (2006), is among the most important global development indicators in the transport sector. It measures the fraction of people who have access to an all-season road within a walking distance of approximately 2 kilometers (km). The original work relied on available household surveys. Although there remains some ambiguity about the methodologies used across countries, the RAI was estimated at 68.3 percent, leaving about one billion rural residents unconnected in the world (map 4). There is significant inequality across

[1] Despite its potential, estimated at US$1 trillion by 2030 (Byerlee et al. 2013), Africa's agriculture sector is still mostly smallholder production. Because of the lack of transport access, farmers do not have access to advanced inputs, such as fertilizer and improved seeds, or output markets to sell their produce at more competitive prices. Poor transport connectivity also imposes high inventory and transaction costs on firms in Africa and undermines their competitiveness (Iimi, Humphrey, and Melibaeva 2015).

[2] See, for instance, World Bank (2012b).

[3] The RAI aims at covering all classified roads. However, the road classification standard and coverage of official roads vary significantly across countries. In Ethiopia, for instance, it is estimated that more than half of the roads are unclassified. In Kenya, unclassified roads account for less than 10 percent (Gwilliam 2011).

Map 4: Original Rural Access Index, 2006

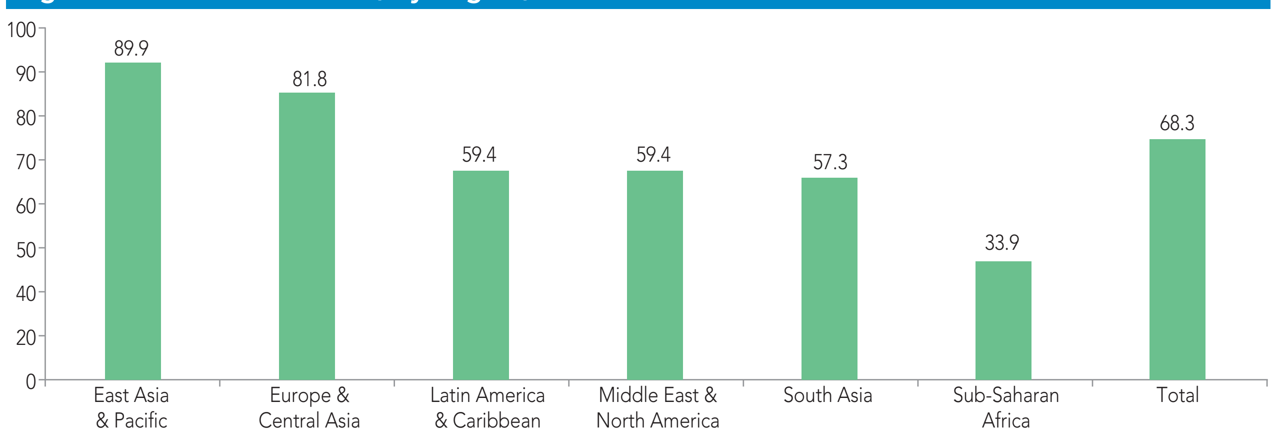


Source: Based on Roberts, Shyam, and Rastogi 2006.

regions: while nearly 90 percent of the rural population in East Asia and Pacific has 2 km access to the road network, in Sub-Saharan Africa the RAI is estimated at only 33.9 percent (figure 7). In general, the RAI is expected to increase as the economy grows. African countries are clearly lagging behind at any particular level of rural accessibility (figure 8).

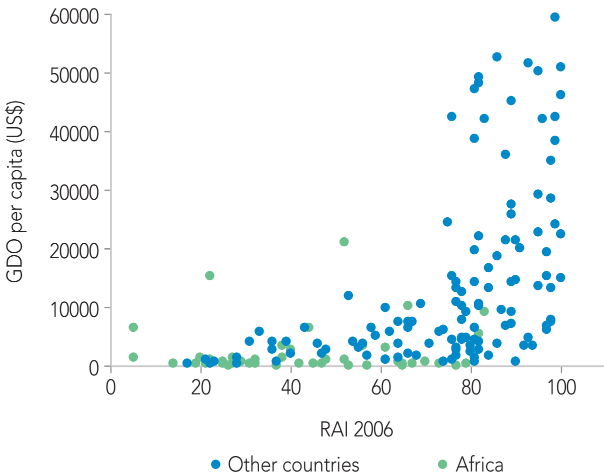
Although it was important in identifying that many rural residents do not have access to the road network in developing countries, the original RAI developed by Roberts, Shyam, and Rastogi (2006) has several methodological disadvantages. First, it uses household surveys and does not have sufficient spatial representativeness. This is a crucial defect for policy makers and other

Figure 7: Rural Access Index, by Region, 2006



Source: Based on Roberts et al. (2006).

Figure 8: Gross Domestic Product Per Capita and Rural Access Index



Source: Roberts, Shyam, and Rastogi 2006.

stakeholders who might utilize the index for informing their decisions on the ground. For instance, a Tanzanian household survey in 2010 covered 3,917 households nationwide, but the sample was only collected from 409 villages in the country's vast land area of 950,000 km^2. Having one national RAI figure for each country may be useful for cross-country comparisons, but is not ideal for actual project planning and monitoring purposes from the practical perspective.

Second, and related, in many countries it is difficult to maintain timely data using household surveys. Household surveys are generally costly and may not be available in all countries. Thus, it is a challenge to update the data at reasonably regular intervals. In Roberts, Shyam, and Rastogi (2006), RAIs based on household surveys were reported for only 50 countries of a total 170 countries for which RAIs were estimated. In Africa, household surveys were used for a handful of countries: Benin, Ghana, Malawi, Nigeria, and South Africa. For all other countries, some existing national statistics were used, or a modeling approach was applied for a rough estimate of rural accessibility under simplistic assumptions.

Third, the previous RAI is difficult to compare across countries, as the methodology and spatial representativeness differ. For instance, Malawi has a similar RAI as Tanzania, according to the 2010 household survey, but with a land area that is about one-tenth the size (table 1). It is not clear whether the RAIs for the two countries are comparable. In addition, although Roberts, Shyam, and Rastogi (2006) clearly define access as connection to an "all-season" road, which allows some predictable interruptions of short duration, subsequent use of the indicator has been plagued by confusion between an all-season road and an "all-weather" road. An all-weather road is held to a higher standard, requiring a road to be motorable all year round and in normal weather conditions. Furthermore, in normal household or community surveys, unfortunately, transport-related questions had not yet been standardized, simply asking "what is the distance to the nearest (major) road?" The surveys relied heavily on respondents' understanding of the question.

Finally, the previous RAI methodology has not proven to be sustainable, as it is not widely connected to day-to-day planning or operations by governments, donors, or other stakeholders. Although a lot of resources are spent on rural road improvement, the RAI may or may not be improved under the previous method. It depends on

Table 1. Comparison of RAIs Based on Household Surveys in Tanzania and Malawi

			Household surveys in 2010		
	Land area (km^2)	Original RAI (%)	Sample size	Sample location	Proportion of HHs with less than 2km access to road (%)
Tanzania	885,800	38	3,917	409	36.9
Malawi	94,280	38	3,246	204	36.1

Sources: Tanzania 2010 Living Standards Measurement Study data; Malawi 2010 Integrated Household Panel Survey data.
Note: HHs = households; km = kilometer; RAI = Rural Access Index.

the sampling frame. As a result, the take-up was very low, and few governments have been interested in updating it regularly. Ideally, an effective development indicator should provide closure to a feedback loop, where the indicator informs where development efforts are most needed, leading to actual development projects, with the results being reflected in future updates of the indicator.

2

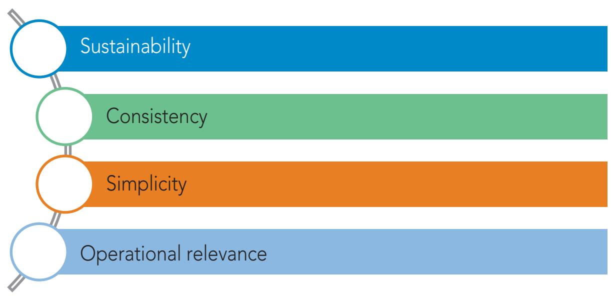
OBJECTIVE AND MAIN PRINCIPLES

Introduction

The main objective of this report is to establish a **sustainable**, **consistent**, and **operationally relevant** method to measure rural access, using newly available data and technologies. A variety of new data and techniques, such as remote sensing, Global Positioning System (GPS), crowdsourcing, and open data, have been developed in recent years. The report aims at not only assessing the current situation of transport accessibility in rural areas, but also measuring and monitoring the efforts that governments and donors have been and are making in this domain to improve people's connectivity. At the national level, the developed methodology is highly disaggregated and therefore practically useful to client governments and other stakeholders in their operations and strategic thinking. At the global level, the developed RAI methodology is expected to contribute to the ongoing discussion of the Sustainable Development Goals (SDGs). Rural access measurement is one of the most important indicators for measuring and achieving several of the SDGs.

The main principles that the new RAI method emphasizes are fourfold: (i) sustainability, (ii) consistency, (iii) simplicity, and (iv) operational relevance (figure 9).

Figure 9: Main Principles of the New Rural Access Index Method



Sources: RAI (2006) and RAI (new methodology).

Sustainability

From the operational point of view, close collaboration with client governments is key for long-term sustainability. Ideally, it is client governments who should update the index, use it, and own it. Thus, the new RAI has been developed based on partnerships with client countries, primarily using government-owned data that are generally focused on the official road network. As will be discussed in section III.D, government data are merely one of the available data sets and may not be perfect. However, it is a complex question what the optimal road network is. It should depend on country context. In addition, road classification is a politically sensitive issue, because of its various implications for government responsibility and resource allocation. Thus, it was decided to rely on the current definition of the official road network, which can be reexamined. For example, in Mozambique this RAI update exercise motivated the government to rethink the coverage and optimality of the official road network (section V.D).

The new method takes advantage of publicly available data that already exist in the international research community. One of the lessons learned from the low uptake of the previous methodology was that it is financially unsustainable to carry out a household-level survey that is spatially representative of a whole nation, although it is done as a part of the existing household survey initiative.[4]

The RAI must be owned by client countries, reflecting the link to the SDGs. It is generally more sustainable to assemble and update existing databases, rather than collect new data. Many client countries already have relevant data, although they tend to be collected and stored in a fragmented manner. The proposed method also partly relies on available global data. Crowdsourced or big data are only partially used in the current method, but may become more important as a sustainable data source in the future. By using government and global data, it is expected that the new RAI structure will foster client countries' ownership, reinforcing sustainability and promoting regular updates. Some countries, such as Ethiopia, report some rural access indexes using their own data and estimation methods. The new RAI can be used as a standardized method by client countries.

Consistency

For the RAI to serve as a global indicator, and as a metric for measuring achievement of the SDG targets, consistency across countries is critical (box 1). There is no doubt that wide variation exists in data quality when existing government data are used. For instance, the extent of road network data coverage varies from one country to another, possibly depending on the countries' road classification systems and administrative responsibilities. However, certain elements, such as road roughness measurements, are common, and some data are globally available, such as WorldPop population distribution data. This report aims to develop a way to synthesize various types of data in the same geospatial format to have a harmonized measurement representing rural connectivity regardless of differences across countries.

Simplicity

The new method needs to be applicable and implementable everywhere. Too much complexity will lose the interest of client countries, eventually threatening the indicator's sustainability and regular updates. From an engineering or operational perspective, for instance, transitability or passability, which determines road accessibility given a very localized event and available structures, such as bridges and culverts, may be a crucial factor to consider. But this requires additional data on the conditions of structures. Moreover, the measurement of passability requires defining where people are heading. This may or may not be easy to determine, particularly if the road network is complex. Thus, as will be discussed in section III.A, the proposed indicator focuses on access to the road network. However, it can be easily expanded to other types of connectivity, such as access to a market or hospital (section IV.C).

Operational Relevance

The new RAI is designed to support the day-to-day operations of client countries. This is related to the sustainability issue. The output is expected to be available not only at the national level, but also at the subnational level. For effective decision-making about road investments, country-level data are typically not informative enough. New geospatial data and techniques confirm that transport connectivity is highly heterogeneous in any given country (see, for instance, World Bank 2009). In Kenya, for instance, road connectivity is likely to be better around major cities, such as Nairobi, Kisumu, and Mombasa. But connectivity is much more limited in North Eastern Province, such as in Garissa and Mandera counties. These differences provide different policy implications to the government regarding, for instance, where to invest and whether to prioritize new construction or maintenance.

Subnational RAIs can be a powerful policy tool to examine rural access in connection to other development objectives, such as poverty reduction and agricultural growth. Subnational RAIs can be used by client governments, donors, and other stakeholders to prioritize and make road investments. In addition, subnational RAIs allow for estimating the financial needs for meeting the existing rural access gaps (section V.D). In developing countries, rural road needs are still enormous. Across Africa, there are 500,000 km of tertiary roads, most of

[4] It is still important to ensure that a standardized transport module is included whenever a household-level survey, such as the Living Standards Measurement Survey, is carried out.

Box 1. Sustainable Development Goals and Requirements for Global Indicators

Main Ideas

The Sustainable Development Goals (SDGs) are a new, post-2015 development framework, following the Millennium Development Goals and building on the international agreement at the Rio+20 conference in 2012. The SDGs aim to support a balanced economic, social, and environmental development agenda (table B1.1).

The need for developing a standard measurement system and the limitations of the current Rural Accessibility Index (RAI) methodology are crucial to the current SDG discussion. Several proposed SDGs and targets are directly or indirectly relevant to rural accessibility and transport. For instance, Goal 2 aims to "end hunger, achieve food security and improved nutrition and promote sustainable agriculture," and one of the targets (2.3) is to "double the agricultural productivity and incomes of small-scale food producers…through secure and equal access to... productive resources and inputs." This clearly requires improved rural road access. The Partnership on Sustainable Low Carbon Transport,[a] in working with the SDG Open Working Group, indicates the importance of universal access to sustainable transport for rural populations and includes the RAI as one of the key indicators.[b]

Although it is not yet finalized, the RAI is proposed in the current draft indicator framework for the SDGs, as indicator 9.1.1, under **Target 9.1 "Develop quality, reliable, sustainable and resilient infrastructure, including regional and trans-border infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all."**[c] The inclusion of the RAI in the SDG indicators underscores the importance of having a globally available and cross-country/regionally comparable measure of transport access.

Table B1.1. Sustainable Development Goals

Goal 1.	End poverty in all its forms everywhere
Goal 2.	End hunger, achieve food security and improved nutrition, and promote sustainable agriculture
Goal 3.	Ensure healthy lives and promote well-being for all at all ages
Goal 4.	Ensure inclusive and equitable quality education and promote life-long learning opportunities for all
Goal 5.	Achieve gender equality and empower all women and girls
Goal 6.	Ensure availability and sustainable management of water and sanitation for all
Goal 7.	Ensure access to affordable, reliable, sustainable, and modern energy for all
Goal 8.	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
Goal 9.	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
Goal 10.	Reduce inequality within and among countries
Goal 11.	Make cities and human settlements inclusive, safe, resilient and sustainable
Goal 12.	Ensure sustainable consumption and production patterns
Goal 13.	Take urgent action to combat climate change and its impacts* (*Acknowledging that the United Nations Framework Convention on Climate Change is the primary international, intergovernmental forum for negotiating the global response to climate change)
Goal 14.	Conserve and sustainably use the oceans, seas and marine resources for sustainable development
Goal 15.	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
Goal 16.	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Goal 17.	Strengthen the means of implementation and revitalize the global partnership for sustainable development

(*continued on next page*)

Box 1. Sustainable Development Goals and Requirements for Global... *(continued)*

As with several proposed indicators, as a global SDG indicator, the RAI suffers from a current lack of baseline data and reliable schedule for data updates. Establishing the RAI as a global indicator will require a methodology that is reliable, yet relatively simple and inexpensive to roll out across a broad country set. In addition to the issues discussed so far, two more factors are important to scale the eventual RAI output as a global indicator: frequency of updates and temporal tolerance of the data.

Frequency of Update

The development and updates of the indicator will rely on the underlying data sets, including population, road network, and road quality, which are often not updated on an annual basis. Road network data are fairly constant in the short to medium term. In addition, large road projects normally take three to five years. Thus, adding 50 or 100 km of new roads to the existing network—which normally amounts to more than 10,000 km in a medium to large country—does not have a large impact on the existing network data.

Time variation may matter more for road quality data. Although some countries update data frequently—normally, once every two to three years—this is not the case for other countries. For their operational purposes, however, many road agencies update their road quality data at least every four to five years. Thus, the developed indicator is not expected to be updated annually. When this program is rolled out globally, the team foresees a maximum duration of updates between two and five years in each country, depending on data availability.

In developing countries, data on secondary, tertiary, and feeder roads (usually unpaved and the largest proportion of the road network) tend to be particularly limited. One reason is that while responsibility for primary or national roads is maintained at the national level, responsibility for rural roads is often devolved to the level of the district or municipality. Data on the roads under the national agency are collected in more detail and more regularly, and the roads are often in relatively good condition. However, the RAI is influenced more by the rural roads under devolved administrations, of which the monitoring and data capacity is often limited. Because of this multi-year update process, the expected RAI will not be available for all countries in any one year. Such a pattern is seen in many World Development Indicators, and is generally considered acceptable by the World Bank's Development Research Group for global indicators.

Temporal Tolerance of Data Sets

Because of the lack of annual availability of the underlying data sets, several or all of the data sets may not be matched by year. For instance, road quality data might be available only for 2013 in a particular country, while some of the population data are only available for 2010 or 2015. Some judgment is needed at the country level to mitigate the impact of using different data sources in different years. A rule of thumb is that a more stable data set should be used with more flexibility. For instance, a national rural roads program could dramatically improve the quality of roads in a certain locality in a relatively short term, while population data are fairly stable over five years. In such a case, the road quality data would be considered as an anchor, with the closest or adjusted population data applied.

[a] The Partnership on Sustainable Low Carbon Transport (SLoCaT) is a multi-stakeholder partnership of more than 80 organizations including United Nations organizations, multilateral and bilateral development organizations, nongovernmental organizations and foundations, academia, and the business sector, which promotes the integration of sustainable transport in global policies on sustainable development and climate change.

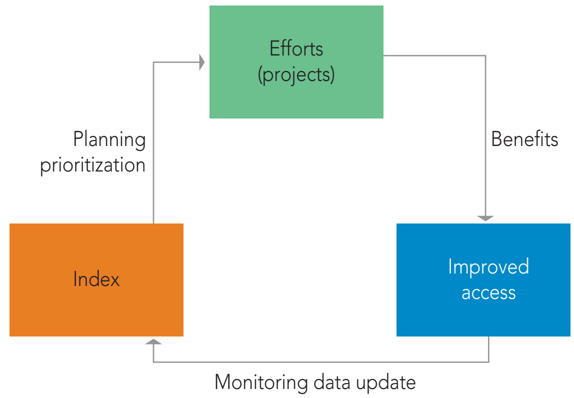
[b] See SLoCaT (2014). The Results Framework not only includes the traditional RAI measure (2 km from an all-season road), but also proposes to measure the proportion of rural population living within a 30 minute walk of formal or informal transport services, calling for the use of geographic information system data.

[c] In preparation for the 47th session of the United Nations Statistical Commission, the SDG Indicator working group prepared a discussion document, including a draft SDG indicator framework. In this document, the RAI, and specifically the "share of the rural population who live within 2 km of an all-season road," is included under Goal 9.

which are in poor condition, and another 500,000 km of unclassified roads. It would cost at least US$75 billion to rehabilitate these roads, if the unit cost is assumed to be US$75,000 per km. It would cost more if a higher road standard is applied. Thus, prioritization of investments, in light of constrained resources, is a must.

Following these principles, the new RAI is expected to provide closure to a feedback loop, where the RAI informs development efforts, which improves rural access, finally being reflected in future updates of the index (figure 10). This report was prepared based on a continuous process, fostering ownership by client countries and building the capacity to maintain a database in connection with their daily operations. It is expected that client countries use, update, and complement their own data, to measure the RAI and support sustainable economic growth.

Figure 10: Expected Operational Feedback Loop



3

PROPOSED METHODOLOGY

Overall Framework

There are many different concepts for measuring transport infrastructure availability or people's transport convenience, such as connectivity, accessibility, travel time, transitability, passability, reliability, and mobility, to name a few. Different measurements can be used for different purposes. In Kazakhstan, farmers' market access is defined by being located within a driving distance of four hours from an urban center. This reflects the fact that the country's major agricultural produce is perishable within four hours (box 2). In Nepal, for instance, national accessibility is measured by the populations within two- and four hour walk-time bands from an all-weather road network in the Terai and Hills areas, respectively. These measures may make sense because travel time matters more than distance in mountainous areas with a lot of rivers and valleys (box 3).

The new RAI method follows the same definition as the original work by Roberts, Shyam, and Rastogi (2006), although it can easily be expanded to measure any kind of connectivity (section V). The index was originally defined as the "share of people who live within 2 km (or about 25 minutes walking time) of the nearest all-season road in rural areas." The definition is practically composed of three elements: (i) origin, (ii) destination, and (iii) norm or threshold of access. Although the origin, which is where people live, is relatively straightforward, the other two elements are potentially complicated.

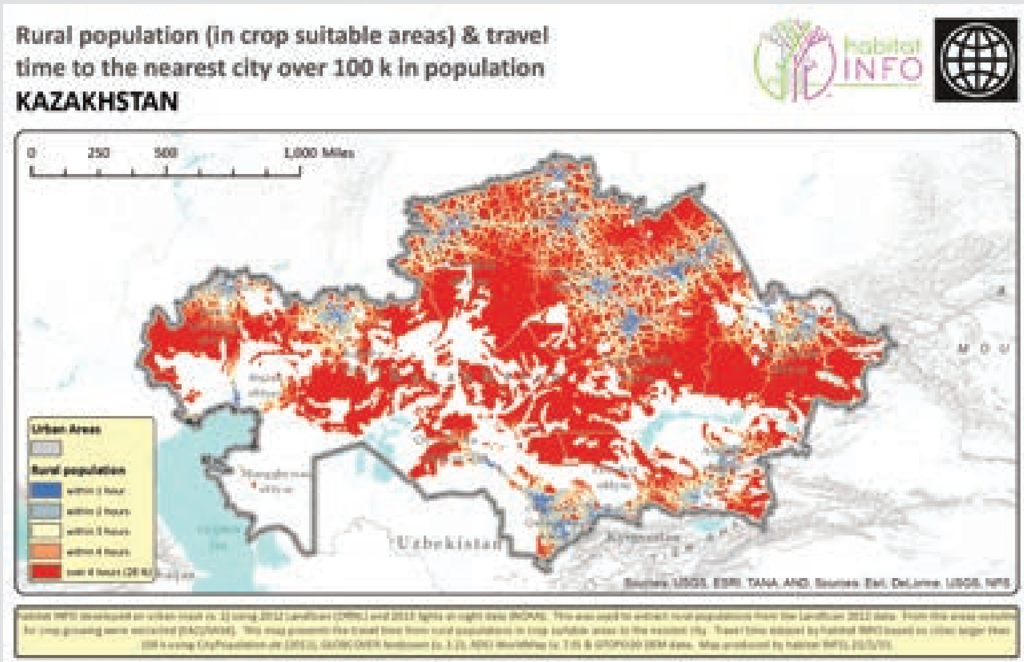
For obvious reasons, the norm of access is open to debate. In Africa, for instance, a 5 km access band may make more sense than 2 km access, given the low population density in many areas (Raballand, Macchi, and Petracco 2010). However, for consistency purposes, the new method maintains the use of the traditional threshold of 2 km.

The destination, in this context, is the nearest road of qualifying quality. As originally defined, consideration of the quality of roads is essential. In many developing countries, the vast majority of rural roads are in poor condition. Thus, the existence of roads does not necessarily guarantee any transport connectivity. In addition, as most development efforts in the road sector are made to rehabilitate, upgrade, and maintain the existing road network, not to construct brand new roads, how road quality is measured is a key question from the monitoring and planning perspectives.

Although the underlying concept remains unchanged, the new method proposes an updated way to collect and measure the road condition data that are available in many countries. Roberts, Shyam, and Rastogi (2006) focus on all-season roads, which are "motorable all year round by the prevailing means of rural transport (often a pick-up or a truck which does not have four-wheel-drive), with some predictable interruptions of short duration during inclement weather (e.g., heavy rainfall) allowed." This may not be common data that road agencies normally collect in their operations. The new method takes advantage of more common parameters in existing databases, such as the International Roughness Index (IRI), Pavement Condition Index (PCI), and visual assessment using four or five categories (excellent, good, fair, poor, and very poor).

Box 2. Agriculture Access to Market Index in Kazakhstan

Map B2.1: Market Accessibility in Kazakhstan



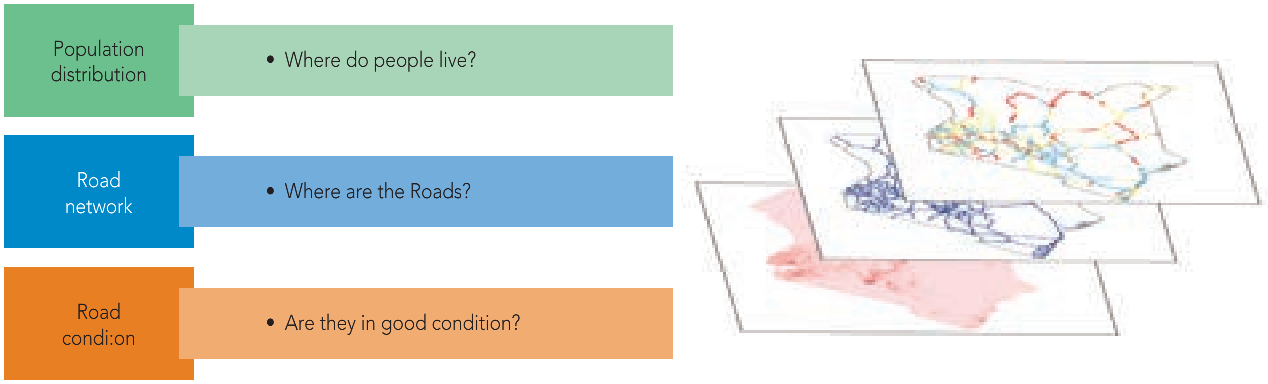
Source: World Bank calculation.

A previously conducted pilot, undertaken by the World Bank's Agriculture Global Practice, utilized geographic information system data to estimate the share of the rural population living within four hours of an urban center in Kazakhstan (map B2.1). This is a useful benchmark to facilitate more commercialized agriculture and is supported by empirical evidence from the country.

Access to markets is critical for farmers and agribusinesses, with the availability of infrastructure, such as roads and transport services, as a fundamental enabling factor for farmers to reach urban markets. The growth in demand for food in urban markets around the world is providing increased opportunities for commercial smallholders, and agricultural productivity needs to increase to supply these growth centers. Agricultural production and yields are found to be positively correlated with proximity to urban centers.

Agricultural production is highly correlated with proximity to urban markets, as measured by travel time. Maximum productivity was found to be reached between three and four hours of travel time to an urban market. Within four hours travel time, producers achieved 45 percent of their production potential, but at eight hours they were only achieving 5 percent of their production potential in Mozambique (Dorosh et al. 2010). In Madagascar, rice yields hold up well between 0.9 and 3.4 hours of travel to a major city, but then start to fall precipitously, so that by 8.9 hours farmer yields are reduced by 45 percent (Stifel and Minten 2008). In Peru, farm labor productivity and rural income increased when journey times to the nearest city from rural areas dropped from nine hours to just under four hours (Webb 2013).

Figure 11: Basic Methodological Framework



The new RAI method proposed here requires three types of data: (i) population distribution, (ii) road network, and (iii) road condition. Geospatial techniques are used to combine the three types of data in the same format (figure 11). Annex I provides quick technical guidance for computing the RAI, which is not a new technique. A variety of similar exercises already exist. Guo, Koo, and Wood (2009) use spatial data to relate market access to input and output farm-gate prices (box 4). Instead, this report aims to contribute by proposing a somewhat standardized method to ensure international consistency, sustainability, and operational relevance.

The use of 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 the country or subnational boundaries. Any given norm of connectivity (for example, 2 km distance from

Box 3. Accessibility Measurement in Nepal

The Government of Nepal uses an "accessibility index" to measure people's accessibility and address poverty and social exclusion. In Nepal, about 23 million people, or 82 percent of the total population, are estimated to live in rural areas (United Nations 2014). The calculation of accessibility is based on an analysis of population distribution, the extent of the all-weather road network, and calculations of the walk-time to access the road network. Because of the highly mountainous topology in the Hills area, the time band is targeted at four hours. In the Terai area, accessibility is measured by the population within two hours of a qualified road.

Based on the government's definition, which is different from the RAI in the current work, it is estimated that accessibility has been improved from 78 percent in 2007 to 86 percent in 2013 (table B3.1). However, it cannot be overemphasized that the definitions are different. In addition, the share of the road network for which the Department of Roads is responsible has been expanded considerably, from an operational strategic road network of 5,030 km in 2007 to a proposed extent of about 10,000 km. Thus, regardless of actual improvements of the road network, "accessibility" will increase. Yet, all the indications are that people's accessibility differs greatly across the country, and people have better access in the Terai region (map B3.1).

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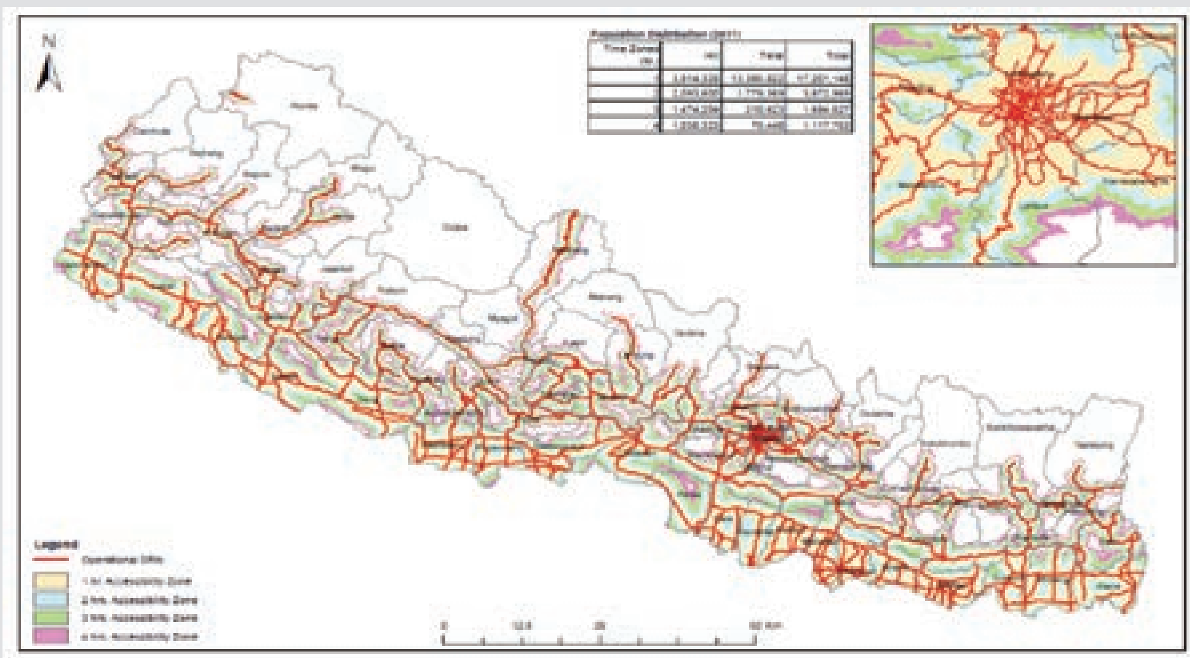
Box 3. Accessibility Measurement in Nepal *(continued)*

Table B3.1. Accessibility: Population and Percentage Served

	Network length (km)	Hill (within 4 hours)		Terai (within 2 hours)		Total	
		Population (million)	Share (%)	Population (million)	Share (%)	Population (million)	Share (%)
Operational SRN 2007	7,360	6.52	58%	13.7	94%	20.22	78%
Extended SRN 2013	10,000	7.94	70%	14.21	97%	22.15	86%

Source: Department of Roads, Nepal. 2014.

Map B3.1: Accessibility to 2013 Operational and Under Construction SRN (13,358 Km)



Source: Department of Roads, Nepal. 2014.

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.

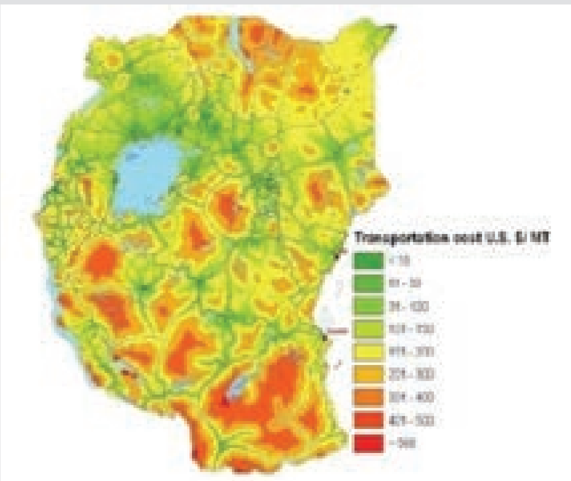
Data Requirement 1: Population Distribution Data

Quality population distribution data are essential for correct measurement of rural access. However, detailed and contemporary census data may not be available in many developing countries. The proposed method relies on

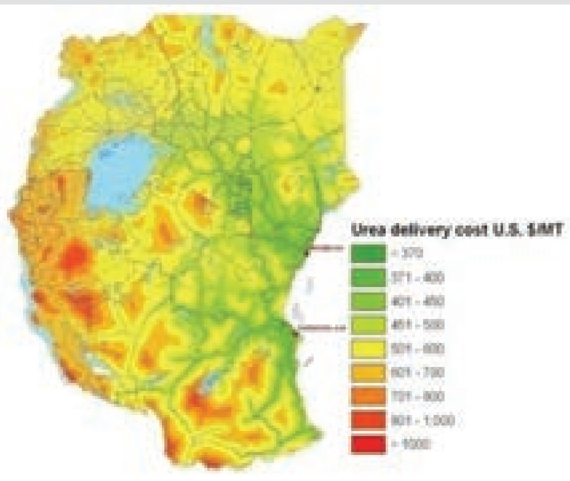
Box 4. Market Access and Crop Productivity in Tanzania

Although its relative importance may have declined in many economies, agriculture is still key to stimulate sustainable economic growth and reduce poverty in many African countries. Access to input and output markets is a challenge for many farmers. Guo, Koo, and Wood (2009) combine various spatial data, such as land cover, road network, and land slope, and estimate transport costs to markets in Tanzania (map B4.1). Given the fact that most fertilizer is imported from abroad, farm-gate prices are calculated using estimated transport costs from the ports (map B4.2). For maize, farm-gate output prices are also calculated (map B4.3). It is clear that farm-gate prices of maize are inversely proportional to transport costs to market.

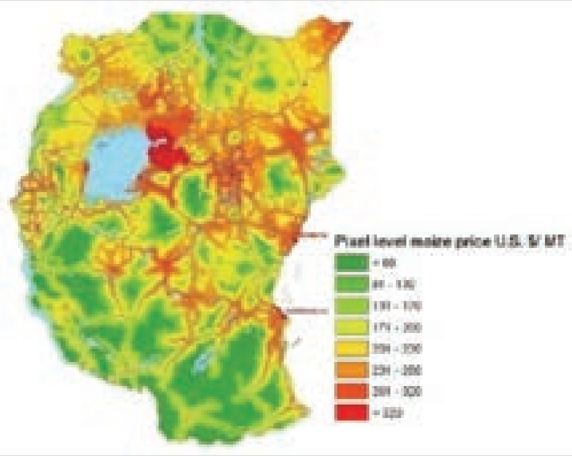
Map B4.1: Transport Cost to Market



Map B4.2: Fertilizer Farm-Gate Prices



Map B4.3: Maize Farm-Gate Prices



Source: Guo, Koo, and Wood 2009.

[a] Guo, Zhe, Jawoo Koo, and Stanley Wood. (2009). Fertilizer profitability in East Africa: A spatially explicit policy analysis. Contribution Paper to the International Association of Agricultural Economists Conference at Beijing on August, 2009. Available at http://ageconsearch.umn.edu/handle/51710.

Table 2: Summary of Global Population Distribution Data Sets

Source	Resolution	Year	Update	Availability of input data	Reproducible methods	Urban/ Rural	Link
WorldPop (AsiaPop, AfriPop, AmeriPop)	~100m	2000/2005/ 2010/2015/ 2020	Ongoing	Yes	Yes (with code)	No	http://www.worldpop.org.uk/
Gridded Population of the World (GPW) – CIESIN	2.5 arc minutes (~5 km)	1990/1995/ 2000/2005/ 2010/2015	Occasional	Yes	Yes	No	http://sedac.ciesin.columbia.edu/gpw/global.jsp
Global Rural Urban Mapping Project (GRUMP) – CIESIN	30 arc seconds (~1 km)	1990/1995/ 2000	Occasional	Yes	Yes	Yes	http://sedac.ciesin.columbia.edu/data/collection/grump-v1
LandScan – Oak Ridge Labs	30 arc seconds (~1 km)	2012	Annual	No	No	No	http://www.ornl.gov/sci/landscan/
UNEP Global Population Databases	2.5 arc minutes (~5 km)	2000	None	Yes	Yes	No	http://na.unep.net/siouxfalls/datasets/datalist.php

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 they remain subject to available data, modeling, and assumptions, these data sets distribute subnational data at the more detailed subnational level, using spatial data and techniques. Although all the available population data sets are derived from population census data, each data set has advantages and disadvantages. LandScan, for instance, provides population distribution at approximately 1 km resolution, and WorldPop is available at 100 meter resolution.

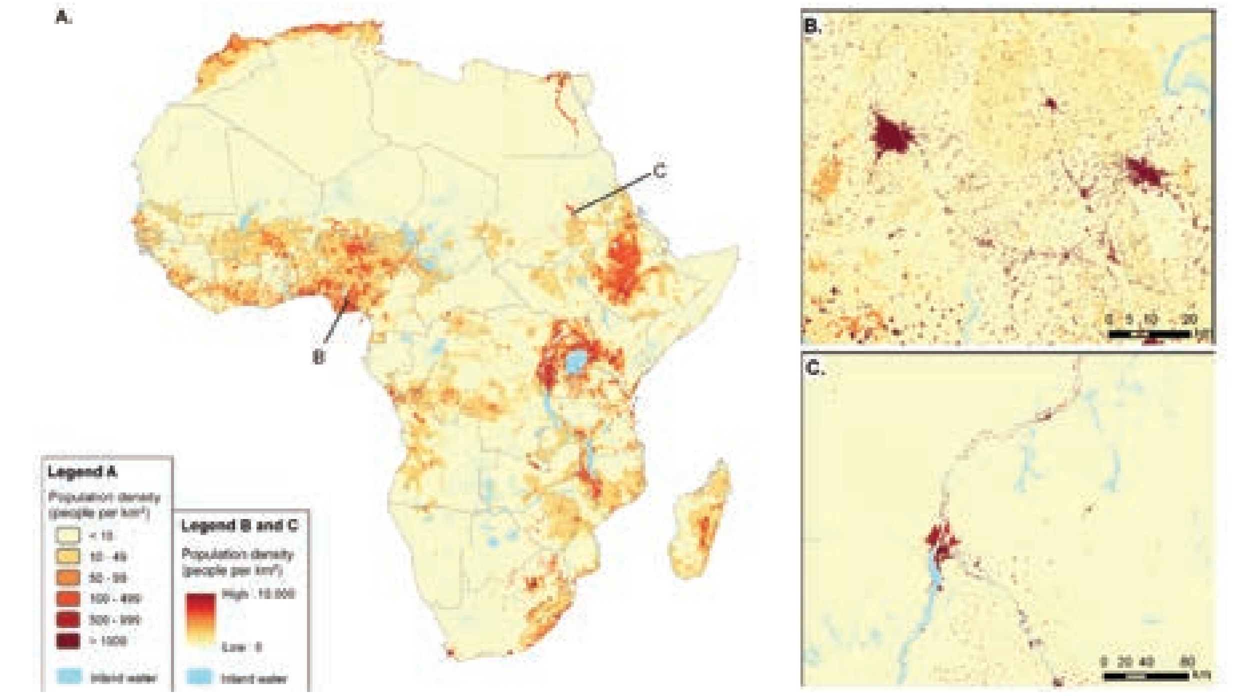
The proposed method relies on the WorldPop data for several reasons. Different databases have different advantages and disadvantages (table 2).[5, 6] The WorldPop data provide the highest spatial resolution and are continuously updated whenever new data become available (map 5). A fundamental source of data is national population census data, which would generally be updated on a five- or ten-year cycle. This is sufficient for RAI purposes, because it measures the proportion of the rural population, not its absolute number. Changes in population would only influence the RAI if there were substantial movements of population across areas, such as urbanization, within a relatively short period of time.[7]

The computational process underlying the WorldPop data is fully transparent. Unlike the Gridded Population of the World (GPW) or Global Rural-Urban Mapping Project (GRUMP), WorldPop uses modeling based on a wide range of input layers and spatial covariates. But all the data and full documentation of the algorithm are being made available. Thus, the computations can be replicated or adjusted based on the underlying data. The model is considered to be the most accurate and robust among the currently available data sets.

A potential matter of concern with the use of model-based population distribution estimates, such as WorldPop, is endogeneity between population estimates and the RAI. In general, the utilization of various input layers, including road location, enables producing

5 For instance, see Balk et al. (2006).
6 Annex II provides a more detailed discussion.
7 It is found that the RAI estimate does not change much even if population data for a different year are used. Section V.A. provides further discussion on this.

Map 5: WorldPop Population Distribution Data for Africa



Source: WorldPop.

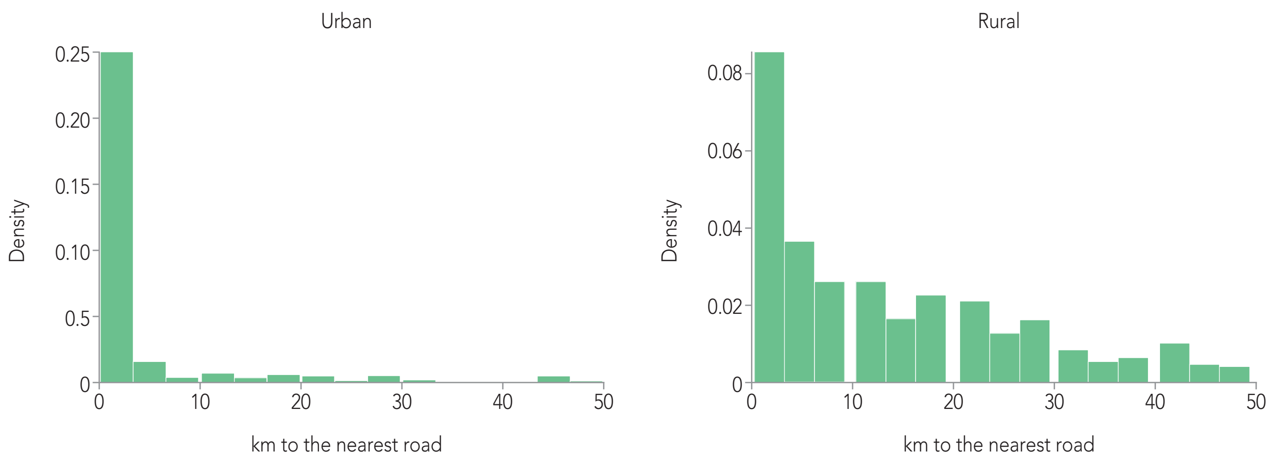
a more accurate population distribution estimate. But this may create a potentially upward bias in the RAI, because more populations are by design distributed along the road network. This may or may not be true. However, in data sets that do not use any ancillary data, like GPW, population distribution estimates tend to be inaccurate, particularly in rural areas. In the current WorldPop algorithm, road location is merely one of various inputs, and the weight given to road location is typically not significant. The actual weights given to the various factors are adjusted on an iterative basis to determine the best fit with the available data through a random forest modeling process. The publication of the algorithm allows for removing roads from the population calculation, testing for the impact of any possible endogeneity.

Rural-Urban Definition

Related to population distribution data, an important challenge facing the index is the need for a consistent and reliable urban and rural definition to exclude urban areas from the calculation. The inclusion of urban areas would create a substantial upward bias in the RAI, because most urban residents have "access to roads," no matter how it is defined. In Tanzania, for instance, the vast majority of urban residents have good access to the road network, but only 20 percent of the rural populations live within 2 km of a reliable road (figure 12). Notably, the size of the urban population is enormous even in Africa where urbanization is still relatively modest but has been accelerating in recent years. About 2.6 billion people, or 52 percent of the total population, live in urban areas in developing countries. In Africa, the urbanization rate is estimated at 40 percent: 455 million people live in urban areas, and 683 million people reside in rural areas. In recent years, urbanization has been accelerating. By 2040, the urban population is forecasted to reach one billion, or about half the total population. Still, it is projected that one billion people will live in rural areas (United Nations 2015).

Ideally, spatial data determining urban-rural boundaries are needed at a similar level of resolution as the popu-

Figure 12: Tanzania: Household Distribution by Distance to the Nearest Road



Source: Tanzania 2010 Living Standards Measurement Study.

lation distribution data. However, no such data are currently available. Several alternatives exist.[8] A traditional way to divide urban and rural areas follows national administrative definitions. The United Nations World Urbanization Prospects defines urban areas and calculates urban populations using the same definitions of urban agglomerations as those used by national statistical offices in carrying out the latest available population census. Different countries may define urban areas differently.[9] There is no common definition behind the various national definitions.

To maintain global comparability and methodological simplicity, the current work relies on the GRUMP, which develops a rural-urban distinction extent in the disaggregation process, including other population data, such as population count grids, population density grids, and urban settlement points (map 6).[10]

The urban extent grids distinguish urban and rural areas based on a combination of population counts, settlement points, and the presence of nighttime lights. Areas are defined as urban where contiguous lighted cells from nighttime lights or approximated urban extents are based on buffered settlement points for which the total population is greater than 5,000 persons. The data are provided at a resolution of 1 km. The latest version is for 1995. The rural population figures calculated by spa-

Map 6: Global Rural-Urban Mapping Project (GRUMP)

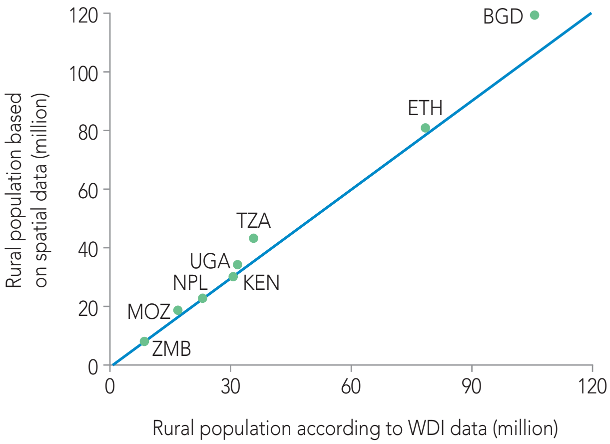
Source: Tanzania 2010 Living Standards Measurement Study.

8 Some new methodologies are being developed for creating such a geospatial division.

9 For further details, see United Nations (2014).

10 GRUMP does not produce its own population database; rather, it utilizes GPWv3 and includes ancillary data on urban and nonurban areas (based on local definitions) to provide improved estimates. The limitations of the GRUMP are the same as those of the GPW. Furthermore, the latest update to the GRUMP was in 2005 (with 1990, 1995, and 2000 data, and it utilizes local definitions of urban and nonurban areas.

Figure 13: Rural Population by Traditional Administrative Definition and Spatial Data



Sources: World Bank calculations based on World Development Indicators, WorldPop, and GRUMP.

tial techniques that use WorldPop and GRUMP are found to be broadly consistent with the global United Nations estimates, although they may be slightly underestimated because the base year for GRUMP is 1995 (figure 13). Urban areas in many countries may have expanded since then.[11]

Data Requirement 2: Road Network Data

Measuring and plotting where "roads" exist is a trickier question than would appear at first glance, especially in developing countries. In particular in Africa, road density is extremely low, and varying proportions of the road network are classified. A significant number of roads are unclassified. It is not uncommon to have different figures of road network length, depending on the definition of roads and the coverage of the data. In Tanzania, for instance, the total road network was about 75,000 km when the last road inventory survey was conducted in 2008. It is currently estimated at about 110,000 km because local governments seem to have added more roads to their networks. In Nepal, the Department of Roads, a main agency responsible for road planning and maintenance, expanded the strategic road network (SRN) to 8,700 km in 2011, from the original length of about 5,000 km in 2005. It is planned to increase to 10,000 km by 2016 (Department of Roads, Nepal 2014).

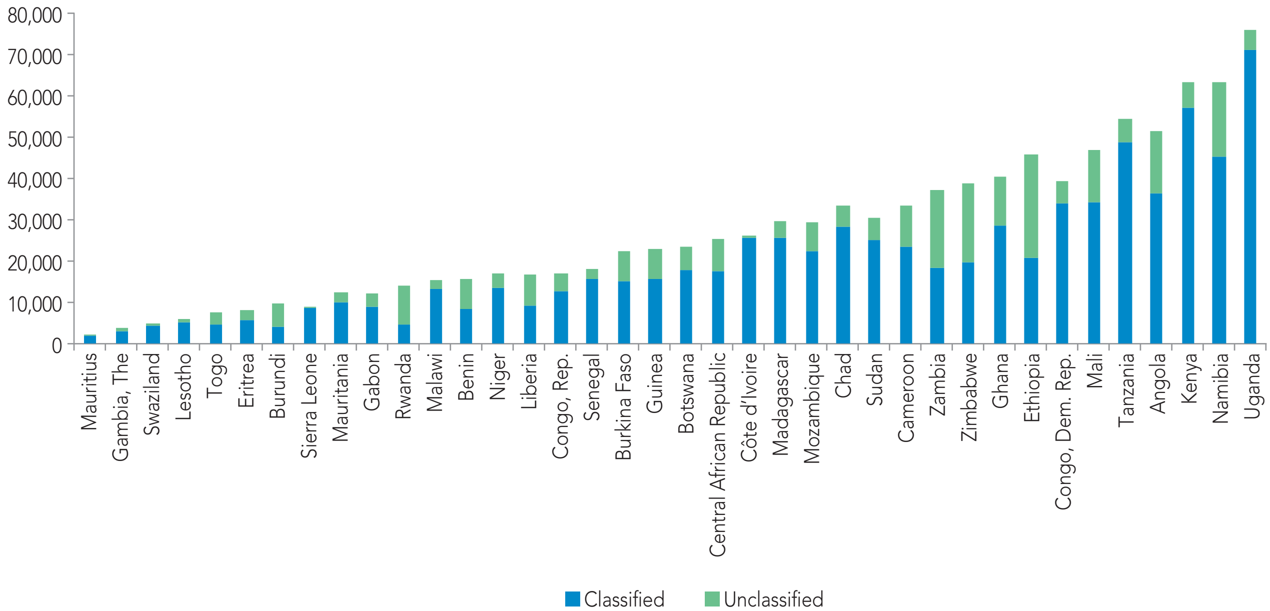
In Africa, it is estimated that one-third of the total roads are unclassified, amounting to nearly 500,000 km (figure 14). Unclassified roads, or even feeder roads, exist on the ground, but data on them tend to be incomplete and fragmented. One reason is that although responsibility for primary or national roads is at the national level, responsibility for rural roads is often at the devolved level, such as the district or municipality. Data on the roads under the national agency are collected in more detail and more regularly, and the roads are often in relatively good condition. However, the RAI is influenced more by the rural roads under devolved administrations, for which monitoring and data capacity are often limited. Many minor access roads are not recorded or captured in the databases.

The new RAI aims to take advantage of georeferenced road network data. The use of spatial data has the particular advantage of locating roads accurately and objectively. In Ethiopia, for instance, the country's total length of roads was believed to be 99,522 km according to the Ethiopia Road Authority data. In 2015, the government carried out a first-ever comprehensive road inventory and quality survey using geographic information system technology, which mapped about 85,880 km of roads and shows unequivocally where they are.

There are several sources of georeferenced road network data. Each has advantages and disadvantages (table 3). On the one hand, an increasing number of countries are developing their own official road network data. On the other hand, several open data sets, such as OpenStreetMap, are also available. Global road network data sets are also available on a commercial basis (for example, DeLorme World Base Map). Global data have

[11] The 1995 extent may not correctly reflect the latest situation, especially given the recent rapid urbanization in developing countries. Technically, it can be expanded under certain assumptions. For consistency and simplicity purposes, the current work uses the data as they are.

Figure 14: Classified and Unclassified Roads in Africa (km)



Source: Gwilliam 2011.
Note: South Africa and Nigeria are excluded for presentation purposes.
The former has 364,000 km of roads, and the latter has 158,000 km of roads.

particular advantages in topological accuracy and cross-country comparability. But they are not associated with government responsibility or classification. In addition, few attributes are available in the data sets. In some cases, OpenStreetMap has little coverage in rural areas, which is critical for RAI purposes. This is simply because the data set relies on the crowdsourced data to which various individuals voluntarily contribute. Input data tend to be extremely limited in less populated areas in developing countries. In Zambia, for instance, OpenStreetMap and the national road network data cover 35,000 and 39,000 km of roads, respectively. Although the former captures much intensive data in urban areas, the latter has much wider representativeness from a spatial point of view (map 7).[12]

In the new 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, which will encourage them to collect condition data and use the resultant RAI outcomes directly in their operations.

A main challenge lies in filling the gap of road inventory, particularly in less developed countries. Technical assistance is needed to improve the government data sets. Road density in the road network data—referred to as "road data density"—differs significantly across countries. This is often because of the difference in road classification systems, but also partly because of lack of monitoring capacity in road agencies, and in some cases a lack of roads or tracks that may or may not reflect differing population densities. Kenya Roads Board possesses extremely detailed road inventory data covering about 160,000 km of all kinds of roads, which translate into a road data density of 28 km per

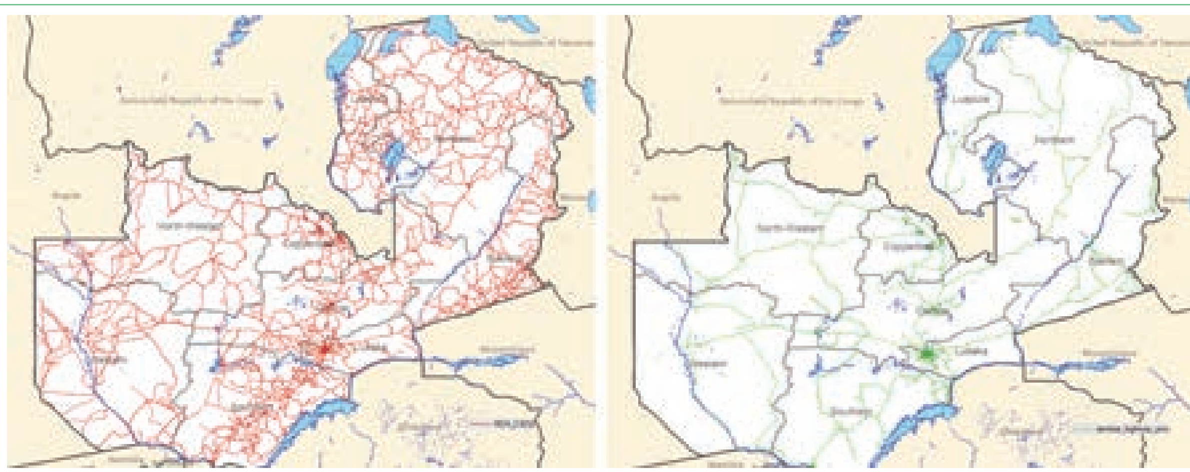
12 The Zambian national road data are spatially more comprehensive but still lack small feeder roads.

Table 3: Summary of Available Road Network Data

Type	Example	Access	Consistency	Relevance
Government data	Road authority, central statistics office, spatial data unit, etc.	Subject to individual country policies.	Different coverage and accuracy across countries.	Often aligned to government's responsibility, possibly with other technical data (e.g., detailed road specifications) merged.
Open data	OpenStreetMap	Subject to individual copyrights, but basically free to copy, distribute, transmit and adapt	Topologically consistent across countries.	No relevance, with a few road attributes included.
Commercial data	DeLorme World Base Map	Commercial license	Topologically consistent across countries.	No relevance, with a few road attributes included.
New data collection by smartphone application	RoadLab	Free application	Method is the same, but topological consistency may not be guaranteed.	Data can be selected selectively.

Map 7: Road Network Data Sets in Zambia

a. National road data **b. OpenStreetMap**

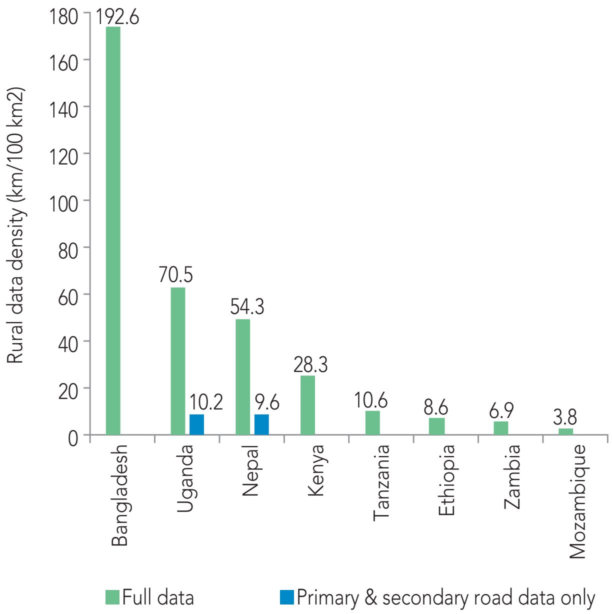


Sources: Central Statistics Office, Zambia; OpenStreetMap.

100 km^2 of land (figure 15). According to the government statistics, Mozambique's classified road network covers 30,464 km of roads. Most of them (about 29,600 km) are accurately mapped. Given the large size of the country, this translates into a road data density of 3.8 km per 100 km^2.

As usual, more data are better. In Uganda, for instance, previously available government data only covered primary and secondary roads, which amounted to about 20,300 km. In 2015, the government carried out a first-ever comprehensive feeder road inventory survey, adding about 120,000 km of feeder, urban, and other roads to the network data. The road data density was increased from 10 to 70 km per 100 km^2. In Nepal, the government road network data, which were initially considered insufficient, were improved under this RAI program. The road data density increased significantly

Figure 15: Road Data Density (km/100 km²)



Source: World Bank calculations based on data from road authorities.

when missing road data were added. The implication of increased data coverage to RAI estimates is dependent on the quality of the tertiary or feeder roads that are excluded from the data, but the RAI generally increases with road data density.

Data Requirement 3: Road Condition Data

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.

There is a variety of ways to collect road condition data at different levels of accuracy (table 4). It is always possible to collect the necessary condition data with reasonable accuracy, although at a cost. Having a variety of data sources will support the sustainability of the RAI.

Road agencies are encouraged to collect and maintain such data as is required to meet their existing operational needs. Among the pilot countries, some road agencies already have good data, and others have just carried out their own road surveys. All governments were keen to collaborate, providing their data to contribute to the current report.

The traditional **road inventory survey** can collect detailed data on road conditions, including the IRI, at a high level of information quality. The IRI is one of the most common objective measurements of road pavement condition, but it is not always available in developing countries. At the lower information quality levels, simpler data are collected, such as the surface distress index and road condition rating based on visual assessment by class value (excellent, good, fair, poor, and very poor).[13] National road agencies are supposed to know the road condition of their entire road networks and normally update the databases at least every three to five years. The updates are needed for their daily operations anyway, for example, to determine which roads should be rehabilitated or maintained, how, and when. The RAI should use the latest road condition data from national road agencies to the extent that they are available.[14] The disadvantage of a traditional road inventory survey is that it requires skilled technicians and proper equipment and is costly.

To complement existing road condition data, several new approaches have emerged. **High-resolution satellite imagery** allows for collecting a variety of information on road surface in a highly systematic way (box 5). This option has the particular advantage of consistency and objectivity. The costs of satellite imagery and heavy computational processing may be able to be brought down when applying the same method and data at

13 See, for instance, Bennett and Paterson (2000).

14 A road network is composed of a number of road segments, which are classified according to a certain country standard. For each road segment, a road agency or its local offices may already know the specification, condition, and type of that segment. If this is the case, all that is needed is a systematic compilation of such data.

Table 4. Summary of Possible Sources for Road Condition Data

Data source	Advantage	Disadvantage
Road inventory survey	• Technically solid with detailed data covered, such as IRI and PCI. • Consistent with government responsibility and needs in the road sector	• Costly • Not regularly updated • Country-specific assessment standards, though broadly similar across countries
Satellite imagery	• Rapid complementary identification of road alignment and surface type • Consistency across countries • Potentially high frequency of data collection	• Technically challenging to identify road condition in detail • High cost of high-resolution satellite imagery • Significant computational process required
Unmanned aerial drone photography and videography	• Rapid complementary identification of road alignment and surface type in a relatively small area • High mobility regardless of geographic or security difficulties	• Technically challenging to identify road condition in detail • Computational process is still required to translate collected imagery
Call detail record	• Consistency across countries • Potentially high frequent data generation	• A few data available in rural areas • Access to data • Noise in data due to other factors, such as congestion
Free app for road assessment (e.g., Road Lab)	• Cost effective • Potential contribution by voluntary road users	• Statistical errors between measured IRI and actual roughness
Commercial app for road assessment (e.g., BumpRecorder, Roadroid)	• Relevant analytical tools provided together	• Statistical errors between measured IRI and actual roughness

scale. It is feasible to locate some road links that are not shown on an official map and identify surface type. During this RAI exercise in Tanzania, some district and feeder roads were located and road surface types were identified with open source road maps and satellite imagery. Road condition class values were also attached to half of the district and feeder roads.[15] With higher resolution satellite imagery, rough identification of the condition of unpaved roads may be possible.

Manned/unmanned aircraft are being used to carry out road surveys quickly in specific areas. There are several commercial options for unmanned aerial vehicle (UAV) survey tools with fixed wing and rotary, vertical takeoff, and landing varieties (box 6). These solutions employ a variety of imaging options with various ranges and capabilities, and have been proven useful for mapping infrastructure under particular circumstances, for instance, in urban and village settings, and in fragile or insecure situations. Still, such solutions require some capital expenditure and operational capacity on the ground. In addition, it is important to ensure that proper airspace regulations are in place, which allows for rolling out a UAV overflight program.

Call detail records (CDRs) may be another possibility. CDRs provide a record of all calls that have been made or received by users. Given the rapidly increasing penetration of mobile phones even in Africa, CDR data may allow for an assessment of people's movements and travel speeds. In general, however, gaining access to such CDR data, which are owned by cell phone carriers, may still be a challenge, because of

15 In Tanzania, a national road agency, TANROADS, regularly updates road condition data for the regional and trunk roads. But district and feeder road condition data that are possessed and managed by local governments are fragmented and not properly georeferenced.

Box 5. Road Mapping with High-Resolution Satellite Imagery

High-resolution satellite imagery has the potential to establish road inventory and condition data, although costs may vary, depending on the availability and quality of the satellite imagery and size of the areas to be covered.[a] This method is advantageous because it can be applied anywhere on the globe, even where actual data collection is difficult on the ground because of geographic or security reasons.

In Nigeria there was a pilot study to examine the technical feasibility of satellite mapping of the road network and conditions. The study focused on Kano State, an arid and semi-desert area in the northern part of the country (map B5.1). With a variety of satellite imagery, including SpotMaps derived from Spot 6/7 at 1.5 meter resolution, 1 meter optical imagery originally collected to support a polio vaccination program, and Pleiades

Map B5.1: Pilot Area: Kano State, Nigeria

Photo B5.1: Example of Pleiades 0.5 Meter Image

(*continued on next page*)

concerns about customer privacy and national laws limiting such access in some countries. In addition, certain reasonable assumptions need to be made to infer road conditions from people's travel speeds. There may be noise in the data, such as traffic congestion. From the rural access perspective, a critical constraint may be that CDR data are less available at the periphery of the road network, where the measurement of RAI is most crucial.

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 commercial and open applications. Although the former may allow for better maintenance and updates of the 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 starting and ending points, while a user is driving with the app running on an Android smartphone or tablet (box 7). 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,

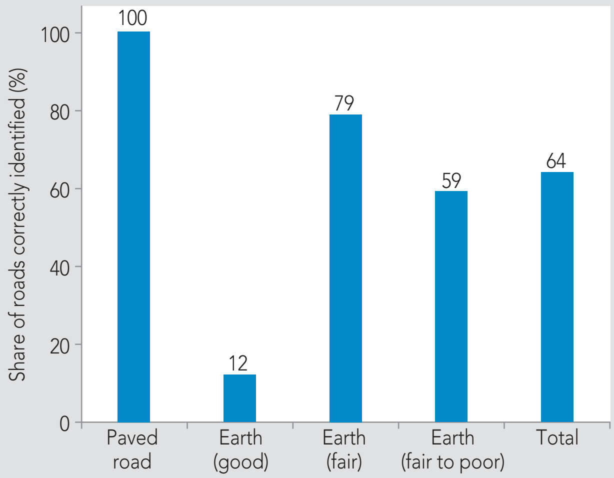
Box 5. Road Mapping Using High Resolution Satellite Imagery *(continued)*

0.5 meter resolution (photo B5.1), about 1,000 kilometers of paved and unpaved roads were virtually assessed, and the prediction was compared with actual roughness data on the ground.

The study clearly demonstrates the feasibility to identify road inventory and structures, such as bridges and culverts, if the quality of high-resolution satellite imagery is sufficient (photo B5.2). Road conditions can also be predicted through examining the edge condition of a road, uniformity of road color, and extent of road winding. The prediction is not perfect, but it is about 64 percent accurate (figure B5.1).

Photo B5.2: Example of Bridge Identification

Figure B5.1: Accuracy of Satellite Prediction



Source: Workman 2014.

[a] Building on a pilot in Nigeria, the United Kingdom's Department for International Development is currently exploring the uses of appropriate high-tech solutions for road network and condition analysis, with a focus on satellite imagery. Partnering with several countries in Africa, the work aims at developing alternative, cost-effective methods to support asset management through enabling countries to gain a better understanding of their rural road networks and to be able to make more informed decisions on funding for maintenance and management of those networks.

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.

Technical Definition of Roads in Good Condition

Different types of road condition data collected by different methods need to be harmonized based on certain conversion factors. Road roughness is one of the most important measurements for road investment planning and asset management. The IRI is a widely accepted objective index, which is closely related to the structural number representing pavement strength. Other aggregated measurements, such as the Overall Condition Index, should be broadly consistent with roughness, but may not always be so because subjective assessments may be included, and how the weights are assigned always matters (box 8).

Box 6. Collecting Road Data with Drones

Drones have been shown to be able to provide valuable data on road quality. According to a recent study by the Department of Transportation in the United States, the latest drone technology can identify road surface distress with 93 percent accuracy (photo B6.1). Of course, the level of achievable accuracy depends on various factors, such as imaging technology, cruising speed and coverage (which differ significantly between fixed wing and rotary systems), and geoprocessing software (Brooks et al. 2014).

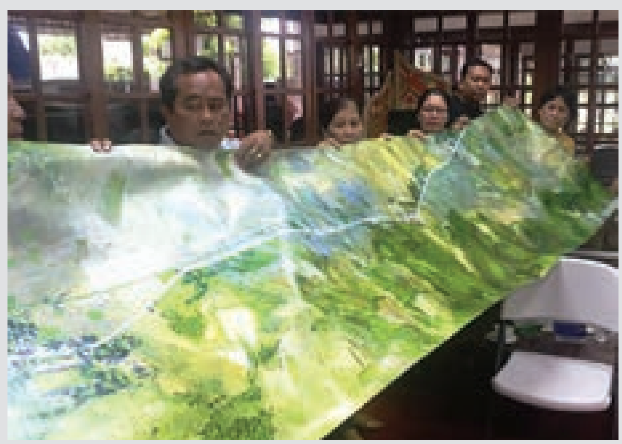
The opportunity to use drone technology has been explored in developing countries. In the Philippines, for example, a World Bank–supported Rural Development Program utilized drones, in conjunction with OpenStreetMap to generate information about road segments and help prioritize work for unmapped roads (photo B6.2).

As technical applicability is rapidly expanding, it is becoming increasingly important to clarify institutional issues, such as licensing, intellectual property, and standards. Many developing countries have not yet established the regulations and requirements for overseeing the use of drones in their airspace, raising the potential for safety concerns. With those institutional issues solved, the potential value of drone technology may increase rapidly as a tool to collect precise data remotely.

Photo B6.1: Examples of Distress Points and Topographical Heat Map Captured by Drone, and Actual Road Surface

Source: Brooks et al. 2014

Photo B6.2: Road Mapping with Drones in the Philippines



Source: Kaiser (2016).

Sources: Kaiser 2016; Brooks et al. 2014.

To follow the original definition of the RAI, which is focused on all-season connectivity, the new method proposes the following working technical definition based on the IRI (table 5):

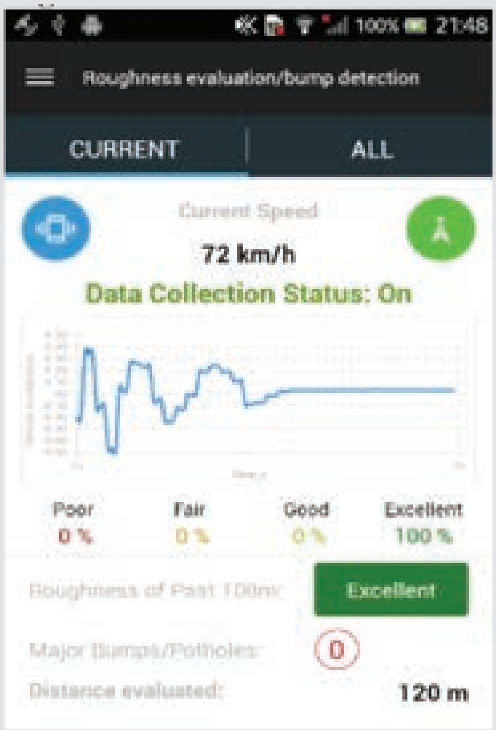
The provisional new RAI is the share of the population who live within 2 km of the nearest road in "good or fair condition" in rural areas. A road in good condition refers to:

Box 7. Example of a Smartphone Road Assessment Tool: RoadLab

RoadLab was designed by the World Bank in collaboration with Beldor Center and Softteco and Progress Analytics LLC, and is a free application available from the Google Play Store. The app runs on all Android smartphones or tablets. Similar to other road assessment applications, which use accelerometers in smartphones, this app automatically records road conditions, such as roughness estimates, average speed, and GPS coordinates of the starting and ending points of each road segment (for example, at 100 meter intervals) (figure B7.1). All that is needed is to have the RoadLab app running on a phone while driving. Users can also manually attach other types of data; road safety hazards, pictures of potholes, black spots, or road accidents can be linked. When an Android device is connected, collected data can be exported in the form of comma-separated values, which can be converted and used in other types of software, such as ArcGIS.

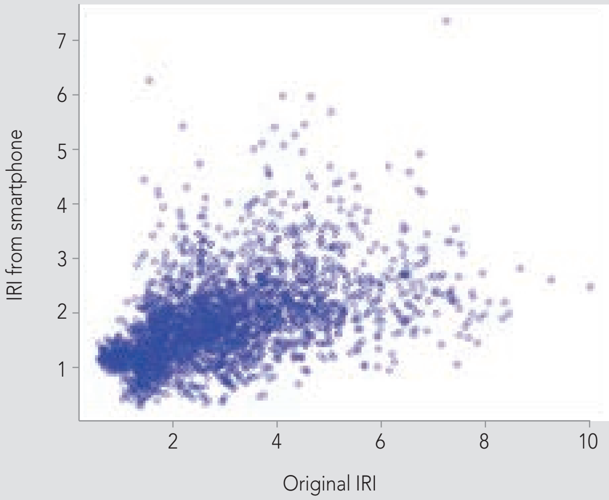
The measured roughness is merely an estimate based on related parameters, such as vehicle speed, vehicle suspension type, vertical acceleration, and phone position. There may be possible measurement and statistical errors in the output data, because the app is designed to calculate roughness estimates based on the tested regression equation. In the pilot project, it was confirmed that the roughness estimated by the smartphone app is correlated with the actual International Roughness Index at a reasonable significance level (correlation = 0.57) (figure B7.2). Because of the statistical confidence, the app is currently designed to be turned on automatically when the speed of a vehicle reaches 30 km per hour (for more technical details, see World Bank 2015b).

Figure B7.1: Road Lab



Source: Road Lab at https://www.roadlab.org/.

Figure B7.2: Actual and Estimated Roughness



Source: World Bank 2015b.

[a] For more technical details, see World Bank (2015). "Smartphone App Innovation Fund – Big Data for Development Revamping Road Condition and Road Safety Monitoring." Report No. 98194, prepared by ROAD LAB.

Table 5. Road Condition Taken Into Account in RAI Calculation

HDM-4 recommended IRI default values				RONET recommended IRI values		
Paved road				Unpaved		
Condition	Primary	Secondary	Tertiary	Condition	Gravel	Earth
				Very good	7	10
Good	2	3	4	Good	10	13
Fair	4	5	6	Fair	13	16
Poor	6	7	8	Poor	17	20
Bad	8	9	10	Very poor	22	24

Note: IRI = International Roughness Index; RAI = Rural Access Index.

Box 8. Roughness Index and Other Road Condition Measurements

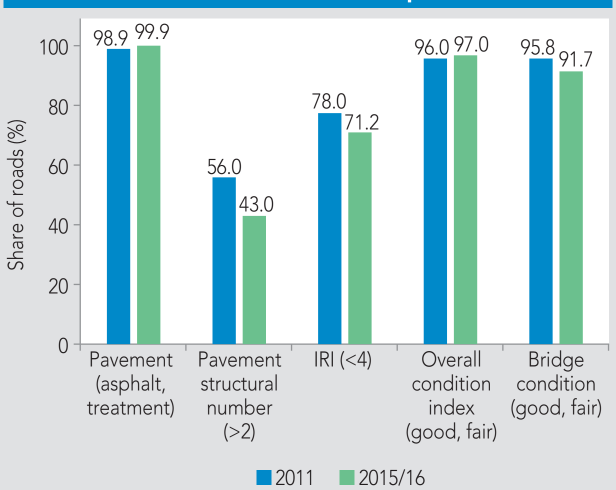
There are several measurements to assess road condition. Different measurements have different advantages and disadvantages. Some are more consistent and objective than others. Since road condition is measured by different factors, for instance, not only road surface but also the condition of structures (such as bridges), comprehensiveness and aggregation are also issues.

The International Roughness Index (IRI) is among the most commonly used measurements. It is normally closely related to pavement strength, which is traditionally measured by pavement structural number. The structural number depends on parameters representing the strength of pavement materials and layers and drainage characteristics. It is fundamental data used for road planning and maintenance.

Theoretically, all these measurements should be consistent with one another. In practice, however, there can be some discrepancy. In Mozambique, there has been concern about road deterioration in recent years, although the official road network is generally well maintained. The share of paved roads has not changed much, but based on the structural number, the share of strong or moderate roads declined from 56 to 43 percent in the past five years (figure B8.1). Consistently, road roughness also deteriorated. The share of roads with an IRI less than 4 decreased from 78 to 71.2 percent.

However, the Overall Condition Index, which is calculated based on cracking, potholes, raveling, deformation, and edge break with weights, marginally improved. There seems to be some noise in the raw data or formula. Moreover, the condition of bridges also seems to have deteriorated. Ideally, all of these measurements could have been taken into account in the Rural Access Index calculation. But for simplicity purposes, the IRI is a good proxy representing the strength and sustainability of the road network.

Figure B8.1: Comparison of Road Condition Data in Mozambique



Source: National Administration of Roads, Mozambique.

Table 6. Kenya: Road Quality Assessment Manual

Rating	Description	Activities required
Paved roads:		
Excellent	Maintainable road with no potholes and no cracks.	Nominal light off carriageway maintenance only required e.g. bush clearing, culvert cleaning, ditch clearing, mitre drains cleaning, repair of road signs
Good	Maintainable road with some cracks and under 5% potholes.	Rating 1 + Light pothole patching +sealing cracks
Fair	Maintainable road with many cracks and potholes (more than 5%)	Rating 1 + Pothole patching + base repair + resealing
Poor	Un-maintainable	Rehabilitation (Holding maintenance)
Very bad	Un-maintainable	Reconstruction (Holding maintenance)
Unpaved roads:		
Excellent	Maintainable road with camber and drainage intact	Nominal light maintenance only required e.g. grass cutting, light bush clearing, culvert cleaning, ditch clearing, mitre drains cleaning, repair of road signs
Good	Maintainable road. Camber and drainage require light maintenance. Or flat sandy road.	Rating 1 + Light grading or light manual reshaping + light pothole filling.
Fair	Maintainable road. Camber and drainage require some reshaping	Rating 1 + Grading or manual reshaping + pothole and ruts filling.
Poor	Passable but Un-maintainable. No camber. Requires reinstatement	Rating 1 + Heavy grading/manual reshaping + compaction; Basically partial rehabilitation.
Bad	Impassable	Reconstruction

Source: Kenya Roads Board, Kenya Rural Road Authority.

i. Paved road with IRI less than 6 meters/km and unpaved road with IRI less than 13 meters/km, when IRI data are available
ii. Paved road in excellent, good, or fair condition and unpaved road in excellent or good condition, when IRI data are not available but other road condition data, such as the PCI or visual assessment by class value, are available.

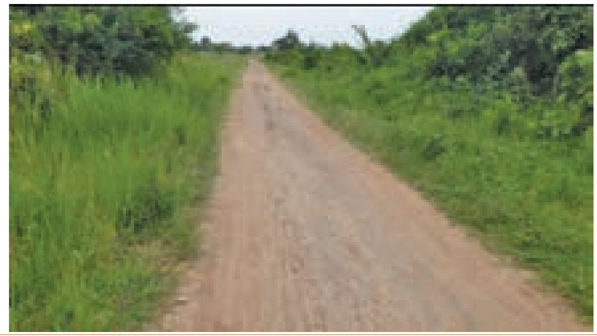
The proposed thresholds are chosen with the concepts of passability and all-season connectivity taken into account. For paved roads, the selected threshold is 6, under which roads are at least passable and motorable in normal weather conditions, although there may exist some potholes and cracks and roads need to be maintained if roughness is close to 6. For unpaved roads, impassability during rainy seasons is of particular concern in developing countries. The selected threshold is 13 for unpaved roads. In broader terms, impassability can be translated into a roughness of 13 or more, although the two measurements are conceptually different.[16]

In the absence of IRI or road condition data, various road condition data by simplified index or class value have to be converted to a standardized measurement. For instance, as in the conventional road assessment, the PCI standardized by the U.S. Army Corps of Engineers can be interpreted as excellent (100–80), good (80–60), fair (60–40), poor (40–20), and very poor (20–0), respectively. Different countries have different road quality assessment standards (for example, see table 6 and photo 1), but these are broadly consistent with one another from the engineering point of view. However, careful conversion will be required.

16 The resultant RAI is particularly sensitive to the threshold for unpaved roads, especially if road condition data are only available on a class value basis (such as good, fair, and poor). The majority of rural roads are unpaved in developing countries. The share of unpaved roads in good condition may be relatively small. But several unpaved roads may be in fair condition. Thus, the inclusion of fair unpaved roads may result in an unrealistically high RAI.

Photo 1: Uganda: District Road Classification Manual

1: Good: Allowing easy runoff from the road surface into the roadside drains; shoulder not eroded



2: Fair: Uneven shape, but allowing most water to run off the road surface into the roadside drains; some erosion of shoulder

3: Poor: Poor shape and seriously restricts water to run off the road surface into the roadside drains; severe erosion of shoulder

4: Bad: Non-functioning or non-existent

Source: Road Inventory Survey Manual, Ministry of Works and Transport, Uganda.

Since a variety of new technologies are currently available, it is always ideal to collect actual road condition data. However, a modeling approach is also possible as in the original RAI study in 2006. From a purely statistical point of view, the estimated model can predict nearly 90 percent of the variation of the RAI. But this should be the last resort when no data are available but rural accessibility still needs to be calculated, possibly at the aggregated level (Box 9).

Box 9. "Naive" Modeling Approach

Although a variety of new cost-effective technologies are available, a significant challenge may still exist in collecting georeferenced road condition data in developing countries. Smartphone applications, such as Roadroid and RoadLab, are cost-effective for collecting roughness data quickly. Drone and satellite imagery technologies also have potential. It cannot be overemphasized that technology is always evolving and costs could be reduced dramatically.

For rough calculation purposes or at a highly aggregated level, it is possible to establish a statistical model to predict the Rural Access Index (RAI) with only general statistics of demographics and road network characteristics (but not georeferenced road data). The RAI differs from location to location. But there are some common determinants of the index, partly because of the way it is defined and partly because of the general patterns of human settlement and road network developments.

(*continued on next page*)

Box 9. "Naive" Modeling Approach *(continued)*

With subnational RAI estimates in eight countries, the RAI is regressed on a set of demographic and road characteristics at the subnational level:

$$\ln RAI_{ic} = \beta_0 + \beta_1 \ln RdDen_{ic} + \beta_2 \ln Quality_{ic} + \beta_3 \ln PopDen_{ic} + \beta_4 \ln PopConc_{ic} + \beta_5 \ln Urban_{ic} + v_c + \varepsilon_{ic}$$

where *RAI* is the rural access measured at district *i* of country *c*. It is determined by road density, *RdDen*, and the share of good roads in the total road length in rural areas, denoted by *Quality*. Only rural areas are considered in the data. The RAI is also considered to be related to rural population density (*PopDen*). It is commonly expected that the RAI would be higher where population density is high, although it depends on the population distribution between near-road and far-road areas, which is expected to be captured by population concentration along the road network, *PopConc*. This is defined by the share of people who live within 2 kilometers of the road network in the total rural population. *Urban* is the usual urbanization rate, which is the share of urban population in the total population.

The results suggest that rural access is related to road density and road condition (table B9.1). The measured RAI is also affected by the population distribution patterns, more specifically, by the share of people living along the road network, not general population density. The model explains nearly 90 percent of the variation of RAI. Of course, this merely shows correlation, not causality. But for prediction purposes, rough estimates can be computed based on the model with the above-mentioned variables.

Table 9. OLS Regression Results

	Coef.	Std. error		Coef.	Std. error	
ln *RdDen*	0.324	(0.031)	***	0.272	(0.046)	***
ln *Quality*	0.543	(0.035)	***	0.564	(0.040)	***
ln *PopDen*	–0.0001	(0.017)		0.001	(0.021)	
ln *PopConc*	0.746	(0.048)	***	0.759	(0.060)	***
ln *Urban*	0.005	(0.003)		0.013	(0.004)	***
v(Ethiopia)				–0.391	(0.096)	***
v(Kenya)				0.014	(0.055)	
v(Mozambique)				–0.039	(0.095)	
v(Nepal)				0.001	(0.069)	
v(Tanzania)				0.005	(0.084)	
v(Uganda)				0.142	(0.056)	**
v(Zambia)				–0.217	(0.083)	***
Constant	0.530	(0.139)	***	0.574	(0.163)	***
Obs.	691			691		
R squared	0.8763			0.8923		
F statistics	985.68			542.54		

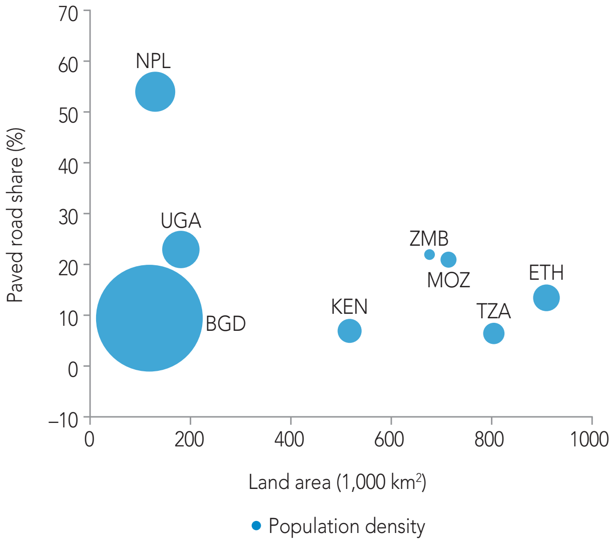
The dependent variable is the log of *RAI*. Robust standard errors are shown in parentheses. *, ** and *** indicate the statistical significance at the 10, 5 and 1 percent, respectively.

Source: Iimi et al. 2016.

MAIN RESULTS FROM THE EIGHT PILOT COUNTRIES

To examine its methodological reliability and practical feasibility, the proposed method was applied to eight countries: Ethiopia, Kenya, Mozambique, Tanzania, Uganda, and Zambia in Africa, and Bangladesh and Nepal in South Asia. These countries were selected with the size of country, population density, and initial data availability taken into account. Bangladesh has extremely high population density. Nepal also has high population density and a high share of paved roads (according to the World Development Indicators data). The African countries included are far larger in size with low population density, except for Uganda (figure 16). On data availability, some countries, such as Kenya, had already developed comprehensive and disaggregated road data, and in other countries, such as Nepal and Tanzania, additional efforts were made toward improving the original data sets.

Figure 16: Characteristics of the Pilot Countries: Size, Population Density, and Share of Paved Roads



Source: World Development Indicators.

The resulting new RAI estimates differ significantly from the original 2006 RAI estimates, and rural access varies significantly across countries, from 17 percent in Zambia to 56 percent in Kenya (table 7). The individual country notes are available in annex III. Compared with the original estimates in 2006, the new estimates are more or less similar for Kenya (figure 17). The new estimates for Nepal and Uganda are much greater than the original ones, which seems to be mainly attributed to their high road and population densities.[17]

By contrast, Zambia has a significantly lower RAI than previously. The differences between the original and current estimates are attributed partly to data and partly to methodology (see the next section for further discussion). In the case of Zambia, the difference is primarily because the road data density is among the lowest in the sample and the condition of the roads, especially feeder roads, is poor in the country. According to the latest Road Condition Report by the Road Development Agency, in Zambia, nearly 90 percent of the paved trunk,

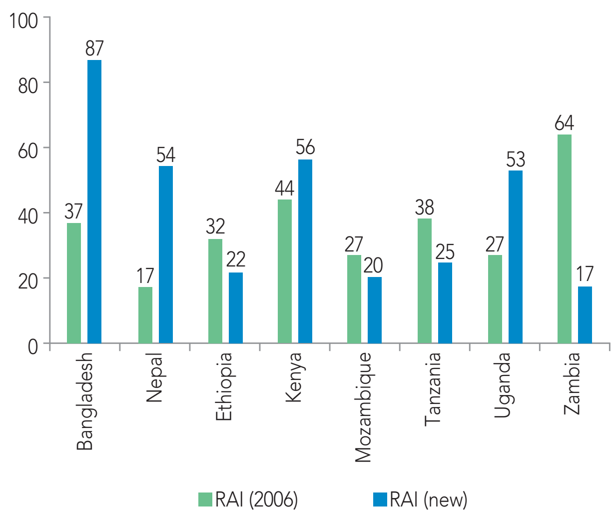
[17] The high RAI for Nepal seems to be consistent with the existing national estimate (see box 3).

Table 7: Summary of New RAI Estimates

Country	Population (million)	Land area (1,000 km²)	Population density	Road data length (km)	Original RAI, 2006	New RAI	Pop. without access (mil)	Year
Bangladesh	159.1	130.2	1,222	250,688	37	86.7	15.9	2015
Nepal	28.2	143.4	197	77,819	17	54.2	10.3	2015
Ethiopia	97.0	1000.0	97	85,880	32	21.6	63.7	2015
Kenya	44.9	569.1	79	160,886	44	56.0	13.3	2009
Mozambique	27.2	786.4	35	29,614	27	20.4	15.0	2010
Tanzania	51.8	885.8	59	94,039	38	24.6	32.8	2008/2014
Uganda	37.8	199.8	189	140,910	27	53.1	16.3	2015
Zambia	15.7	743.4	21	51,070	64	17.0	6.9	2011

Source: World Bank calculations.
Note: km = kilometers; RAI = Rural Access Index.

Figure 17: Comparison of Original and New Rural Access Index Estimates



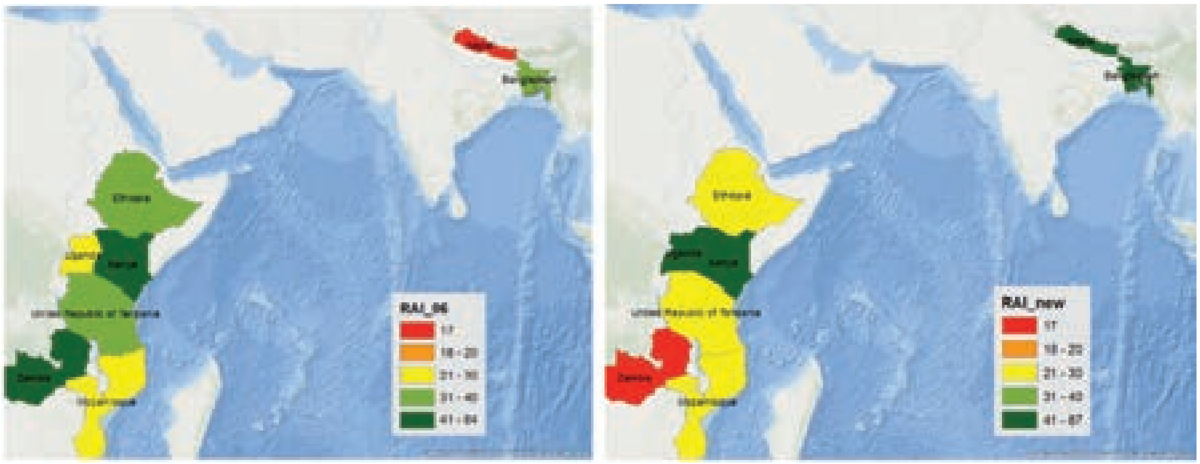
Sources: Roberts, Shyam, and Rastogi (2006); World Bank calculations.

main, and district roads are in good condition. However, 80 percent of the unpaved feeder roads are in poor condition.

The original RAI was only available at the national level, which has also changed in the new index (map 8). The greatest advantage of the new method is that the RAI can be calculated at the subnational level or any level of spatial aggregation (map 9). This is a significant value added by the use of spatial data and techniques. The subnational estimates will be useful for policy makers and other stakeholders for planning and monitoring purposes.

Map 8: Original and New RAI Estimates at the National Level

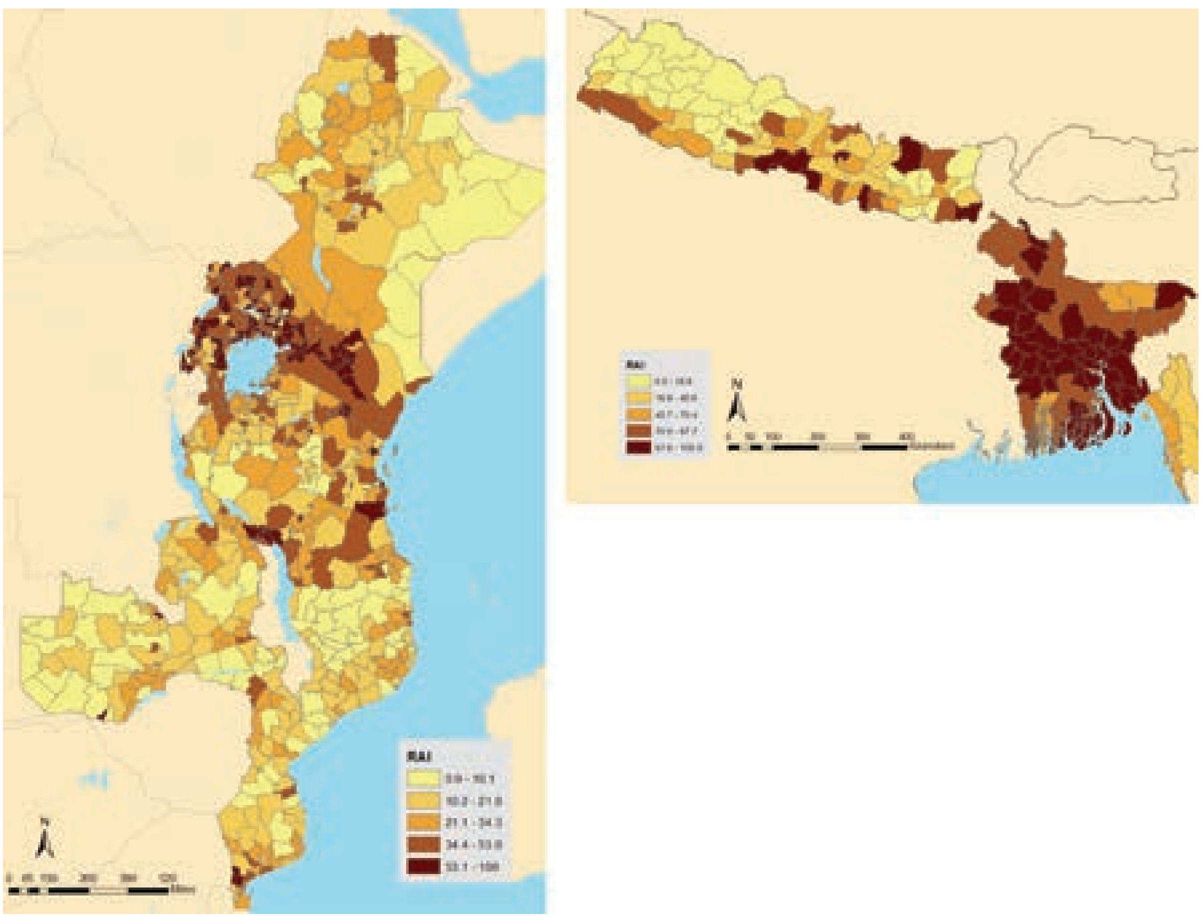
a. Original, 2006 **b. New, 2008–15**



Sources: Roberts, Shyam and Rastogi 2006; World Bank calculations.

Map 9: New Rural Access Index Estimates at the Subnational Level

a. East Africa **b. South Asia**



Source: World Bank calculations.

5

DISCUSSION

Robustness

Introduction

It is important to check the robustness of the estimated RAI results against different data sources and assumptions. Several selected sensitivity analyses were carried out focusing on three issues: population data, threshold of proximity, and data comprehensiveness.

Population Distribution Data

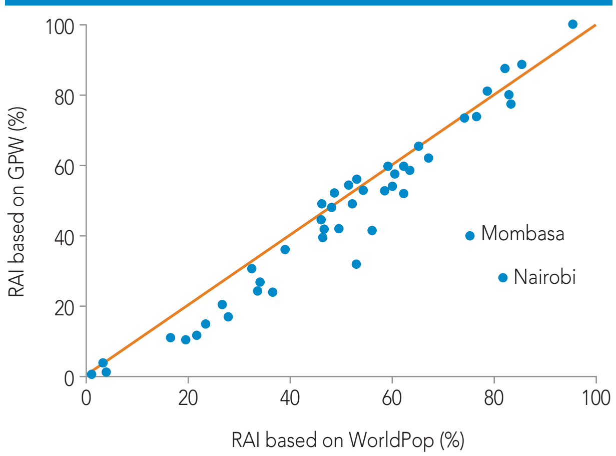
The currently available global population distribution data sets are broadly consistent, although estimated based on different assumptions and techniques. The results are compared between the two major population data sets: WorldPop (the default) and the GPW. For Kenya, the RAI with the GPW is estimated at 51.3 percent, slightly lower than the estimate with the WorldPop data set (56.0 percent). For Mozambique, the result is similar: the RAI is 17.9 percent with the GPW, and 20.4 percent with the WorldPop. The RAIs with the GPW are systematically lower than the results with WorldPop at the subnational level, particularly in populated areas, such as Nairobi and Mombasa (figure 18). This is because the GPW distributes population uniformly within each grid space; therefore, it allocates too much of the population in rural or remote areas where fewer people may actually live.

The year of the global population data may not be the same as the year of the road data that are available. WorldPop provides population estimates for every five years, that is, 2005, 2010, and 2015 in the most recent sets. The selection of the population data does not have much influence on the RAI, because the RAI measures the proportion of rural population, not its absolute number. In Tanzania, for instance, the RAI is estimated at 24.59 percent with the 2015 population data. It is 24.49 percent if the 2010 data are used instead. The two estimates are practically the same.

Threshold of Proximity

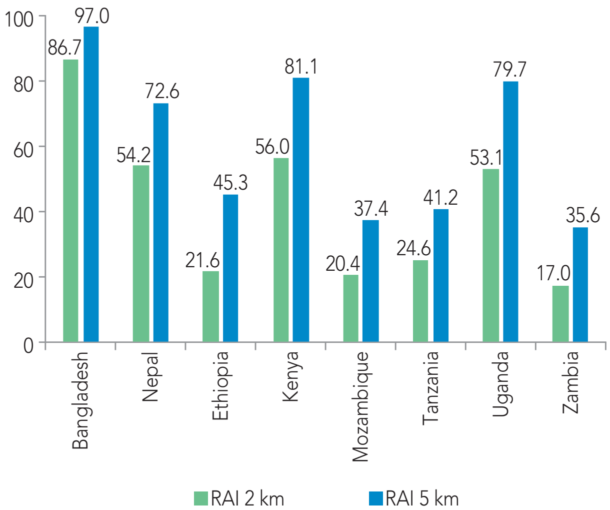
There is no reason for rural access to be measured by 2 km distance. Spatial data and techniques allow any other thresholds to be used. Raballand, Macchi, and Petracco (2010) propose 5 km access for Africa. The 5 km distance would cover more population along the road network, increasing the RAI estimates. But the international ranking follows broadly the same pattern. By using the 5 km threshold, the RAI generally increases by about 15 to 25 percentage points (Figure 19). The extent to which the RAI increases depends on where people live along the

Figure 18: Kenya: RAI Based on WorldPop and GPW



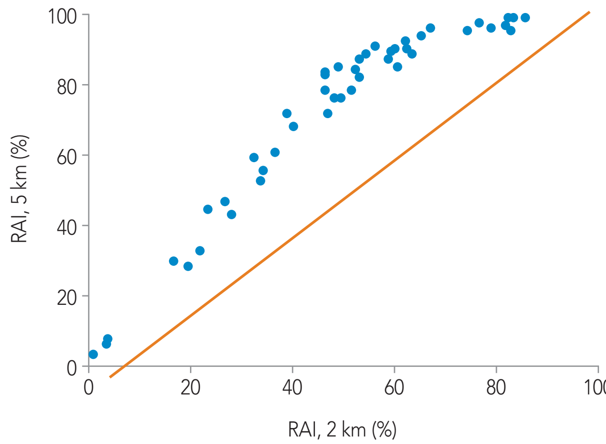
Source: World Bank calculations.
Note: GPW = Gridded Population of the World; RAI = Rural Access Index.

Figure 19: Rural Access by 2 km and 5 km Distance Thresholds



Source: World Bank calculations.

Figure 20: Kenya: Rural Access 2 and 5 km Thresholds, by County



Source: World Bank calculations.

road network that is in good condition. When the 5 km threshold is used, the RAI increases substantially in Kenya and Uganda. Mozambique is also estimated to have a relatively high RAI with the 5 km definition, which means that many people would likely live just beyond the 2 km distance from the road network. The policy implication is that rural accessibility could be improved by marginally extending the current network, thus connecting more people to the network.

In countries where the baseline RAI with a 2 km threshold is low, such as Zambia and Tanzania, the RAI tends to remain relatively moderate even if the 5 km threshold is used. This result can be interpreted to mean that not many people live close to a road that is currently in good condition. If this were the case, relatively large efforts would be required to improve rural accessibility. This pattern holds even at the subnational level, reflecting the challenge of improving access for communities in remote areas, widely separated from one another. In Kenya, the RAI with a 5 km threshold tends to be higher where the 2-km RAI is already high. People live along the road network even beyond the 2 km distance. But in low RAI counties, the extension of distance does not matter much: the challenge to increasing rural access seems to be greater (figure 20).

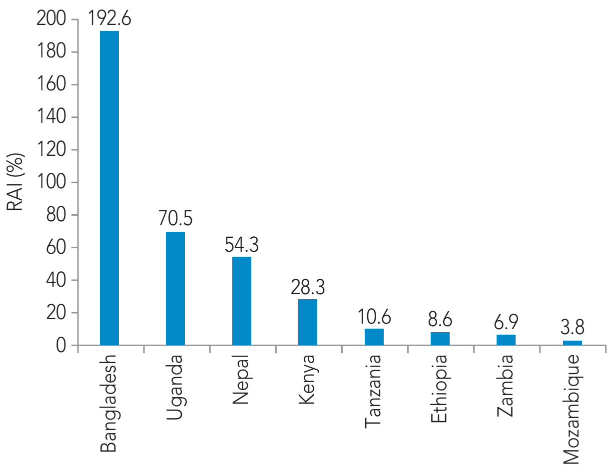
Road Data Density

From the methodological point of view, it is noteworthy that the new RAI method really depends on the quality of the underlying spatial data. Road density in the data varies significantly from 3.8 km per 100 km^2 in Mozambique to 70.5 km per 100 km^2 in Uganda (Figure 21). More data are always better. Efforts are required to collect detailed road data, including tertiary or feeder roads, which may not be covered in the existing spatial road network data regardless of whether government or open data sources are used.

The RAI generally increases if a more comprehensive data set is available. How the RAI estimate changes with different levels of data depends on the condition of the tertiary or feeder roads covered. In Nepal, the RAI was estimated at 19.2 percent with a limited data set, but complementary data collection of feeder road conditions resulted in a much higher RAI of 54.2 percent (figure 22). This result seems to be attributed to the country's high population and the relatively high share of paved roads among the limited sample countries.[18] In Uganda, the

[18] In the World Development Indicators database, the share of paved roads is estimated at 53.9 percent. Given the new geo-referenced data, about 17.8 percent of the mapped roads are recognized as paved.

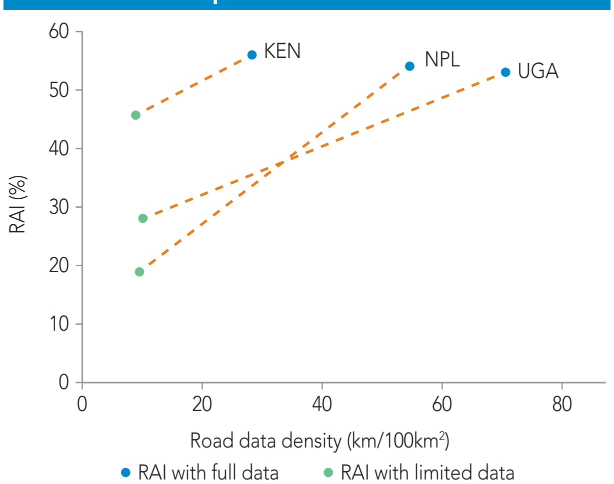
Figure 21: Road Data Density (km/100 km²)



Source: World Bank calculations.

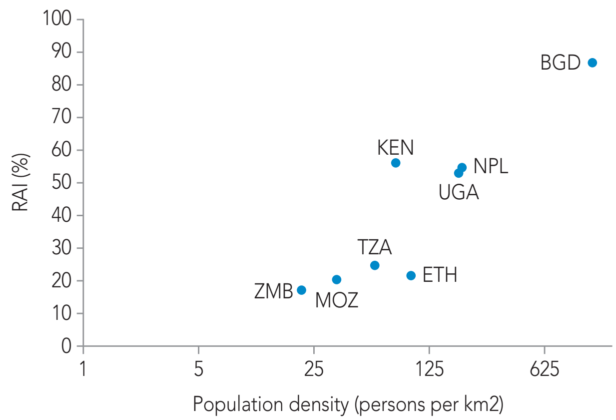
addition of newly collected feeder road data (covering nearly 120,000 km) resulted in an increase in the index from 28.3 to 53.1 percent. For Kenya, if tertiary roads (109,400 km) were not included in the data set, the RAI would be estimated at 45.8 percent, lower than the estimate with the actual full data set. But the difference is less drastic, implying that the condition of tertiary roads is mostly poor.

Figure 22: RAI and Road Data Comprehensiveness



Source: World Bank calculations.

Figure 23: RAI and Population Density



Source: World Bank calculations.

Consistency with Other Road Sector Measurements

Population Density and Road Density

The estimated RAIs are found to be broadly consistent with the traditionally discussed basic demographic indicators. First, the estimated RAI is correlated with the logarithm of population density.[19] The RAI estimates tend to be higher when rural population density is high (figure 23).[20] This is among the most predictable results. Second, the estimated RAI increases with road density, which may be partly because of the data comprehensiveness issue. Still, there is an important positive correlation between the RAI and road density: the more roads there are, the higher is rural accessibility (figure 24).

However, there is no clear correlation between the RAI estimates and traditional road quality indicators, such as the share of paved roads. The surface type does not seem to be a good predictor of rural accessibility, because rural roads are generally unpaved in developing countries (figure 25). Even if rural roads are paved, they are often in poor condition. Conversely, unpaved

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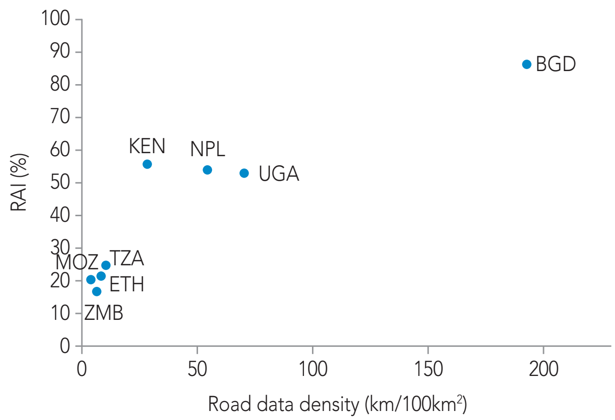
[19] Bangladesh has an extremely high population density among the sample countries.

[20] Rural population density is calculated with the same data as the RAI estimation (WorldPop and GRUMP data).

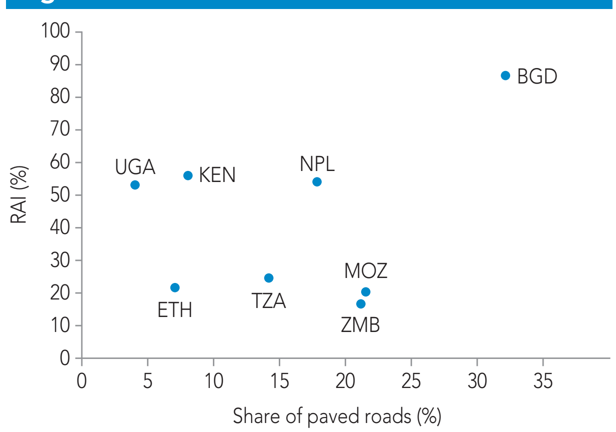
Figure 24: RAI and Road Density



Source: World Bank calculations.

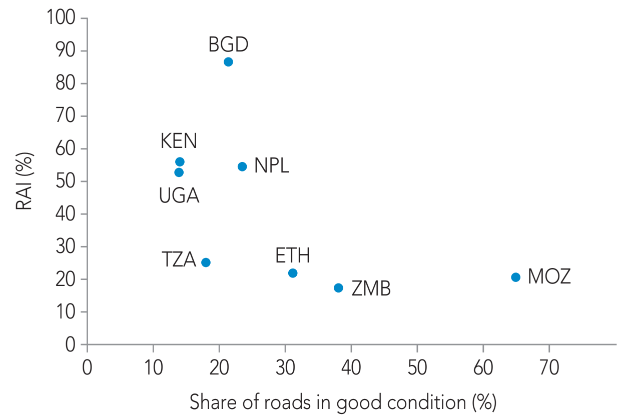
roads can be in good condition, if they are well maintained. And there is no systematic trend between RAI and the share of roads in "good" condition (figure 26). In Uganda and Nepal, there are a lot of feeder roads in poor condition; thus, the shares of good roads are low. But important roads where people live seem to be well maintained, resulting in high RAI estimates. By contrast, Mozambique has an exceptionally high share of roads in good condition.[21] But the RAI is low because its official road network is currently narrowly defined. Unclassified roads are potentially in poor condition in the country.

Figure 25: RAI and the Share of Paved Roads



Source: World Bank calculations.

Figure 26: RAI and the Share of Roads in Good Condition



Source: World Bank calculations.

Consistency with Household Surveys

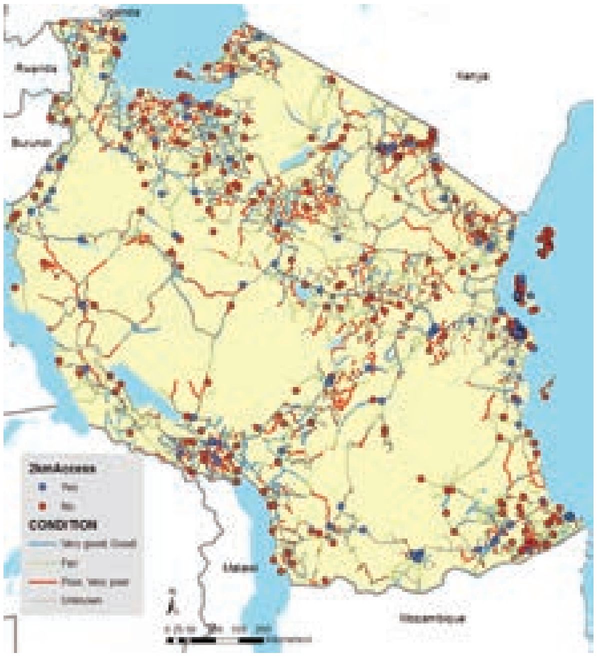
The estimated RAI is broadly consistent with available household-level data. In Tanzania, for instance, the 2010 household survey covers 3,917 households in 409 villages all over the country, although it is still far from representative from a spatial point of view. Where the road conditions are poor, households seem to be less likely to have 2 km access to the road network (map 10). More formally, there is statistically significant correlation between the RAI and the share of households with 2 km access at the district level (figure 27). Similarly, there is a negative correlation between the RAI and the average distance to the nearest road calculated based on household survey data (figure 28). Thus, the new RAI is not something new, it is consistent with actual micro data collected on the ground. The important difference is that the new RAI method does not require anyone to visit households and ask questions.

Comparison with Project-Level Data

The developed RAI method can in principle be used for project monitoring and evaluation in the road sector. Many transport projects adopt the number of beneficia-

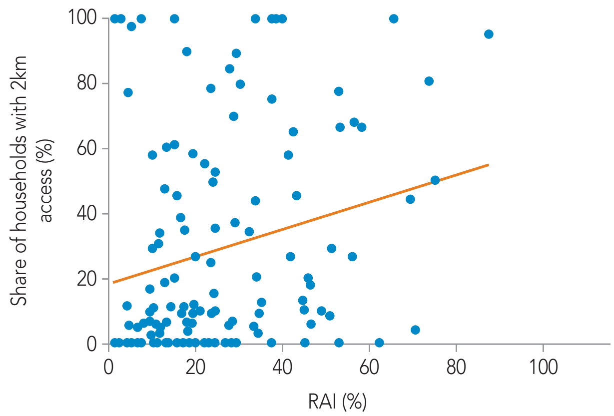
21 According to the latest PES/PRISE report prepared by the National Roads Administration, about 74 percent of the road network is in good or fair condition.

Map 10: Tanzania: RAI and Household-Level Data



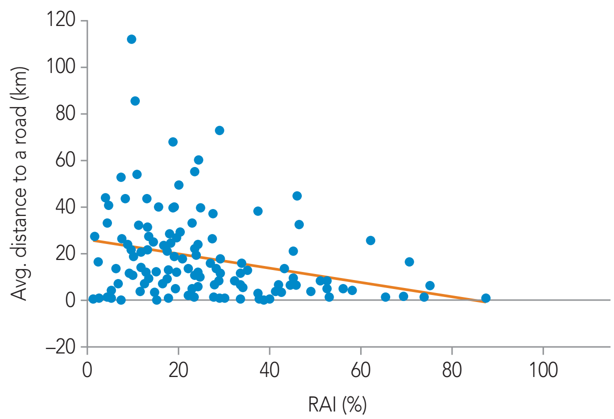
Source: Tanzania 2010 Living Standards Measurement Study; World Bank calculations.

Figure 27: RAI and Share of Households with Access



Source: Tanzania 2010 Living Standards Measurement Study; World Bank calculations.

Figure 28: RAI and Average Distance to Road



Source: Tanzania 2010 Living Standards Measurement Study; World Bank calculations.

ries along the project roads as one of the main project development objective (PDO) indicators. A baseline survey is normally carried out based on the latest available census data. Although census data may be available at a very disaggregated level, for instance, enumeration area, it still does not have granularity of proximity to a particular road. Beneficiary estimates based on census data tend to be overestimated.

In Ethiopia, for instance, the World Bank's Transport Sector Project in support of the Government's Road Sector Development Program Phase IV is using the number of project beneficiaries as a PDO indicator (World Bank 2012a). The project supports the upgrading of five selected roads, of which the total length is 434.5 km (map 11). According to the baseline survey, about 1.9 million people would benefit from the project (table 8). Based on the global population data and georeferenced road data that the current RAI calculation is using, the number of people who live within 2 km of these five road segments is estimated at about 400,000. This is not necessarily contradictory to the project assessment, because people who live beyond 2 km distance can benefit from the improved roads. Especially if an unpaved road is upgraded to paved standard, economic benefits are expected for a greater distance.

In Mozambique, the Integrated Road Sector Program has been prioritizing transport investments and focused on maintaining and improving the core road network, especially the north-south corridor, which is a backbone road infrastructure through the country (map 12). One

Map 11: Ethiopia: Project Road Links under the World Bank Transport Sector Project

of the PDO indicators for the World Bank project is the number of project beneficiaries in rural areas (World Bank 2015a). Based on the census data, it was originally estimated in 2006 that 1.5 million people would benefit from phase 2 of the program.[22] According to the spatial data, about 2.5 million people live along the program road links. When urban areas are excluded (again, by using the GRUMP extent), about 0.9 million people are estimated to benefit from the program (table 9). This is lower than the project estimate.

Relevance to Broader Development Objectives

Despite the various advantages and caveats, an important question from the policy-making point of view is

Table 9. Mozambique: Beneficiaries from PRISE

Measure	Number of beneficiaries
Project appraisal in 2006	1,500,000
Spatial data for 2010	
Total	2,463,892
Excluding urban areas	926,797

Source: World Bank.

whether the new RAI is relevant to other development agendas. Three issues are discussed in the following subsections.

Different Types of Accessibility

The RAI is focused on measuring the most fundamental accessibility, that is, access to a road. However, there are many other types of accessibility that matter to people and governments. For instance, access to a market (often defined by a populated area or administrative center) is essential to agricultural development in Africa. From the social development point of view, access to a school and health services is also important. In addition, in the new RAI method, some road segments, although well maintained, can be hanging in the middle of nowhere. Thus, it is critical to confirm that the estimated RAI is systematically relevant to other types of accessibility.

22 The percentage of the rural population within 2 km of an all-season road is also one of the PDO indicators. It was originally 11 percent in 2006. It was updated to 34 percent in 2014. Since the definition of all-season road is less strict than the new RAI criteria, it is potentially upward biased.

Table 8. Ethiopia: Beneficiaries from the World Bank Transport Sector Project

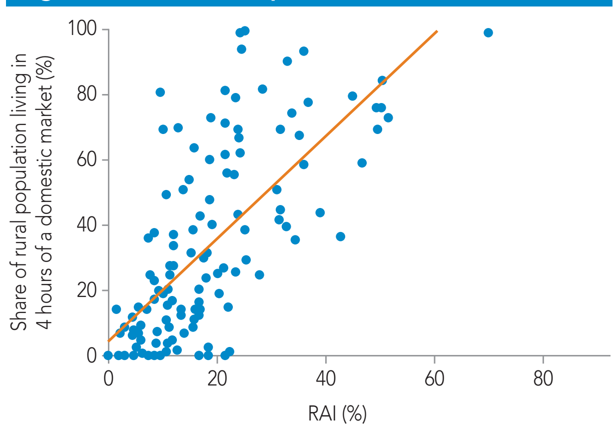
Road	Length (km)	Population in "project areas"	Population in 2 km of project roads
Ambo – Weliso	63.8	508,649	125,940
Debre Birhan – Ankober	42.0	262,556	61,246
Kombolcha – Bati – Mille	130.0	472,108	155,266
Mizan – Dima	91.6	269,067	24,991
Konso – Yabelo	107.1	431,023	33,620
Total	434.5	1,943,403	401,063

Map 12: Project Road Links under PRISE

Map 13: Mozambique: Four-Hour Access to a Market

An advantage of using spatial techniques is that the developed RAI method can easily be extended to measure other types of access, by overlapping a variety of spatial data in the same format. For instance, many cities, as a proxy for a market, have already been georeferenced. There is a significant correlation between market accessibility and the RAI. In Mozambique, for instance, market accessibility, which is defined by the share of the total rural residents who live within four hours of travel time to a large city, is 38.3 percent at the national level. The vast majority of rural areas are too far from large cities (map 13). At the district level, the market accessibility is highly correlated with the RAI estimates. The correlation is about 0.69 (figure 29). This means that if people have good access to roads, they are also likely to have good access to a market.

Figure 29: Mozambique: RAI and Market Access



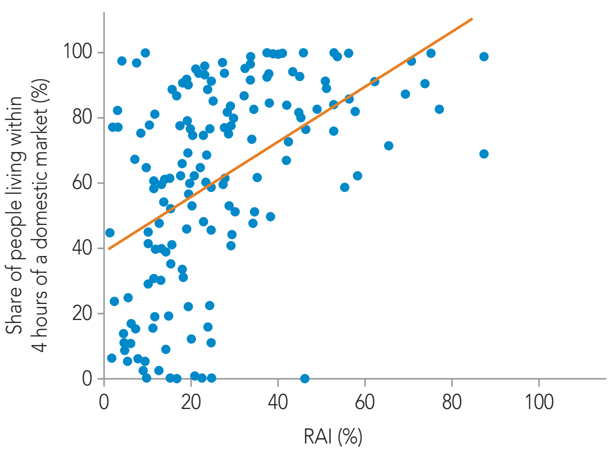
Source: World Bank calculations.

Similarly, in Tanzania it is estimated that 58.6 percent of the total rural residents live within four hours travel distance of a market (map 14). The correlation is about 0.5 (figure 30).

The observed relationship between the RAI and market access is consistent with existing data. In Tanzania, for instance, the 2010 household survey indicates that transport costs to a large city are correlated with local road

Map 14: Tanzania: Four-Hour Access to a Market

Figure 30: Tanzania: RAI and Market Access



Source: World Bank calculations.

Figure 31: Tanzania: Road Access and Market Access

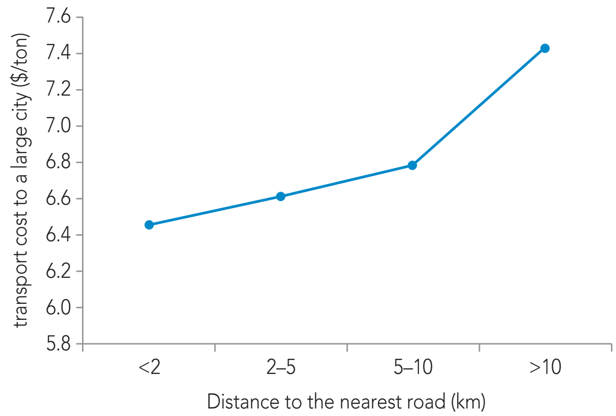
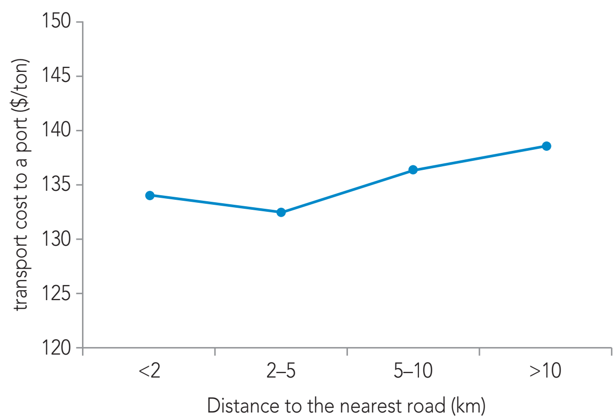


Figure 32: Tanzania: Road Access and Port Access



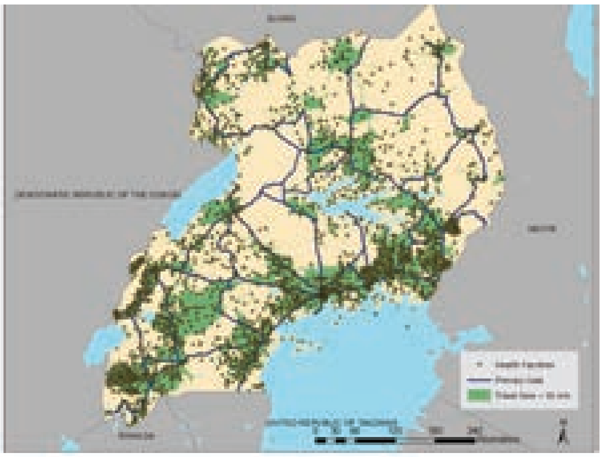
Source: World Bank calculations based on Tanzania 2010 Living Standards Measurement Study data.

connectivity. If people do not have good access to roads, their transport costs to go to the nearest large city also tend to be high (figure 31). The correlation is relatively weak when transport costs to a port—which is a proxy for the global market—are considered. Still, rural access is correlated with accessibility to the global market (figure 32).

The new RAI estimates are also relevant to connectivity to social facilities. For instance, in Uganda, health access is correlated with the estimated RAI. As an example, health access is defined by the share of rural people who can visit a health facility within 30 minutes.[23] In

[23] Travel time is calculated based on average travel speed measured in the recent road inventory survey. Where no actual average speed data are available, travel time is estimated based on the underlying road condition data, including surface type, road class, and surface condition index.

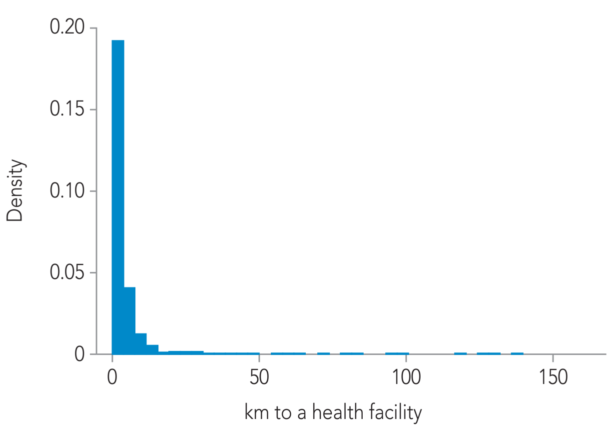
Map 15: Uganda: Health Facilities and 30 Minute Access



Source: World Bank calculation based on Uganda National Road Authority data.

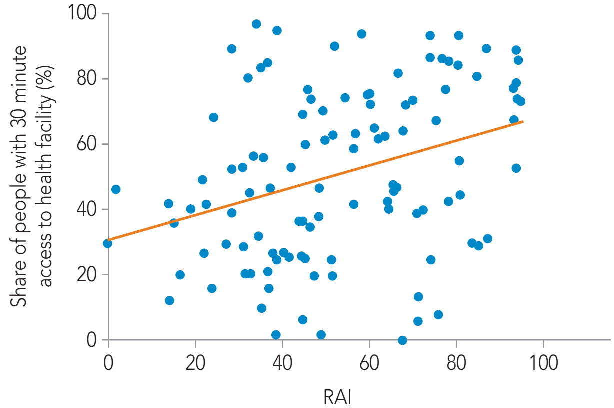
Uganda, people have fairly good access to a health facility primarily because of the country's high road density. According to the 2010 Living Standards Measurement Study, about half of the sample households have less than 2 km access to health services (figure 33). When spatial data are used (map 15), it is estimated that 55.7 percent of rural people have a health facility within 30 minutes travel distance, and there is significant correlation between the RAI and access to health services at the district level (figure 34).

Figure 33: Uganda: Distance to a Hospital



Source: Uganda 2010 Living Standards Measurement Study data.

Figure 34: Uganda: RAI and Health Accessibility, by District



Source: World Bank calculations.

Similarly, there is strong positive correlation between the estimated RAI and access to a school. In Uganda, primary schools exist all over the country. However, secondary schools are relatively limited. The share of people who live within less than one hour travel distance to a secondary school is estimated at 18.3 percent. It is significantly correlated with the RAI estimates at the district level (figure 35).

Agricultural Production

Access to a road is no doubt the most fundamental constraint in many developing countries. The literature

Figure 35: Uganda: RAI and Secondary School Access

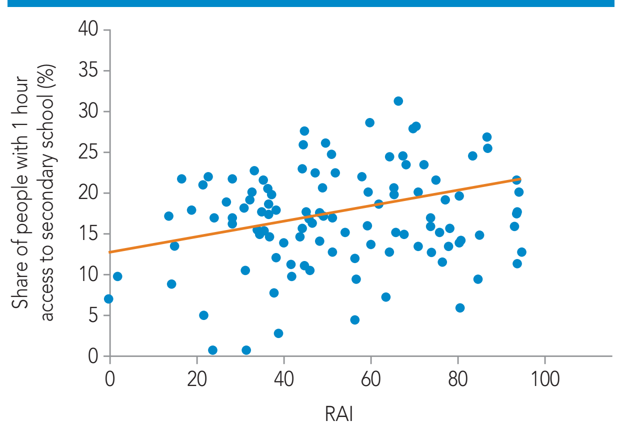


Figure 36: Kenya: Agricultural Production and the RAI, by County

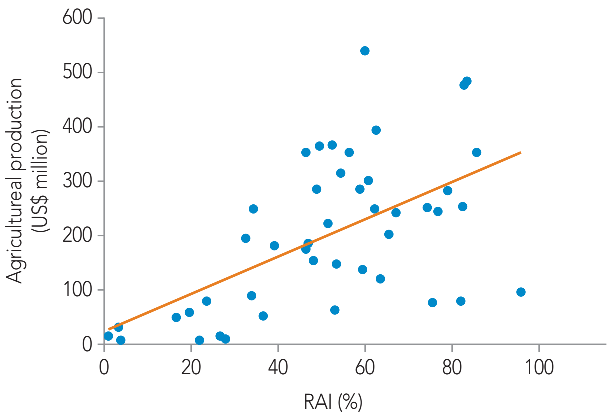


Figure 37: Kenya: Poverty Rate and the RAI, by County

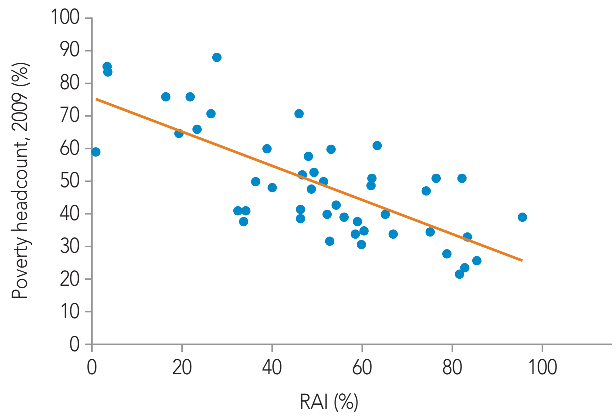


Figure 16: Kenya: Agricultural Production Value

Sources: World Bank calculations; International Food Policy Research Institute Spatial Production Allocation Model.

indicates that limited road accessibility has an adverse effect on agricultural production, raising prices of inputs such as fertilizer, decelerating farmers' crop shift toward cash crops, reducing farm-gate prices, and restraining agricultural income that households can earn. In Kenya, there is strong correlation, although not causality, between agricultural production and the RAI (figure 36 and map 16). It cannot be overemphasized that this does not show any causality between them: there may be other factors that simultaneously affect the RAI and agricultural productivity. It is merely a correlation. But it is still important to confirm the relevance of the new RAI method.

Poverty

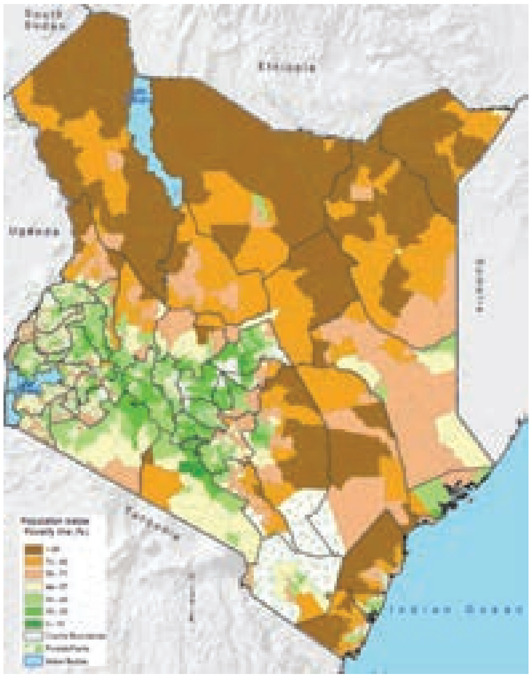
Limited rural access tends to be an important constraint to alleviate poverty in remote areas. The new RAI is highly correlated to poverty incidence. Again, this does not show any causality. In Kenya, the correlation is estimated at –0.729 (figure 37 and map 17). In Mozambique, the correlation is –0.559 (figure 38 and map 18). Not surprisingly, the poor tend to live where road accessibility is limited, which has long been a common challenge in many developing countries, especially in Africa.

Universal Access, Financial Needs, and Prioritization

Universal Access

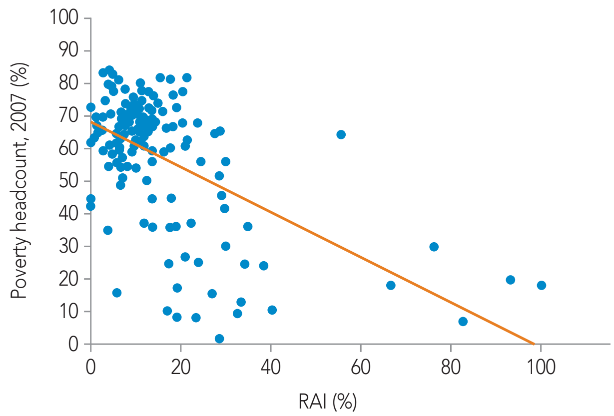
Under the new RAI method, universal access is challenging, especially in Africa where rural population density is generally low. The new RAI method measures the acces-

Map 17: Kenya: Poverty Rate

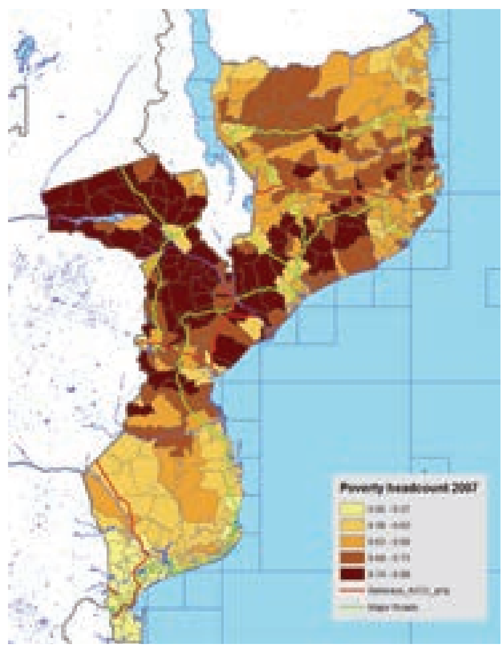


Sources: World Bank calculations; KNBS and SID 2013.

Figure 38: Mozambique: Poverty Rate and the RAI, by District



Map 18: Mozambique: Poverty Rate



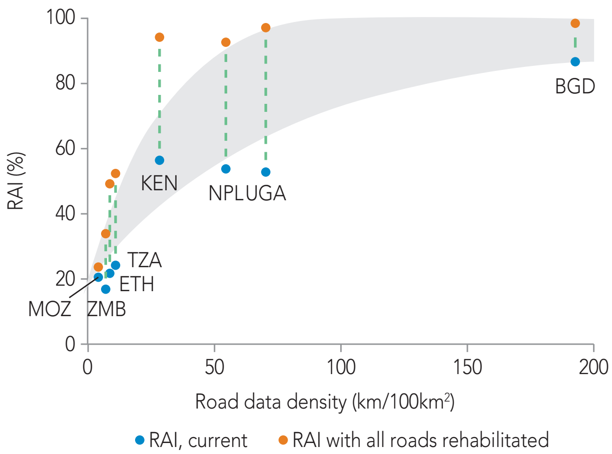
Source: World Bank calculations.

sibility of individual households that may live in very remote areas beyond administrative agglomerations, such as district centers or even villages. In simulations where the current road network is narrowly defined and many people live beyond the network, universal access is theoretically impossible to achieve.

In Ethiopia, Mozambique, Tanzania, and Zambia, the RAI would be less than 60 percent even if the entire official road network was rehabilitated and maintained in good condition (figure 39). In Mozambique, the maximum possible RAI would be 25.1 percent under the current official road network. To achieve a higher level of rural access, the country would need to build new roads, or more practically, reclassify unclassified rural roads and maintain them in good condition. The current RAI update exercise motivated the Government of Mozambique to start to rethink the coverage and optimality of the current classified road network. Road classification is of course a complex issue involving government responsibility and resource allocation at the central and local levels. It would not be optimal to reclassify unofficial roads into the network without any legal mandate specified or fiscal resources allocated.

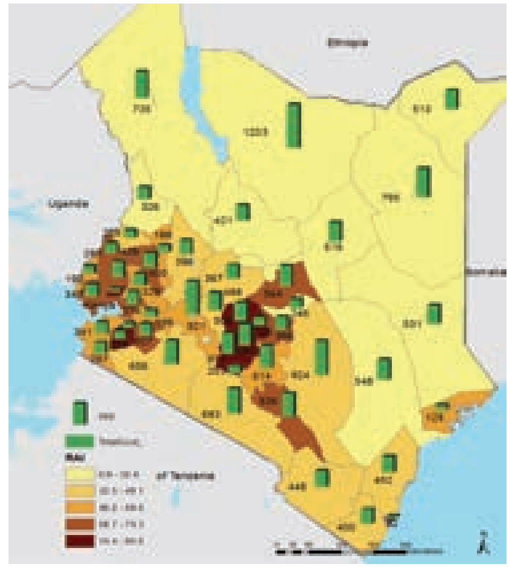
In theory, Kenya, Nepal, and Uganda could achieve almost universal access by reinstating the existing road network to a good condition. The shaded area in figure 39 indicates

Figure 39: Current RAI and Maximum Achievable RAI



Source: World Bank calculations.

Map 19: Kenya: RAI and Financial Requirements, by County (US$ Million)



Source: World Bank calculations.

the possible improvement in rural access by rehabilitating the current road network. To improve the RAI further, extension of the road network would be required.

Financial Needs

An important policy question may be how much would be required to achieve universal access. In the case of Kenya, where almost universal access could be achieved by rehabilitating the entire current road network, it would require about \$20.4 billion.[24] Not surprisingly, more resources would be required where the RAIs are low (map 19). In 2014/15, the Government of Kenya allocated about KSh32 billion or US\$361 million to road development and maintenance, of which US\$102 million or about 28 percent of the total budget was allocated to the Kenya Rural Roads Authority (and local governments). This is merely 0.5 percent of the estimated total financial needs.

The financial challenge is obviously significant, and strategic prioritization is a must. The advantage of using spatial techniques and data is that different types of data can be overlapped on the same map. For instance, governments may be interested in identifying where rural access is missing but agricultural potential exists. It may also be useful to examine how efficiency in rural road investment can be maximized. Spatial data allow for estimation of how many people could be served by one unit of road (for example, 1 km) or by one unit of road spending (for example, US\$1 million). Strategic prioritization can be done with different objectives combined.

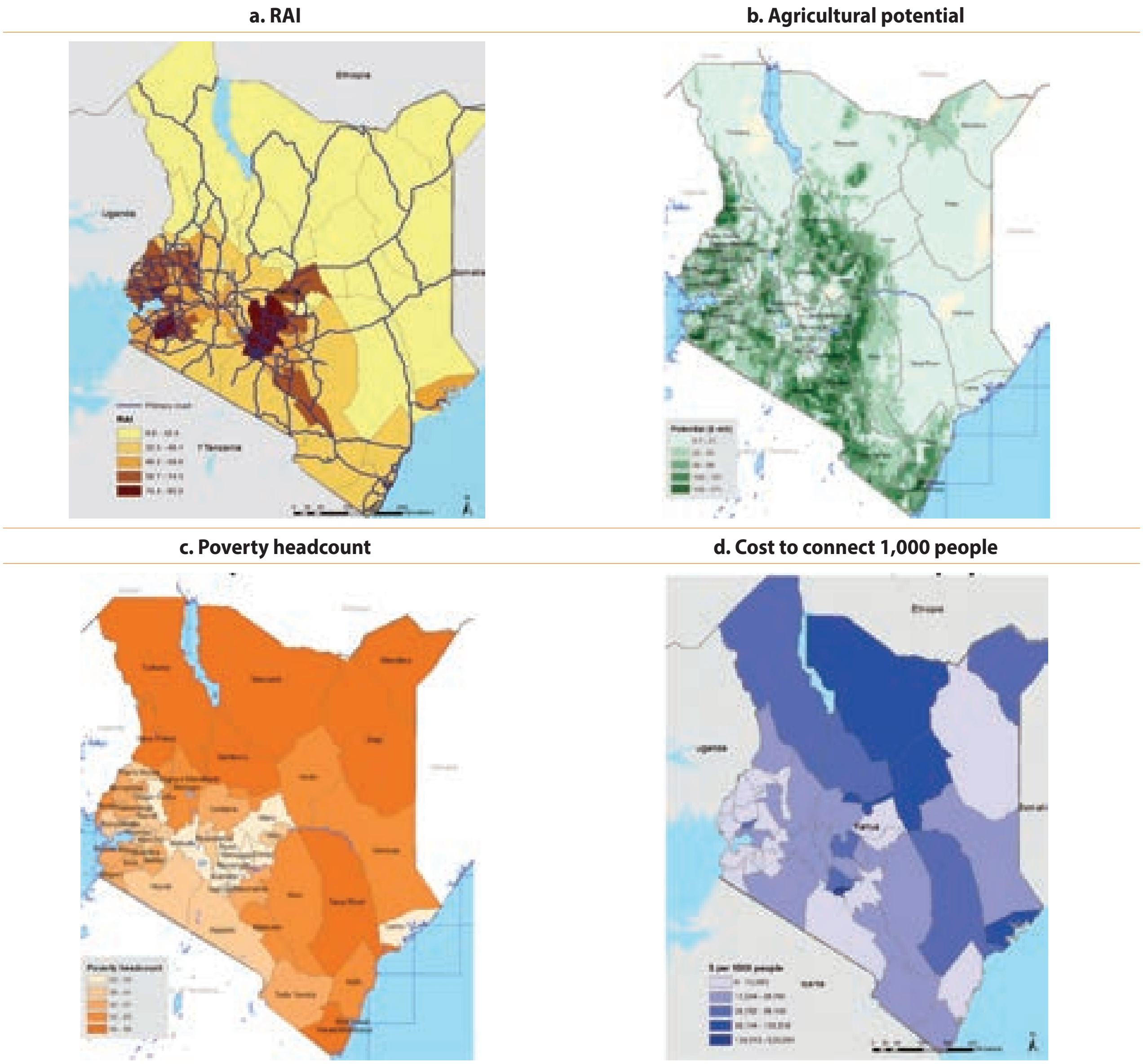
Prioritization Based on Measured RAI and Other Development Objectives

Spatial techniques and data are advantageous for analyzing different themes of data simultaneously and possibly discovering important links or complementarities. For instance, there is an ongoing discussion in Kenya and Mozambique on how to prioritize rural road investments, given the huge amount of unmet demand. Subnational RAI estimates can be used to show visibly where rural access is currently missing despite existing economic potential.

In the case of Kenya, crop production and livestock have been identified as important activities in rural ar-

[24] The following unit costs are assumed: US\$1 million per km for primary roads (Class A, B, and C) to be at least in good or fair condition; US\$300,000 for secondary roads (Class D and E) to be in good condition; and US\$75,000 for tertiary roads to be in good condition.

Map 20: Kenya: RAI, Agricultural Potential, Poverty, and Efficiency in Investment



Source: World Bank calculations.

eas. Global data on agro-climatic crop productivity are already available, such as the Agro-Ecological Zones database by the Food and Agriculture Organization and the International Institute for Applied Systems Analysis. Comparing agro-potential and rural access, there are several areas where potential exists with low accessibility, although they broadly coexist (map 20). The government may also be interested in addressing poverty. Many countries now have disaggregated poverty maps. In Kenya, rural accessibility is low where poverty is high. Thus, rural road investment focused on low-access areas is expected to contribute to poverty alleviation as well.

A challenge may emerge when potentially competing objectives are pursued. From the project administration point of view, it may make sense to ensure that a certain level of investment efficiency is achieved. For instance, one possible measurement is the estimated cost of connecting an additional 1,000 people, which mainly depends on the condition of roads, unit costs of road works, and population density along the roads that need to be rehabilitated or maintained. In the case of Kenya, the average costs per additional 1,000 people tend to be high where poverty rates are high. Thus, to address more poverty, more resources would be needed. Practically, a certain weight matrix needs to be agreed to balance different objectives and select project areas and road segments in an objective manner.

Climate Vulnerability and Adaptation

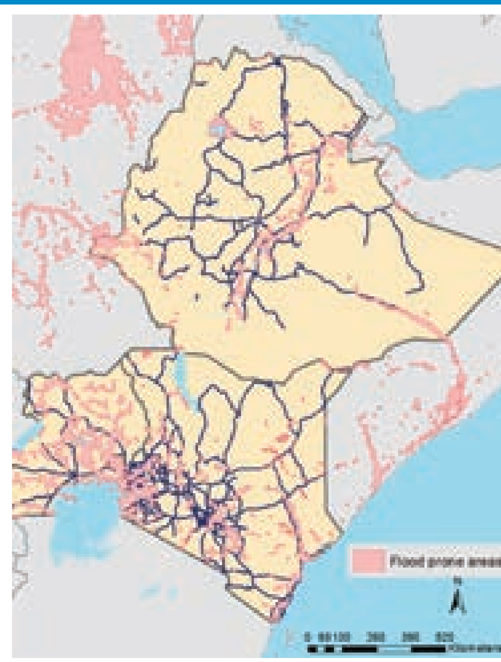
Rural roads are mostly unpaved and vulnerable to extreme climate events, such as floods. With heavy precipitation, road surface materials are easily washed away. For instance, Mozambique has experienced frequent catastrophic floods in recent years. The flood in 2000 was among the largest, causing significant loss of life, displacement of people, and destruction of social and economic infrastructure. Clearly, certain road links in Sofala and Zambezia provinces are exposed to higher risk of floods (map 21).

In Ethiopia, Kenya, and Uganda, there are also flood prone areas (map 22). In particular in Kenya and Uganda, about 22 to 23 percent of the total roads are in flood prone areas. In total, more than 71,000 km of roads are exposed to the risk of floods in the three countries. More than 85 percent of these roads are in poor condition (table 10). They are particularly vulnerable and need to be properly adapted to extreme climate events. Additional resources would be needed for adaptation purposes. To make the road network resilient, even more resources may be needed, possibly to develop some redundancy in the transport network. Further investigation can be done using the developed network data.

Map 21: Mozambique: Flood Prone Areas

Source: Mozambique National Road Administration.

Map 22: Eastern Africa: Flood Prone Areas



Source: IGAD 2013.

Table 10. Road Length in Flood Prone Areas

	Total length	Of which, roads within flood prone areas		Of which, roads in poor condition	
	km	km	% of total	km	%
Ethiopia	85,880	4,205	4.9	3,956	94.1
Kenya	160,886	35,268	21.9	30,082	85.3
Uganda	140,910	31,650	22.5	28,263	89.3

Source: World Bank calculations based on IGAD 2013 and road authorities' data.

6

MOVING FORWARD

From the experience during the pilot phase, four issues are of particular importance for moving forward and bringing the new RAI to the next level: scaling up, new technologies, platform and open data, and partnership with client governments.

Scaling Up

Given the increasing demand for RAIs in light of the SDGs, it is required to scale up the new RAI quickly to a much wider set of countries. Various efforts are needed at different levels. At the individual country level, the DFID and the World Bank are jointly preparing the second phase of the RAI exercise, which will apply the developed method to approximately 30 developing countries all over the world.[25] Still, this will cover only a small portion of developing countries. Every country is encouraged to calculate the RAI, whenever the necessary data are available. The technical guidance note on how to compute the RAI (annex I) will be useful to this end.

New Technologies

The largest challenge in the new RAI lies in collecting reliable and updated road quality data. A wide range of data are available, and new technologies are rapidly evolving. In principle, the RAI should be kept neutral on how to collect data. The RAI should adopt the most reliable and cost-effective technology in a country. At the moment, traditional road inventory surveys are practical and useful when a variety of road data on not only roughness but also the condition of structures are collected together. Smartphone applications, such as Roadroid and RoadLab, are also cost-effective for collecting roughness data quickly. Satellite imagery and UAV technologies have potential but are costly at the moment. DFID is currently supporting a study to examine the use of appropriate high-tech solutions, such as satellite imagery, for road network and condition analysis. Depending on the results, the RAI may be able to embrace more new technologies.

Platform and Open Data

It may be important to establish a common open platform for everyone to contribute, share, and use available road network data. This could help to maximize synergy across different sectors, while possibly bringing down the costs of data collection. For instance, the same satellite imagery can be used for multiple purposes. Any smartphone users can contribute to assessing the road condition while they are driving. If a platform to store and share the data is designed properly, there may be a possibility that the road network data could be updated collectively by road users. To consolidate all these data, a common platform, like OpenStreetMap and Google Earth, needs to be developed. Some global initiative may be needed. In addition, common standards for data quality also need to be prepared (such as what kinds of data are to be collected and how). Data quality assurance will be a key in collecting, consolidating, and managing big data.

[25] Candidate countries tentatively include the following: Burundi, Cameroon, Chad, Ghana, Liberia, Madagascar, Malawi, Nigeria, Rwanda, Sierra Leone, Afghanistan, Bhutan, India, Sri Lanka, Vietnam, Argentina, Bolivia, Colombia, Ecuador, Haiti, Honduras, Mexico, Nicaragua, Paraguay, Peru, Armenia, Azerbaijan, Georgia, Kyrgyz, Macedonia, Moldova, Tajikistan, and Morocco.

Partnership with Client Governments

Still, it is important to reiterate that collaboration with client governments, particularly road agencies, is necessary, although it may not be sufficient, because they own and use the relevant road network data. In particular, to ensure ownership and operational relevance of the RAI, it is required to work with client governments. Road agencies are generally keen about how to use their data to measure rural access, because it has a lot of policy implications. For instance, the RAI is often used as a core outcome indicator in road projects. Some countries, such as Ethiopia and Mozambique, have already developed their own ways to measure people's accessibility, which vary across countries. Given the new methodology, road agencies can improve their methods of data collection to meet the RAI requirements and examine the best way to increase the measured RAI. As in Mozambique and Zambia, reclassification of unofficial roads may have to be considered, which would likely bring up political and financial implications.

From the data point of view, an idea for governments is to publish their existing road network data or contribute them to global platforms, such as OpenStreetMap. This will depend on government policy on information disclosure. Publishing data generally helps to enhance citizens' engagement and improve transparency and governance, for instance, of road asset management in the current case. Publication of data may also help to facilitate the development of various applications and services based on the disclosed data.

7

CONCLUSION

There is no doubt that rural access is essential to achieve many of the SDGs and for inclusive growth and poverty reduction. In many developing countries, the vast majority of rural residents and local businesses are still disconnected from local, regional, or global markets. The SDGs call for reliable, sustainable, and resilient infrastructure for all. In this regard, the RAI established by Roberts, Shyam, and Rastogi (2006) is among the most important global development indicators.

In light of the requirements for sustainability, systematic updating, consistency across countries, and operational relevance, this report proposed a new way to measure the RAI using spatial data and techniques. High-resolution population distribution data—in this case, the WorldPop data—developed by the international research community provide sufficient information about where rural residents live. It is still an estimate. But the WorldPop data are reliable at 100 meter resolution. Overlaying digitized road network data, including road conditions, the RAI can be calculated virtually by spatial software, without counting households on the ground.

The new method is expected to be more sustainable and more consistent than the previous method, which was based on household surveys and modeling. The new method was found to be broadly robust using different data sets and definitions. In addition, the spatial technique allows estimation of the index at any disaggregated level (for example, districts or villages or even the project level). Thus, governments and road agencies can use the index in their operations, for example, for prioritization of feeder roads, and for monitoring the results from road investments.

The most difficult challenge in the new RAI calculation lies in collecting road condition data at the individual road segment level. Some data may exist but they are often fragmented in different formats, and often not georeferenced. However, it is always possible to collect the necessary condition data with reasonable accuracy, although at a cost. A wide variety of technologies are available, from traditional road inventory surveys to smartphone applications to assess road roughness while driving. Some technologies, such as high-resolution satellite imagery, are currently prohibitively costly but may have potential in the future. The developed method using existing spatial data and techniques is more cost-effective and sustainable than the previous RAI method based on household surveys. The proposed approach clearly motivates road agencies to collect and maintain road quality data, which are required to meet their existing operational needs anyway.

The new RAI estimates turned out somewhat different from those using the original methodology. This is because the method and data used are fundamentally different. All the indications are that there exists a significant infrastructure gap in rural access in developing countries, and enormous resources would be required to meet the gap. For Kenya alone, it is estimated that about US$2 billion would be required to rehabilitate and improve the entire road network, which would result in almost universal access. However, it was also found that universal rural road access is much more challenging in some countries, such as Mozambique and Zambia, where the current official road networks are narrowly defined. People live beyond the reach of the current official road networks. Significant efforts are likely to be required toward not only rehabilitating the current network, but also extending the network (possibly including reclassification of roads).

The new RAI method is designed to be a practical tool not only for rural road development, but also in a broader development context. Of course, it can be used for planning and monitoring rural road investments. In addition, it was shown that the new RAI is closely related to other development objectives, such as access to markets and access to schools and health services. Road accessibility is the most fundamental connectivity of people in rural areas. If people do not have good access to roads, they are also unlikely to have access to a market or social services. The RAI was also found to be relevant for agricultural growth and poverty reduction. Improved rural access is likely to contribute to bringing more market opportunities to farmers and rural residents and stimulating economic growth among local communities.

ANNEX I. QUICK REFERENCE: HOW TO COMPUTE THE RURAL ACCESS INDEX

Overview

This annex provides step-by-step guidance explaining how to compute the Rural Access Index (RAI) given available data. The following describes the simplest process to calculate a national RAI. It can be easily extended to more complex cases, for instance, to calculate subnational RAIs. The following explanation is provided based on particular geospatial software, ArcGIS. However, similar processes and techniques are often available in other software and geographic information system (GIS) applications.

The new proposed RAI method mainly requires three data sets: (i) population distribution, (ii) road network, and (iii) road condition (Figure AI.1). Another data set is required to define "rural areas," which is globally available and therefore should not be a matter of concern.

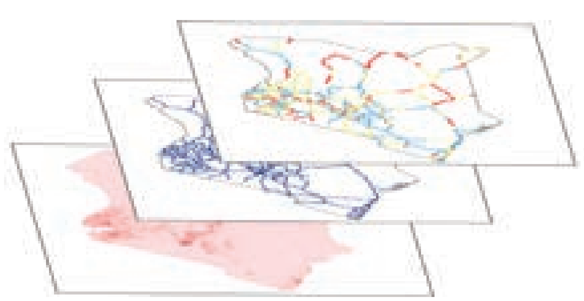
Compute the Total Rural Population

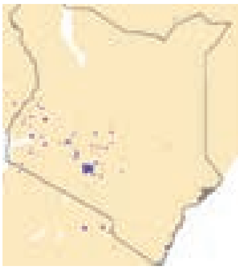
Step 1. Obtain spatial population distribution data. The WorldPop is among the best population distribution datasets. The WorldPop data are available at http://www.worldpop.org.uk/. For each country, there may be several population values for different years, primarily depending on the availability of census data. The data closest to the year of interest should be downloaded.

Step 2. Obtain urban extent data. The GRUMP data set provides a raster data of urban areas (section III.C),

Figure AI.1: Basic Methodological Framework

Population distribution	• Where do people live?
Road network	• Where are the roads?
Road condition	• Are they in good condition?





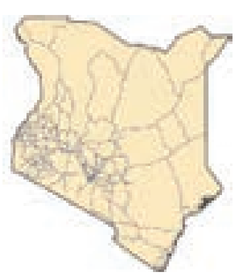
which can be downloaded from http://sedac.ciesin.columbia.edu/data/collection/grump-v1.

Step3. Convert the obtained urban extent data to the vector data GIS format, such as shapefile (.shp). The GRUMP data set is a raster consisting of a matrix of cells (pixels) of urban areas and needs to be converted to a polygon for convenience. To do this, a conversion tool from "Raster to Polygon" can be used.

Step 4. Prepare a polygon of rural areas. Given an administrative boundary data (for example, country X or district Y) in the GIS format, the urban areas defined above can be erased by using an Analysis Tool, "Erase."

Step 5. Compute the total rural population for each boundary (for example, country X or district Y). Overlaying the prepared polygon of rural areas and the population raster from step 1, the sum of the raster values, such as, population estimates in individual pixels, is calculated by using the Spatial Analyst Tool, "Zonal Statistics."

Compute the Rural Population That Has Access to the Good Road Network[26]



Step 6. Prepare road network data in the vector data GIS format. As discussed in section III.D, there may be more than one data set with different road extents. The more, the better. Although it is not necessarily required for the following RAI calculation, it is recommended to make sure that the data set is free of topographical errors, such as disconnected or duplicated features.

Step 7. Attach road condition measurements to the road network data, if not included yet. As discussed in section III.E, different measurements can be used, such as International Roughness Index (IRI) and visual assessment by class category (for example, excellent, good, fair, poor and very poor). Data can be imported by using the "Spatial Join" tool to join attributes of the features from another data set.

Step 8. Generate areas of 2-km buffers of the road network data. To do this, the "Buffer" geoprocessing tool can be used, by selecting only roads that are considered to be in "good condition" and setting the threshold at 2 km. All features may need to be dissolved to eliminate overlapped areas and not to double count the populations in those areas.

Step 9. Erase urban areas from the above 2 km buffer area. The same technique as in step 4 can be used. This provides a basis for calculating the rural population that lives within 2 km distance.

Step 10. Compute the total rural population within the buffer areas. Overlaying this 2 km buffer area (rural only) and the population raster from step 1, the sum of the raster values (population estimates in individual pixels) is calculated by using the Spatial Analyst Tool, "Zonal Statistics."

Step 11. Calculate the RAI. Finally, the RAI can be calculated by dividing the rural population within the buffer area (step 10) by the total rural population (step 5).

26 For illustration purposes, only the primary road network is shown in the maps.

ANNEX II. COMPARISON OF GLOBAL POPULATION DISTRIBUTION DATA

Overview

A globally developed geospatial population distribution map allows for an international comparison of national populations that relies not only on varying national census definitions, but also on population counts and density measurements of individual urban agglomerations irrespective of administrative boundaries. In recent years, multiple population distribution data have been produced in the international research community, all of which are tied to census data and the underlying global administrative units. There are four gridded population products with global coverage: (i) WorldPop, (ii) Gridded Population of the World (GPW), (iii) Global Rural-Urban Mapping Project (GRUMP), and (iv) LandScan. GPW is simply a rasterized census map, GRUMP adds a rural-urban distinction in the disaggregation process, whereas LandScan and WorldPop use modeling based on a wide range of input layers and spatial covariates. The following subsections describe the main characteristics of the potential data sets, summarized in BoxAII.1.

WorldPop

The WorldPop product—while not yet available for all regions of the world—is considered to be the best for the needs of this initiative for several reasons. It has the highest resolution (100 meters), is continuously updated as better input data become available, and unlike LandScan is free and publicly accessible with a transparent, replicable methodology. The WorldPop project was initiated in October 2013 to combine the AfriPop, AsiaPop, and AmeriPop population mapping projects.

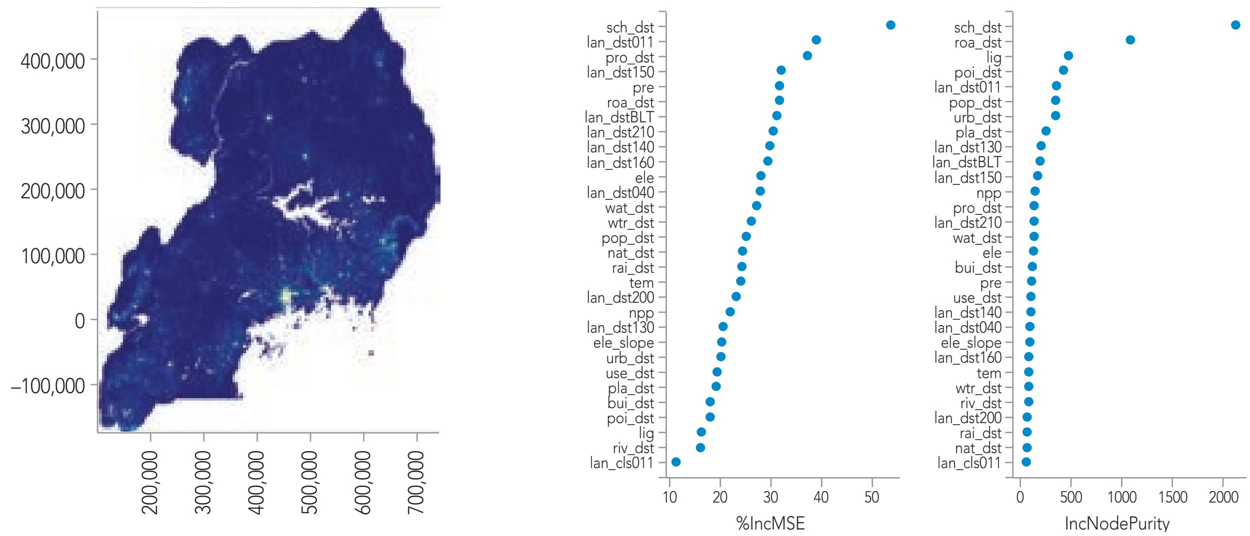
One of the initial purposes of creating a high-resolution mapping in Africa (originally AfriPop) was to better understand the spatial distribution of people in rural areas. The WorldPop method of distribution builds on previous work undertaken in East Africa to provide the most accurate and the highest resolution product.[27]

In addition to high-resolution spatial distribution of the population, WorldPop also provides other spatially distributed data sets, such as births and pregnancies. WorldPop is constantly updated when new data becomes available, and therefore offers current, past, and projected population estimates. Table AII.1 presents the data sets currently available for download in the pilot countries.

WorldPop has traditionally used detailed mapping of settlements in combination with local high-resolution census data. The model utilized by WorldPop, Random Forest Classification and Regression, utilizes a machine learning approach that is robust to outliers and noise. In addition to a set of standard inputs into the model, WorldPop uses additional input data that vary from country to country based on availability, refining the resulting country maps. The process utilizes various spatial inputs (such as nighttime lights, earth observation data, and land cover, among others) to distribute population census data from larger units. The model also provides

[27] Tatem et al. (2007); Linard et al. (2010); Linard, Gilbert, and Tatem (2010).

Figure AII.1: WorldPop Sample Dataset



Source: Gwilliam 2011.
Note: South Africa and Nigeria are excluded for presentation purposes.
The former has 364,000 km of roads, and the latter has 158,000 km of roads.

useful internal estimates of error, strength, correlation, and variable importance; has built-in cross-validation; and is easily parallelized.

This process is repeated for every country using the most detailed information available. However, this results in a trade-off between accuracy at the country level and uniformity at the global level. The final distribution contains a metadata file with information about the inputs to the model and the weighting importance of this file.

The utilization of various inputs creates the most accurate product; however, it should be noted that as rural accessibility is calculated, there might be some correlation between roads and the distribution of the population, as this is one of the inputs utilized for the disaggregation. However, roads are simply one of many inputs that are included in the distribution; and the importance of the input can be validated using the available metadata. The example below shows the output, input, and weighing for the distribution of population in Uganda. As seen from this example (which is similar to the output of other countries), roads is one of various inputs and is not weighted heavily in the distribution of population.

Gridded Population of the World

The GPW is another open access database created by the Center for International Earth Science Information Network (CIESN) at Columbia University. The forthcoming version 4 release will provide data at 1 kilometer (km) resolution (version 3 currently has 5 km resolution) globally. The GPW gridded (raster) data product was developed to provide a spatially disaggregated population layer that

Map AII.1: Gridded Population of the World Database Example

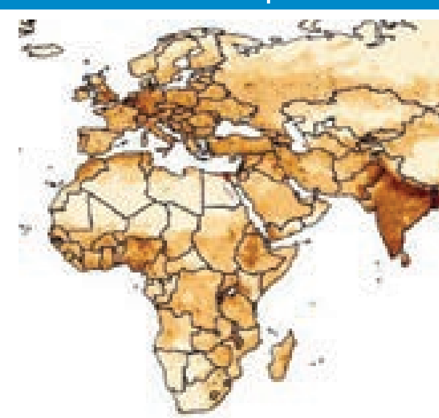


Table AII.1. Summary of Gridded Population of the World, Versions 1–4

	GPWv1	GPWv2	GPWv3	GPWv4
Publication Year	1995	2000	2005	2014/2015
Years of Estimation	1994	1990, 1995	1990, 1995, 2000	2000, 2005, 2010, 2015, 2020
Number of Input Units (subnational geographic units)	19,000	127,000	c. 400,000	> 13,000,000
Grid Resolution	2.5 arc-minute	2.5 arc-minute	2.5 arc-minute	30 arc-second (1 km)
Census variables	Total Population	Total Population	Total Population	Total Population, Sex, Age, Urban/Rural status

is compatible with data sets from the social, economic, and Earth science fields. GPW is a minimally modeled product; it does not incorporate ancillary data (although it appears that version 4 will include some ancillary data) and uniformly distributed population based on land area. Therefore, the accuracy of the GPW product is directly related to the original size of the administrative unit of the census, which is usually large in the study areas.

GPW was originally created in 1995, and has been updating and improving its distribution since then. The forthcoming version 4 will be a big improvement on previous versions, as it begins to include some ancillary data and provides a higher resolution. However, this version is not currently available. The use of a uniform algorithm makes GPW highly dependent on the original size of the administrative unit. In rural areas, where the Rural Access Index (RAI) will be measured, administrative units will most likely be quite large, making the GPW inaccurate. Furthermore, GPW only releases information on population in global versions (unlike WorldPop, which is constantly updating with the best data available) and therefore it would be difficult to do RAI monitoring with GPW.

Global Rural-Urban Mapping Project and United Nations Environment Programme

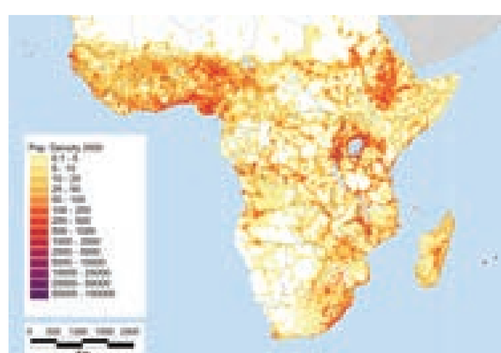
The last two open products are the GRUMP and the United Nations Environment Programme (UNEP) Global Population Database, GRID.

GRUMP was also created by CIESEN, and consists of eight global data sets: population count grids, population density grids, urban settlement points, urban-extents grids, land/geographic unit area grids, national boundaries, national identifier grids, and coastlines. GRUMP does not produce its own population database, rather it utiliz-

Map AII.2: Global Rural-Urban Mapping Project and Global Population Database Examples

Global Rural-Urban Mapping Project (GRUMP)

United Nations Environment Programme, Global Population Database (GRID)



Box AII.1. Techniques to Disaggregate Population

Areal weighting assumes that the population is uniformly distributed within each administrative unit. The population assigned to a grid cell is simply the total population of the administrative unit divided by the number of cells in the administrative unit. Every grid cell of an administrative unit has therefore the same population value. This method was used to construct the Gridded Population of the World (GPW) database, versions 2 and 3.

Pycnophylactic interpolation starts with the areal weighted method, but smoothes the population values using the weighted average of nearest neighbors, while preserving the summation of population data to the original population per areal unit. Pycnophylactic interpolation was used to generate GPW version 1.

Dasymetric modeling involves using ancillary data—often this may include satellite derived land cover data—to redistribute populations within administrative units. Weightings are attributed to the different land cover classes and the population is redistributed accordingly. For example, the Global Rural Urban Mapping Project uses a similar approach to GPW, but incorporates urban-rural extents and their corresponding populations in the spatial reallocation of census counts.

Smart interpolation, a more sophisticated modeling approach, involves modeling the finescale distribution of populations using a range of satellite and other ancillary data. For example, an accessibility surface developed from road networks and populated places can be used to redistribute people, as was done in the construction of the Unite Nations Environment Programme database. The LandScan data set is another example of smart interpolation, where various ancillary data such as roads, slope, land cover, and nighttime lights are used to determine the probability of population occurrence in cells.

es GPWv3 (details in the previous section) and includes the ancillary data of urban and non-urban areas (based on local definitions) to provide improved estimates. The limitations of the use of GRUMP are the same as those of the GPW. Furthermore, the latest update to the GRUMP was in 2005 (with 1990, 1995, and 2000 data), and it utilizes local definitions of urban and non-urban areas.

The last open product is the UNEP GRID. The spatial resolution of this product is 5 km, and it has reproducible methods and inputs. However, the data have not been updated since 2000, and there are no plans to update it in the future. Therefore, it is not a feasible option for this project.

LandScan

Finally, LandScan also provides a high-resolution mapping, which is consistently updated. Like the WorldPop product, LandScan utilizes input data other than population as weights to determine the geospatial distribution of the population. Unlike WorldPop, however, LandScan does not disclose the detailed method with which it does the distribution, the inputs that were used to create the product, their importance in the distribution, or any indicator of accuracy. Furthermore, the data are not freely available. Furthermore, a clause in the LandScan database indicates that the product should not be used to detect change over time. Although the explanation for this is that the "input data sets are constantly improving which in turn cause changes in the population distribution" (LandScan). However, without further understanding of the algorithm or the impact of changes over time, the degree of these improvements is unknown. The lack of temporal comparability, undisclosed method and inputs, as well as cost of LandScan make this not an adequate product for this project.

ANNEX III. COUNTRY NOTES

Bangladesh

Overview of the Road Network

According to the two principal road databases in Bangladesh, the Roads and Highways Department and the Local Government Engineering Department, there are 325,681 km of classified roads in Bangladesh. While the former is responsible for 21,302 km of primary roads, the latter is managing 304,379 km of feeder roads. Based on the government road data, about 269,000 km or 83 percent of the total roads are georeferenced. Classified road density is very high, at more than 200 km per 100 km^2 of land, favorably compared with even high-income countries. Most of the primary network is paved and in good condition. About one-third of feeder roads are paved, and the rest are mostly earth roads.

Classification and Standards

The Roads and Highways Department is responsible for the major road and bridge network of Bangladesh. It currently supervises just over 21,302 km, 8,000 of which are national and regional highways and the rest district roads. The remaining subdistrict, union, and village roads are under the management of the Local Government Engineering Department (LGED), comprising more than 300,000 km.

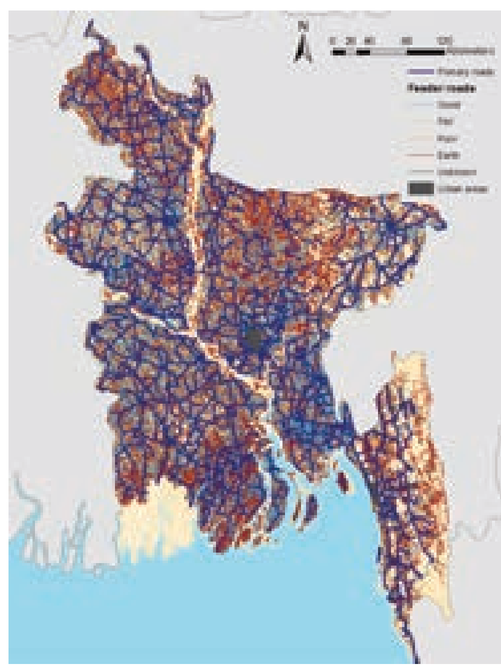
Data Issues and Assumptions

Road location and quality data for the Roads and Highways Department and LGED maintained roads were obtained from LGED. Road location data are available for about 269,000 km, with extremely dense coverage across the country. Road quality is in principle

Basic data

Population[a]	159 million	(2014)
Land area[a]	130,170 km^2	(2014)
Population density[a]	1,222 per km^2	(2014)
Length of road[b]	325,681 km	(2011)
Paved road (%)[b]	32.1%	(2015)
Length of road (GIS)[c]	269,127 km	(2015)
Of which, "Good quality road"	53,316 km	(2015)
Of which, road quality data are missing	135,704 km	(2015)
RAI[c]	86.7%	(2015)

[a] World Development Indicators
[b] Roads & Highways Department; Local Government Engineering Department
[c] World Bank estimates based on government data



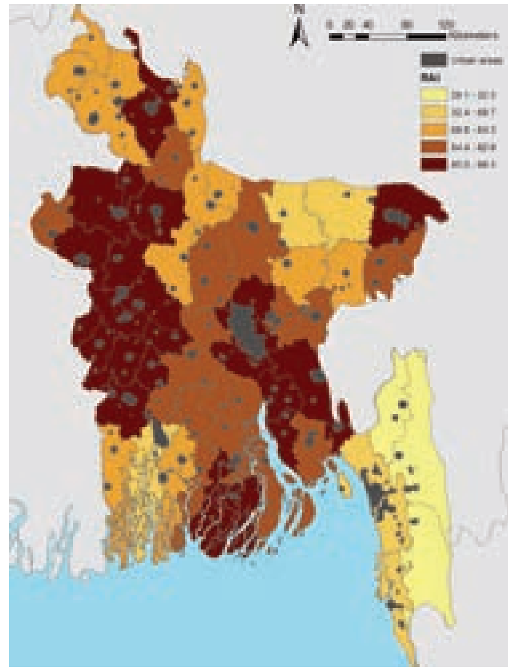
available for most of the paved road network with the International Roughness Index (IRI). However, there are several duplicated data entries and contradictory information in the currently available data. Most of the duplications were corrected, but road condition information may still be incorrect. The corrected data are being clarified with LGED.

For unpaved roads, there is no quality data. There are more than 135,000 km of unpaved roads in the available georeferenced road data (c.f., 220,000 km of unpaved roads according to the government road statistics). These roads are not taken into account in the RAI calculation. Notably, however, since density of the road network with roughness data is already high, a significant portion of the country's land area is covered regardless of the unpaved road network.

Using a distribution based on WorldPop (2010 edition), urban areas are excluded based on 1995 University of Columbia (Center for International Earth Science Information Network, CIESIN) urban area imagery, and rural population for 2015 is calculated at 119.7 million.

Estimated Rural Access Index

The national RAI is estimated at as high as 86.8 percent, leaving about 16 million rural residents unconnected.



The high RAI is largely attributed to the country's extremely high population density and road density. The estimated RAI is systematically relatively low in the southern part of Chittagong Division.

Nepal

Basic data

Population[a]	28.2 million	(2014)
Land area[a]	143,350 km^2	(2014)
Population density[a]	197 per km^2	(2014)
Length of road[b]	13,358 km	(2014)
Paved road (%)[c]	17.8%	(2007)
Length of road (GIS)[c]	77,818 km	(2015)
Of which, roads in "good" condition	18,248km	(2015)
Of which, road quality data are missing	8,140 km	(2015)
RAI[c]	54.2%	(2015)

[a] World Development Indicators
[b] Department of Roads, Nepal
[c] World Bank estimates based on government data

Overview of the Road Network

According to the Nepal Department of Roads, there are 13,358 km of classified Strategic Road Network (SRN) roads in the country, with about 64,000 km of additional local roads. Classified road density is relatively low by regional standards, at 9.3 km per 100 km^2 of land. Especially in the Hill region, roads are less limited, in line with the country's population concentration in the Terai region, in the southern band of the country. Most roads lie along Nepal's southern border with India. In the more rugged northern sections, lack of road infrastructure and poor quality greatly impede the delivery of goods and services.

Classification and Standards

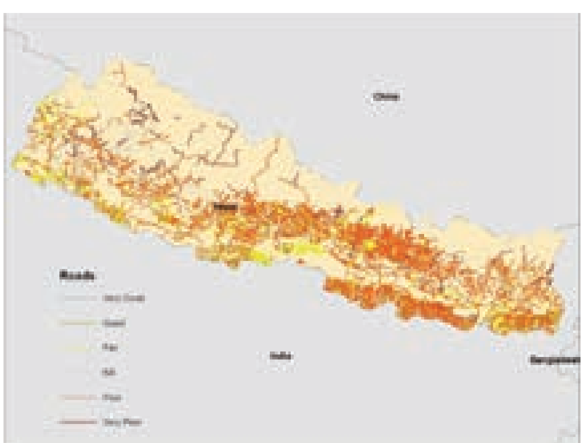
The Department of Roads is responsible for maintaining the SRN. Data on the SRN are published on a bi-annual basis by the department, including geographic information system (GIS) mapping and road quality using IRI.

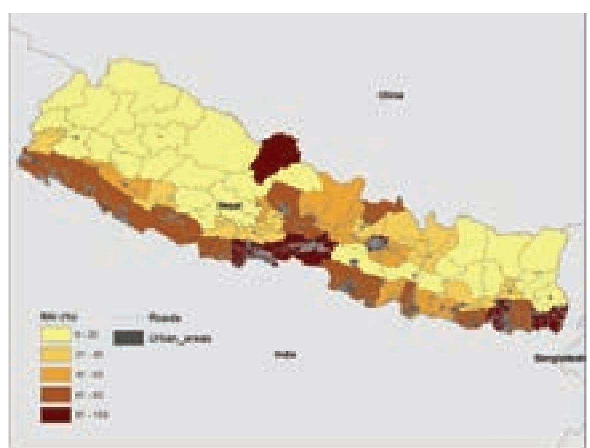
However, local roads are managed and maintained by the local district governments, outside the control or oversight of the central Department of Roads. The Local Road Network (LRN) is prepared during the course of district level operations through development and execution of District Transport Master Plans. LRN data are not collected centrally, and road condition IRI data are not uniformly available, with visual quality assessment being used where it is the only feasible manner for determining road quality.

Data Issues and Assumptions

SRN road data, updated in 2015 are available on an open basis through the Department of Roads' Annual Road Maintenance Program. The SRN data were only updated to a limited extent to account for ongoing construction. SRN roads have IRI values associated, for which a value of 6 or less was used, along international standards.

Because of the lack of preexisting consolidated LRN data at the country level, district governments were visited to collect current road data, and gaps in the road quality data were filled through spot assessments. In many of the districts, formal IRI values are not available. As such,





visual road quality ratings were used to calculate the IRI. Where this was the case, paved or gravel roads with ratings of very good, good, and fair were assumed to meet the criteria for being all-season roads. On earth roads only very good and good ratings were used.

Using a distribution based on WorldPop (2015 edition), urban areas are excluded based on 1995 University of Columbia (CIESIN) urban area imagery, and rural population in 2015 is calculated at 22.5 million.

Estimated Rural Access Index

The national RAI is estimated at 54.2 percent, leaving about 10.3 million rural residents unconnected to roads in good or fair condition.

Connectivity is the highest along the southern lowlands, where road density and population density are the highest. In several districts, the RAI is greater than 80 percent.

In the northern portions of the country, mountainous terrain, coupled with lower road density and poor road quality, leaves large portions of the population disconnected. There is no connectivity at all in some districts.

Ethiopia

Basic data

Population[a]	97.0 million	(2014)
Land area[a]	1,000,000 km^2	(2014)
Population density[a]	97.0 per km^2	(2014)
Length of road[b]	99,522 km	(2015)
Paved road (%)[b]	17.0%	(2015)
Length of road (GIS)[c]	85,880 km	(2015)
Of which, roads in "good" condition	26,700 km	(2015)
Of which, road quality data are missing	38,284 km	(2015)
RAI[c]	21.6%	(2015)

[a] World Development Indicators
[b] Ethiopia Roads Authority
[c] World Bank estimates based on government data

Overview of the Road Network

According to the existing government statistics, Ethiopia's road network is composed of 99,522 km of roads, of which 12,640 km or about 17 percent are paved. Road density is estimated at 10.0 km per 100 km^2, which is the same level as Tanzania (9.8) but compares unfavorably with Kenya (28.4). Although paved roads are generally maintained in good condition, the quality of unpaved roads has long been a challenge. To address this, the Government of Ethiopia embarked on the Universal Rural Road Access Program in 2010, which aims at connecting all communities (*kebeles*) by all-weather roads and providing year-round connectivity.

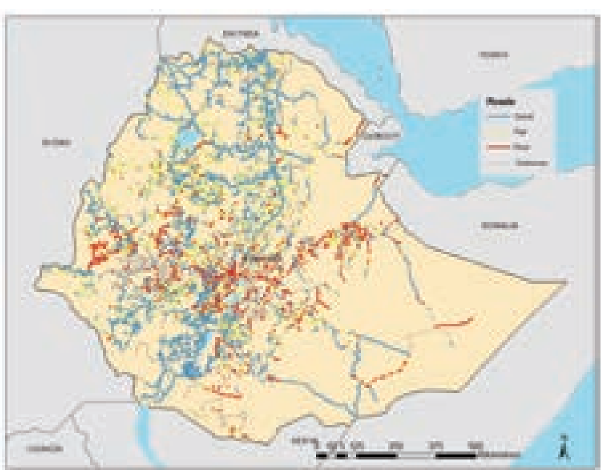
Classification and Standards

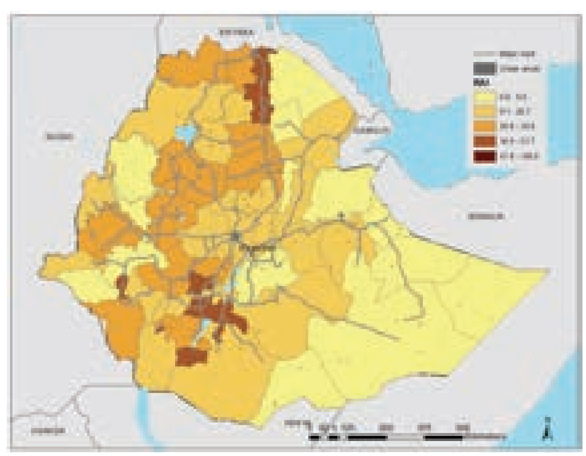
Ethiopia's road network comprises about 26,000 km of federal roads, half of which are paved; 32,000 km of regional roads; and 46,000 km of district (*wareda*) roads. The Ethiopia Roads Authority is responsible for developing and maintaining federal roads, which are generally well maintained. Regional and district roads are managed primarily by subnational governments and generally unpaved and in poor condition.

By functionality, federal roads are classified into five categories: trunk roads (Class A) connect Addis Ababa to centers of international importance and international boundaries and amount to about 6,080 km. Annual average daily traffic (AADT) normally exceed 1,000 vehicles. Link roads (Class B) extend 5,600 km, connecting major cities and urban centers with each other, and carry a typical AADT of 400 to 1,000. Main access roads (Class C, 4,920 km) connect regional centers, and AADTs vary from 30 to 1,000. Collector roads (Class D, 2,250 km) connect other locally important centers, with AADT of 25 to 400. Feeder roads (Class E) are minor roads with less than 100 AADT, which amount to 2,260 km.

Data Issues and Assumptions

In 2015, the Government of Ethiopia carried out a first-ever comprehensive road inventory and quality survey, based on which the road network that was able to be mapped, about 85,880 km of roads. The survey data remain to be finalized. Using the preliminary data, road conditions are assessed based on four road distress





measurements: potholes, rutting, corrugation, and road camber. For each aspect, two ratings are available for severity and extent. Following conventional formulae elsewhere, the overall index is calculated by adding the two ratings for each and taking an average of the four measurements:

$$\text{Overall} = ((Poth_S + Poth_E) + (Rut_S + Rut_E) + (Cor_S + Cor_E) + (Cam_S + Cam_E))/4$$

The road condition is considered as good if the overall index is less than 3. When the index is greater than 3 but less than 5, the condition is classified as fair. The rest of roads are in poor condition. The RAI takes into account paved roads in good and fair condition, and unpaved roads in good condition. About 29 percent of the total network is in good condition, 23 percent in fair condition, and 11 percent in poor condition. The road condition data are still under preparation for the rest (that is, 31,000 km).

Using the WorldPop data (2010 edition), the rural population in 2015 is estimated at 81.3 million with urban areas excluded. Urban areas are defined based on the 1995 University of Columbia (CIESIN) urban area imagery.

Estimated Rural Access Index

The national RAI is estimated at 21.6 percent, leaving about 63 million rural residents unconnected to roads in good or fair condition. Although the RAI is relatively high in the Southern Nations, Nationalities, and Peoples' and Tigray regions, it is less than 10 percent in Somali Region.

Kenya

Basic data

Population[a]	45.5 million	(2014)
Land area[a]	569,140 km^2	(2014)
Population density[a]	80 per km^2	(2014)
Length of road[b]	161,451 km	(2015)
Paved road (%)[b]	6.9%	(2015)
Length of road (GIS)[c]	160,886 km	(2009)
Of which, roads in "good" condition	22,684 km	(2009)
Of which, road quality data are missing	19 km	(2009)
RAI[c]	56.0%	(2009)

[a] World Development Indicators
[b] Kenya Roads Board
[c] World Bank estimates based on government data

Overview of the Road Network

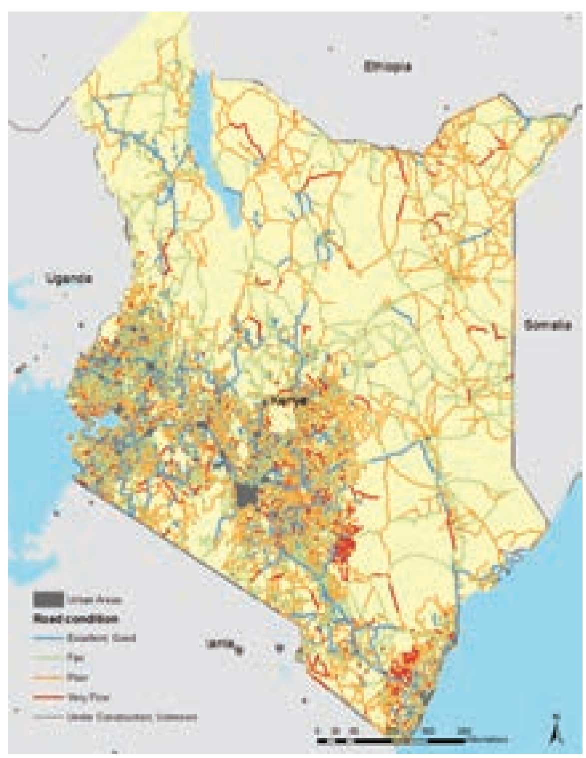
According to the government statistics, Kenya has a road network comprised of 161,451 km of roads. Based on this, road density is as high as 28.4 km per 100 km^2 of land, which is near the regional average, and compares favorably with some of the neighboring countries (9.8 in Tanzania) and less so with others (70 in Uganda). Generally, the length and coverage of the official road network is sufficient to provide basic regional and national connectivity. Still, only about 11,200 km or 6.9 percent of the total roads are paved. Paved roads are mostly in good or fair condition. But road maintenance remains a challenge in many areas, with 25 percent of secondary roads and 40 percent of tertiary roads in poor condition.

Classification and Standards

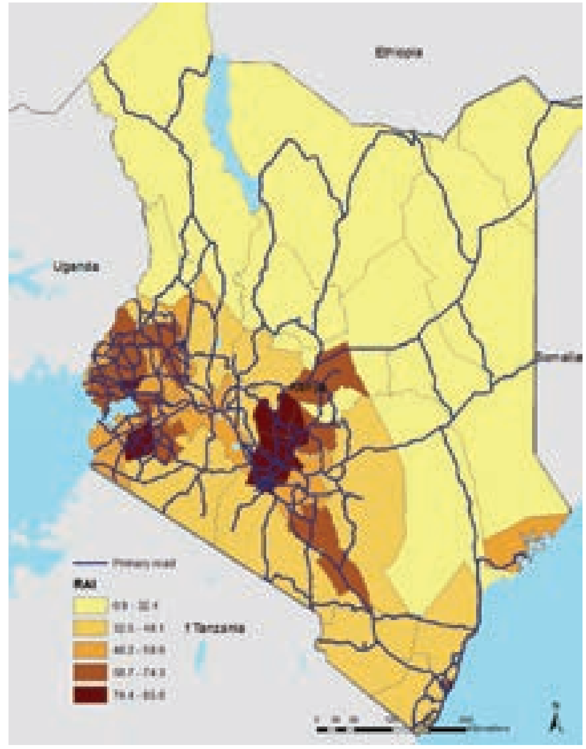
According to the Kenya Roads Act of 2007, there are three national institutions: the Kenya National Highways Authority is responsible for international and national trunk roads, as well as the primary roads (Classes A, B, and C, respectively); Kenya Rural Roads Authority is responsible for secondary and minor roads (Classes D and E) and other roads; and the Kenya Urban Roads Authority is responsible for urban roads. Kenya's 2010 constitutional devolution delineates roads as either national or county. While the national government is responsible for Class A, B, and C roads, county governments handle Class D and E and unclassified roads.

Regional, trunk, and primary roads connect major towns and ports and are mostly in good condition. As the population is located primarily along the Mombasa-Kisumu corridor, much of the country's road network follows a similar path, with density much lower in the sparsely populated north. In the northern and eastern provinces, roads are limited and mostly in poor condition.

Kenya's national road database is extremely detailed, with about 160,000 km of classified and unclassified roads included. Surface type and road classification are included. The road condition data are collected based on visual assessment by engineers. Paved and unpaved roads are categorized into five conditions: excellent, good, fair, poor, and very bad, depending on certain physical parameters, such as cracks and potholes for paved roads, and culvert and drainage condition for unpaved roads.



The last available road condition data are from 2009. As per this data, about 18,094 km of roads or about 11.2 percent of total roads are considered in excellent or good condition, 52,026 km or 32.3 percent in fair condition, and the rest in poor or very bad condition.



Data Issues and Assumptions

Using a distribution based on WorldPop (2010 edition), urban areas are excluded based on 1995 University of Columbia (CIESIN) urban area imagery, and the rural population in 2010 is calculated at 30.3 million. While RAI can be calculated at the more granular district level, it is estimated at the county level, which is informative enough in the case of Kenya. Current district boundaries are still in flux.

Estimated Rural Access Index

The national RAI is estimated at 56.8 percent, leaving about 13.4 million rural residents unconnected to roads in good or reasonably fair condition.

The RAI was found to be generally high around Nairobi and Lake Victoria, where populations are concentrated. It is highest, at 96 percent, in Vihiga County, followed by Kirinyaga (86 percent), and Kiambu (83 percent). As would be expected, the rural areas score well around large urban areas, such as Mombasa and Nairobi (88 and 82 percent, respectively). By contrast, the RAI is low in the north (and especially northeast) counties, with Garissa, Madera, and Wajir Counties all below 10 percent.

Mozambique

Basic data

Population[a]	26.4 million	(2014)
Land area[a]	786,380 km^2	(2014)
Population density[a]	34 per km^2	(2014)
Length of road[b]	30,464 km	(2015)
Paved road (%)[b]	24.1%	(2015)
Length of available data (GIS)[c]	29,363 km	(2010)
Of which, roads in "good" condition	19,132 km	(2010)
Of which, road quality data are missing	736 km	(2010)
RAI[c]	20.4%	(2010)

[a] World Development Indicators
[b] National Administration of Roads (ANE), Mozambique
[c] World Bank estimates based on government data

Overview of the Road Network

According to the government statistics, Mozambique has a road network of 30,464 km of classified roads, of which 7,355 km or about 24 percent are paved. Classified road density is 3.9 km per 100 km^2 of land, which is much lower than the regional average and some of the neighboring countries (28 km in Kenya and 9.8 km in Tanzania). Paved roads are mostly in good and fair condition. But concern remains about the road quality of non-primary roads, particularly unpaved roads. The government report indicates that about 64 percent of paved roads and 26 percent of unpaved roads are in good or fair condition. In total, about 26 percent of the road network is in poor condition, and 4 percent is inaccessible.

Classification and Standards

In Mozambique, the road network is classified into primary, secondary, tertiary, and vicinal roads based on a new road classification system, Decree 50/2000, dated December 21, 2000. Primary roads are mostly paved and connect provincial capitals and main ports. Secondary roads, composed of some 40 road links, connect primary roads and important ports, border posts and economic poles. One-third of these are paved. The rest are classified as tertiary or vicinal roads, most of which are unpaved, connecting district centers and villages.

Mozambique's road management system includes a variety of road structure and condition parameters. The IRI is only available for primary roads and several other road links. The quality of roads is mainly managed by the Segment Condition Index,[28] which is a weighted average score of three dimensions:

$$SegmentConditionIndex = 0.4SCI + 0.3LDCI + 0.3TDCI$$

where *SCI* is the Surface Condition Index, which represents the share of road surface that does not have any defect; *LDCI* is the Longitudinal Drainage Condition Index, which is the average score of longitudinal drainage structure and functionality of gutters, ditches, and canals that exist along a road segment; and *TDCI* is the Transversal Drainage Condition Index of culverts and channels.

The last available road condition data that are georeferenced are for 2010. Based on the SCI, about 16 percent

[28] ANE "IRMS Conceptual Manual: Condition Index Calculation".

of the roads are considered in good condition, 56 percent in fair condition, and 28 percent in poor condition.

Data Issues and Assumptions

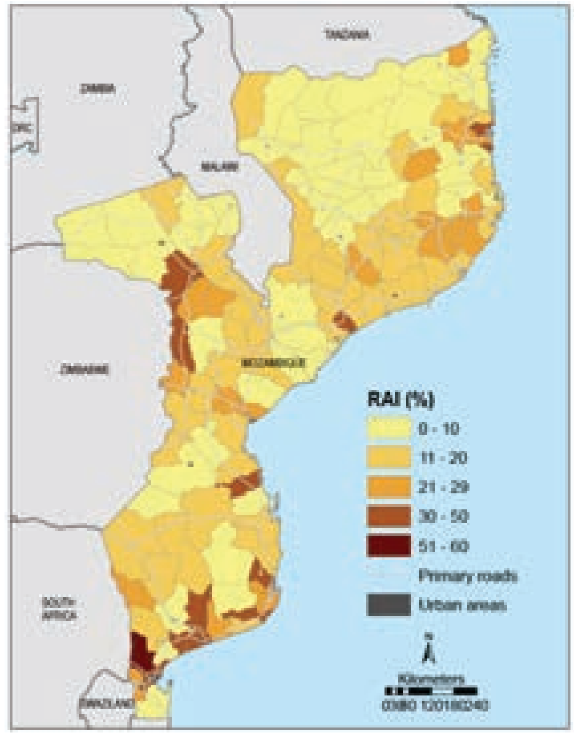
Using the IRI and SCI, 18,296 km of roads are considered to be in good or fair condition. There are about 2,700 km of roads for which no quality data are available. These are likely to be the segments that were not passable during the last road quality survey. Their road condition is assumed to be poor.

Using a distribution based on WorldPop (2010 edition), urban areas are excluded based on 1995 University of Columbia (CIESIN) urban area imagery, and the rural population in 2010 is calculated at about 18.8 million.

Estimated Rural Access Index

The national RAI is estimated at 20.4 percent, leaving about 15.0 million rural residents unconnected to the road network in good or fair condition.

The RAI is calculated at the district level, which is generally high in the south, especially, in Maputo Province, especially in Moamba District (49 percent), Maputo District (46 percent), and Manhiça District (45 percent).



In more than 75 percent of the districts, however, the RAI is estimated at under 25 percent, with lower than 10 percent rural accessibility in many districts.

Tanzania

Basic data

Population[a]	51.8 million	(2014)
Land area[a]	885,800 km^2	(2014)
Population density[a]	59 per km^2	(2014)
Length of road[b]	86,472 km	(2012)
Paved road (%)[a]	31.2%	(2012)
Length of road (GIS)[c]	94,039 km	(2008, 2014)
Of which, roads in "good" condition	16,911 km	(2008, 2014)
Of which, road quality data are missing	34,564 km	(2008, 2014)
RAI[c]	24.6%	(2008, 2014)

[a] World Development Indicators
[b] Government of Tanzania
[c] World Bank estimates based on government data

Overview of the Road Network

According to the Tanzania National Roads Agency (TANROADS), established in 2000 to maintain and develop the trunk and regional road network of the Tanzanian mainland, the total length of the classified road network is 86,472 km. Classified road density translates into 9.8 km per 100 km^2 of land, which compares favorably with Mozambique (3.9) and Zambia (5.4), but less so with East African neighbors like Kenya (28) and Uganda (70). Although the data remain fragmented, it was reported in the World Development Indicators that 31.2 percent of the total classified road network was paved. With the latest available data complied, at least about 12,030 km are paved, of which 55 percent is maintained in good or fair condition. Most of the country's rural roads remain unpaved, and the vast majority of these, nearly 90 percent, are estimated to be in poor or very poor condition.

Classification and Standards

TANROADS, under the Ministry of Works, was established by the Executive Agencies Act. TANROADS manages 33,891 km of the classified roads network, with the remaining 53,460 km of urban, district, and feeder roads managed by the Prime Minister's Office—Regional Administration and Local Government (PMO-RALG). Trunk roads provide primary connectivity between major towns and cities, while regional roads provide links with district centers. The Government of Tanzania has prioritized improvement of the road network in its recent infrastructure development budgets; however, with the majority of investment going toward upgrading and maintenance of the trunk network, regional and local roads have remained largely of poor quality.

Data Issues and Assumptions

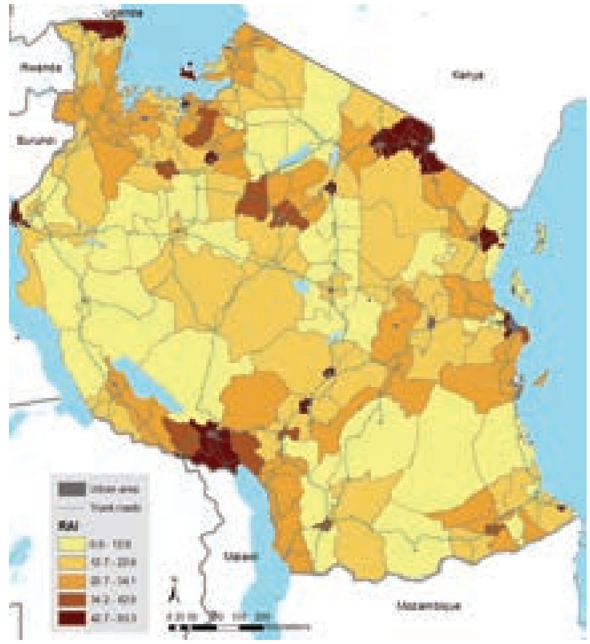
Road quality data in Tanzania are housed individually by TANROADS and PMO-RALG, for their respective managed networks. Covering major links between towns and district centers, TANROADS data are largely available with associated IRI values and were updated in 2014. PMO-RALG data are an aggregation of data collected and managed by local governments in 2008, and available as a function of road surface type (earth, gravel, or paved) and quality rating (good, fair, or poor), listed by district and road end points. Because of the lack of road names in many cases, associating PMO-hosted road quality with TANROADS-hosted road location data can prove a challenge. Some of the PMO data are unidentifiable in the combined GIS data set. To expand on identified and tracked roads with PMO quality data, efforts are underway in Tanzania to utilize satellite and open source data to expand on formal GIS road location data sets.

Using a distribution based on WorldPop for 2015, urban areas are excluded based on 1995 University of Columbia (CIESIN) urban area imagery, and the rural population in 2015 is calculated at about 43 million.

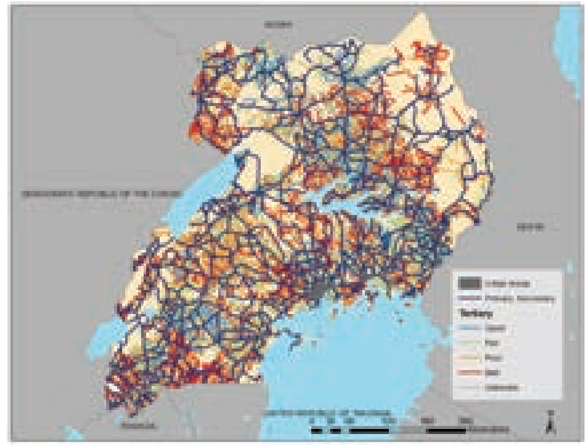
Estimated Rural Access Index

The national RAI is estimated at 24.6 percent, leaving about 33 million rural residents unconnected to roads in good or fair condition. Although road maintenance remains a challenge and impediment to improving access, the classified road network itself will need to be expanded. Assuming good quality of all classified roads only improves the hypothetical RAI up to 52.4 percent, still leaving more than 20.7 million people without 2 km access to a road of any quality.

The RAI was found to be generally highest in the districts around Mt. Kilimanjaro, Dar es Salaam, and Mbeya, averaging above 50 percent in these areas. Although access remains poor in much of the rest of the country, districts in the center and west of the country are the most disconnected, with RAI estimates below 10 percent in many areas.



Uganda



Basic data

Population[a]	37.8 million	(2014)
Land area[a]	199,810 km^2	(2014)
Population density[a]	189 per km^2	(2014)
Length of road[b]	20,997 km	(2014)
Paved road (%)[b]	18.1%	(2014)
Length of road (GIS)[c]	140,910 km	(2015)
Of which, roads in "good" condition	19,611 km	(2015)
Of which, road quality data are missing	8,941 km	(2015)
RAI[c]	53.1%	(2015)

[a] World Development Indicators
[b] Uganda Bureau of Statistics (UBOS)
[c] World Bank estimates based on government data

Overview of the Road Network

With its relatively high population density by African standards, Uganda has a well-developed intensive road network covering the entire country. The road network is composed of the national road network and other tertiary and urban roads. According to the national statistics, the national road network comprises 20,997 km of primary and secondary roads, of which 3,795 km or 18.1 percent are paved. At this level, road density is already relatively high by regional standards, at 10.5 km per 100 km^2 of land. In addition, there are about 120,000 km of feeder roads, such as district, urban, and community access roads, which are generally unpaved. Although paved roads are largely in good and fair condition, about half of the unpaved roads are in good or fair condition.

Classification and Standards

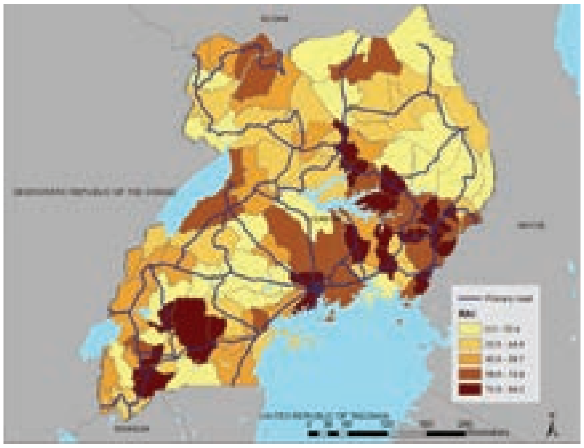
As per the Uganda National Roads Authority Act of 2006, the Uganda National Roads Authority has responsibility for managing, operating, and maintaining the National Road Network, comprising about 21,000 km, including some 10,000 km of district roads that were transferred to national roads in 2008.

For the primary road network, Uganda collected the IRI data for 2,957 km of major paved national roads in 2014. On average, the IRI is 3.38 meters/km. The Pavement Condition Index (PCI) is also available for a wider range of primary and secondary roads, based on which roads are classified as very good (PCI > 80), good (60 < PCI < 80), fair (40 < PCI < 60), poor (20 < PCI < 40), or very poor (PCI < 20). In total, the road quality data are available for three-quarters of the georeferenced primary and secondary roads. According to the most recent data, about 79.2 percent of paved roads are in good condition. By contrast, the condition of unpaved roads is generally poor: only about 25.7 percent of unpaved roads are in good condition.

There are other types of roads, such as district roads (20,373 km), urban roads (5,548 km), and community access roads (78,354 km). These roads are the responsibility of the respective levels of local governments, to which the Ministry of Works and Transport provides technical assistance for planning, guidance on work standards, and procurement. In 2015, the Government of Uganda carried out its first-ever comprehensive feeder road inventory survey, which shows that most of these feeder roads are unpaved and in poor condition. About 10.4 percent of feeder roads are in good condition, 22.4 percent in fair condition, 32.6 percent in poor condition, and 34.6 percent in bad or very poor condition.

Data Issues and Assumptions

Using a distribution based on WorldPop (2010 version) with urban areas excluded based on 1995 University of



Columbia (CIESIN) urban area imagery, the rural population in 2015 is estimated at 34.7 million in Uganda. The RAI is calculated at the district level, breaking the country into 111 districts and Kampala city.

In the data, there are about 1,346 km of roads, for which rehabilitation or maintenance works are currently ongoing or under the procurement process. Those roads are considered as a part of the road network in good condition, since they will be improved in the near future.

Estimated Rural Access Index

The national RAI is estimated at 53.1 percent, with 18.4 million rural people within 2 km of the road network in good or reasonably fair condition. This leaves about 16.3 million rural residents unconnected to the road network. Rural access is generally high around Lake Victoria, where more of the population lives. Particularly around the capital city, Kampala, the RAI tends to be high (for example, 86.5 percent in Wakiso District). The RAI is also high along main national highways, such as Kampala-Jinja-Malaba and Tororo-Mbale-Soroti Road (for example, 93.7 percent in Busia, 93.3 percent in Mable, and 77.9 percent in Soroti District).

Zambia

Basic data

Population[a]	15.7 million	(2014)
Land area[a]	743,390 km^2	(2014)
Population density[a]	21.2 per km^2	(2014)
Length of road[b]	66,781 km	(2014)
Paved road (%)[b]	19.0%	(2014)
Length of road (GIS)[b]	51,070 km	(2011)
Of which, roads in "good" condition	19,344 km	(2011)
Of which, road quality data are missing	19,044 km	(2011)
RAI[c]	17.0%	(2011)

[a] World Development Indicators
[b] Road Development Agency, Zambia
[c] World Bank estimates based on government data

Overview of the Road Network

According to the Zambia Road Development Agency's (RDA's) road condition report, Zambia has a road network comprised of 40,454 km of classified roads, called the Core Road Network (CRN). Of this, about 10,100 km or one-third of trunk, main and district roads are paved. Classified road density is 5.4 km per 100 km^2 of land, which is among the lowest in the region, although compared favorably with a neighboring country, Mozambique (3.9). The coverage of the classified road network is relatively narrow despite the size of the country. Nearly 90 percent of paved roads are in good condition. But the vast majority of unpaved roads are in poor condition.

Classification and Standards

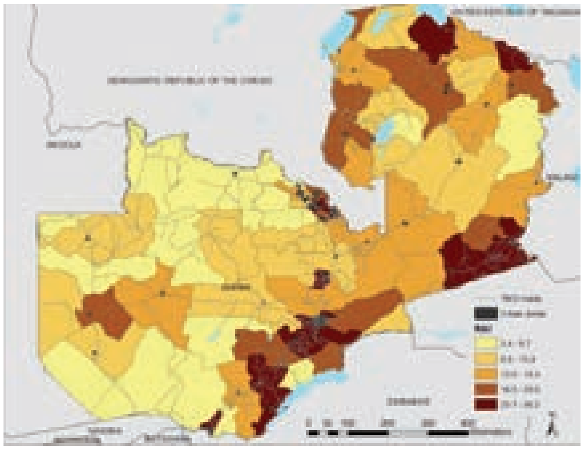
According to the Zambia Public Roads Act No. 12 of 2002, the RDA is responsible for ensuring that the core road network is kept in maintainable condition. The CRN is composed of the trunk, main, district, urban, and primary feeder roads. Trunk roads function as international highways, of which the total length is about 3,100 km. Main roads connect district centers to the trunk road network, and amount to about 3,700 km. Most of them are paved and kept in good or fair condition. District roads connect district centers within the country (about 13,000 km). More than three-quarters are unpaved and generally in poor condition. In total, about 11,000 km or half of the trunk, main, and district road network is in good or fair condition. In recent years, however, the quality of the district roads has been deteriorating.

Urban roads comprise about 5,600 km of roads in urban areas, of which about one-third are paved and about two-thirds are in good or fair condition. However, unpaved urban roads are mostly in poor condition. On the rural side, there are about 13,000 km of primary feeder roads, which are generally unpaved and the vast majority are in poor condition.

Data Issues and Assumptions

There are at least two sources of official road network data used by the Government of Zambia. One is used by RDA, and includes about 37,000 km of classified roads. The Central Statistics Office (CSO) has another data set, which includes an additional 14,000 km of unclassified roads. These two data sets were merged. In the RDA data set, road conditions are identified for about 87 percent of road segments. The latest available data were collected in 2011. For paved roads, the IRI is available, and unpaved roads were assessed using a visual rating from 1 (ride very smooth) to 5 (impassable). Weighted averages are calculated to match the road condition data to the network data. For the CSO data set, no attribute is available.

Using a distribution based on WorldPop (2010 edition), urban areas are excluded based on 1995 University of



Columbia (CIESIN) urban area imagery. The rural population in 2010 is estimated at 8.3 million.

Estimated Rural Access Index

The national RAI is estimated at 17.0 percent, leaving about 6.9 million rural residents unconnected to roads in good or fair condition.

The RAI was found to be generally high in Lusaka and Copperbelt Provinces. Especially around major urban areas, such as Lusaka, Kitwe, and Ndola, the RAI ranges from 30 to 40 percent.

North-Western and Western Provinces generally are lagging. In most districts in these provinces, the RAI is estimated at less than 10 percent.

ANNEX IV. SUB-NATIONAL RAI ESTIMATES

Bangladesh					
District	**RAI (%)**	**District**	**RAI (%)**	**District**	**RAI (%)**
Barisal	86.4	Jamalpur	82.9	Narail	90.1
Bhola	89.0	Kishoreganj	77.5	Shatkhira	80.8
Borgona	95.3	Madaripur	91.6	Bogra	94.0
Jhalakati	98.9	Manikgonj	90.4	Jaipurhat	96.4
Patuakhali	93.2	Munshigonj	97.4	Naogaon	95.8
Pirojpur	90.9	Naray Angonj	97.8	Natore	96.9
Bandarbon	32.3	Narshingdi	92.2	Nawabganj	87.7
Brahmanbaria	92.1	Nasirabad	85.4	Pabna	94.2
Chandpur	95.3	Netrakona	66.3	Rajshahi	94.9
Chittagong	68.5	Rajbari	94.7	Sirajgonj	78.4
Comilla	99.3	Shariatpur	90.9	Dinajpur	83.8
Cox's Bazar	56.7	Sherpur	80.5	Gaibanda	87.4
Feni	98.9	Tangail	89.0	Kurigram	79.4
Khagrachari	29.1	Bagerhat	74.0	Lalmonirhat	94.8
Lakshmipur	95.5	Choua Danga	98.5	Nilphamari	75.6
Noakhali	92.9	Jessore	97.6	Panchagarh	84.3
Parbattya Chattagram	31.5	Jhenaidah	96.8	Rongpur	93.8
Dhaka	97.7	Khulna	69.7	Thakurgaon	81.5
Faridpur	91.6	Kustia	94.8	Hobiganj	83.1
Gazipur	97.0	Magura	97.7	Moulvibazar	86.3
Gopalgonj	87.5	Meherpur	98.8	Sun Amgonj	49.6
				Sylhet	94.0

Nepal					
District	**RAI (%)**	**District**	**RAI (%)**	**District**	**RAI (%)**
Bhaktapur	91.4	Ilam	24.6	Humla	0.0
Dhading	52.5	Jhapa	93.0	Jumla	0.0
Kathmandu	95.8	Panchthar	9.0	Kalikot	0.0
Kavrepalanchok	70.4	Taplejung	1.8	Mugu	0.0
Lalitpur	49.1	Khotang	0.0	Dang	66.4
Nuwakot	35.9	Okhaldhunga	0.0	Pyuthan	9.1
Rasuwa	76.5	Saptari	96.0	Rolpa	3.3
Sindhupalchok	22.5	Siraha	62.7	Rukum	0.0
Dhanusa	76.5	Solukhumbu	0.0	Salyan	23.9
Dolakha	35.4	Udayapur	36.6	Baglung	6.4
Mahottari	89.0	Baitadi	0.0	Mustang	0.0
Ramechhap	28.9	Dadeldhura	29.8	Myagdi	16.8
Sarlahi	58.7	Darchula	0.0	Parbat	45.6
Sindhuli	21.7	Kanchanpur	84.9	Gorkha	40.2
Bara	93.8	Achham	0.0	Kaski	78.7
Chitawan	68.8	Bajhang	0.0	Lamjung	58.5
Makwanpur	42.3	Bajura	0.0	Manang	0.0
Parsa	125.4	Doti	12.4	Syangja	39.8
Rautahat	73.9	Kailali	74.3	Tanahu	60.9
Bhojpur	0.9	Banke	66.9	Arghakhanchi	32.6
Dhankuta	48.6	Bardiya	78.3	Gulmi	12.2
Morang	83.7	Dailekh	1.4	Kapilbastu	74.8
Sankhuwasabha	7.3	Jajarkot	1.9	Nawalparasi	98.7
Sunsari	82.9	Surkhet	46.7	Palpa	34.9
Terhathum	18.4	Dolpa	0.0	Rupandehi	80.0

Ethiopia					
District	**RAI (%)**	**District**	**RAI (%)**	**District**	**RAI (%)**
Addis Ababa Zone 1	n.a.	Metekel	6.3	Basketo Special Woreda	46.1
Addis Ababa Zone 2	34.6	Dire Dawa	3.2	Benchi Maji	28.7
Addis Ababa Zone 3	24.4	Gambela Peoples Zone 1	12.4	Burji Special Woreda	42.2
Addis Ababa Zone 4	100.0	Gambela Peoples Zone 2	8.4	Dawuro	19.4
Addis Ababa Zone 5	n.a.	Hundene	11.3	Derashe Special Woreda	46.0
Addis Ababa Zone 6	23.9	Arsi	9.0	Gamo Gofa	34.0
Afar Zone 1	16.1	Bale	17.1	Gedeo	51.7
Afar Zone 2	8.1	Borena	12.6	Guraghe	31.4
Afar Zone 3	15.8	East Harerghe	12.4	Hadiya	44.5
Afar Zone 4	1.4	East Shewa	17.8	Kaffa	20.7
Afar Zone 5	4.6	East Wellega	22.0	Kembata Alaba Tembaro	18.3
Awi	24.6	Illubabor	4.2	Konso Special Woreda	39.3
Bar Dar Sp. Zone	100.0	Jimma	24.4	Konta Special Woreda	10.3
East Gojam	25.9	North Shewa (K4)	17.6	Shaka	42.5
North Gonder	15.7	West Harerghe	14.0	Sidama	39.4
North Shewa (K3)	20.4	West Shewa	12.0	South Omo	19.8
North Wollo	28.8	West Wellega	23.2	Wolayita	49.9
Oromia Zone	25.4	Dege Habur	1.9	Yem Special Woreda	42.2
South Gonder	14.5	Jijiga	5.1	Central Tigray	34.8
South Wollo	22.4	Liben	3.2	Easetern Tigray	47.6
Wag Hemira	14.7	Shinile	4.1	Mekele	100.0
West Gojam	25.3	Unknown	2.9	Southern Tigray	39.3
Asosa	15.6	Welwel & Warder	0.0	Western Tigray	31.5
Kemashi	3.8	Amaro Special Woreda	23.6		

Kenya					
County	RAI (%)	County	RAI (%)	County	RAI (%)
Baringo	46.7	Kisumu	65.3	Narok	34.1
Bomet	62.2	Kitui	38.9	Tharaka Nithi	32.4
Bungoma	74.3	Kwale	46.2	Nyamira	82.2
Busia	53.1	Laikipia	40.1	Nyandarua	46.3
Elgeyo Marakwet	49.5	Lamu	52.9	Nyeri	78.8
Embu	60.6	Machakos	54.3	Samburu	26.6
Garissa	0.9	Makueni	63.4	Siaya	59.2
Homa Bay	48.8	Mandera	3.4	Taita Taveta	36.4
Isiolo	19.4	Marsabit	21.8	Tana River	16.6
Kajiado	33.7	Meru	60.0	Trans Nzoia	46.4
Kakamega	62.1	Migori	51.4	Turkana	27.9
Kericho	56.1	Mombasa	75.3	Uasin Gishu	67.1
Kiambu	82.8	Muranga	83.3	Vihiga	95.6
Kilifi	48.1	Nairobi	81.8	Wajir	3.8
Kirinyaga	85.5	Nakuru	58.6	West Pokot	23.4
Kisii	76.4	Nandi	52.3		

Mozambique					
District	RAI (%)	District	RAI (%)	District	RAI (%)
Ancuabe	28.1	Gondola	24.2	Nipepe	9.7
Balama	12.1	Guro	27.8	Sanga	1.3
Chi·re	23.6	Machaze	8.1	Buzi	16.7
Macomia	10.1	Macossa	4.6	Caia	16.5
Mecufi	35.9	Boane	69.8	Chemba	18.4
Meluco	13.6	Magude	15.2	Cheringoma	16.8
Mocimboa da Praia	16.0	Manhiþa	44.8	Chibabava	10.0
Montepuez	11.7	Maputo	46.4	Dondo	25.1
Mueda	9.5	Marracuene	31.4	Gorongosa	19.0
Muidumbe	8.5	MatutuÝne	21.5	Machanga	13.9
Namuno	21.1	Moamba	49.3	Maringue	15.6
Nangade	21.3	Namaacha	30.8	Marromeu	5.8
Palma	8.3	Angoche	14.6	Muanza	5.4
Pemba	50.2	Erati	10.0	Nhamatanda	24.5

Mozambique *(continued)*					
District	**RAI (%)**	**District**	**RAI (%)**	**District**	**RAI (%)**
Quissanga	12.8	Lalaua	6.9	Ang¾nia	13.2
Bilene	49.0	Malema	8.4	Cahora Bassa	10.6
Chibuto	50.2	Meconta	24.2	Changara	38.9
Chicualacuala	16.4	Mecuburi	17.5	Chifunde	13.1
Chigubo	10.8	Memba	14.7	Chiuta	11.1
Ch¾kwÞ	51.5	Mogovolas	21.3	Macanga	5.0
Guijß	33.6	Moma	11.6	Magoe	5.6
Mabalane	11.0	Monapo	25.0	Maravia	6.2
Mandlakazi	21.4	Mongincual	23.9	Moatize	16.7
Massangena	7.4	Mossuril	34.9	Mutarara	18.3
Massingir	25.2	Muecate	9.4	Tsangano	9.4
Xai-Xai	36.6	Murrupula	15.5	Zumbu	2.2
Funhalouro	9.0	Nacala Velha	18.7	Alto Molocue	18.4
Govuro	42.5	Namapa	8.5	Chinde	0.1
Homoine	23.0	Nampula	23.2	Gile	15.7
Inharrime	32.8	Ribaue	22.0	Gurue	10.5
Inhassoro	5.7	Cuamba	11.9	Ile	21.5
Jangamo	35.9	Lago	20.2	Inhassunge	0.0
Mabote	10.6	Lichinga	7.3	Lugela	11.1
Massinga	19.9	Majune	2.9	Maganja da Costa	16.8
Morrumbene	31.4	Mandimba	2.0	Milange	11.6
Panda	7.9	Marrupa	8.6	Mocuba	18.0
Vilanculos	18.0	Ma·a	8.5	Mopeia	6.9
Zavala	23.7	Mavago	3.0	Morrumbala	5.1
Manica	31.5	Mecanhelas	10.7	Namacurra	32.5
Mossurize	12.6	Mecula	4.5	Namarroi	15.7
Sussundenga	18.5	Metarica	4.3	Nicoadala	23.1
Tambara	22.2	Muembe	4.5	Pebane	10.8
Barue	34.2	N'gauma	10.5		

Tanzania					
District	**RAI (%)**	**District**	**RAI (%)**	**District**	**RAI (%)**
Arusha	52.8	Kilwa	9.2	Mtwara Urban	52.7
Arusha Urban	41.2	Kinondoni	73.6	Mufindi	19.0
Babati	19.6	Kisarawe	17.3	Muheza	43.2
Babati Urban	69.2	Kishapu	28.9	Muleba	33.9
Bagamoyo	27.5	Kiteto	20.0	Musoma	19.1
Bahi	6.7	Kondoa	2.0	Musoma Municipal	52.7
Bariadi	13.5	Kongwa	17.7	Mvomero	20.1
Biharamulo	28.6	Korogwe	27.0	Mwanga	45.0
Buhigwe	11.6	Korogwe Township Authority	38.7	Nachingwea	27.4
Bukoba Rural	15.6	Kusini	n.a.	Namtumbo	13.1
Bukoba Urban	87.2	Kwimba	37.4	Nanyumbu	19.2
Bukombe	30.1	Kyela	62.0	Newala	8.3
Bunda	29.3	Kyerwa	18.7	Ngara	34.1
Busega	20.6	Lindi Rural	13.2	Ngorongoro	7.2
Butiama	24.5	Lindi Urban	4.3	Njombe Rural	11.3
Chake Chake	n.a.	Liwale	9.6	Njombe Urban	27.8
Chamwino	6.2	Longido	17.4	Nkasi	8.9
Chato	28.2	Ludewa	29.0	Nyamagana	57.6
Chemba	1.2	Lushoto	16.6	Nyang'wale	20.7
Chunya	10.0	Mafia	24.3	Nyasa	27.4
Dodoma Urban	19.6	Mafinga Township Authority	53.4	Nzega	11.5
Gairo	20.1	Magharibi	n.a.	Pangani	11.1
Geita	23.8	Magu	33.5	Rombo	70.5
Hai	75.1	Makambako Township Authority	38.1	Rorya	29.3
Hanang	23.2	Makete	35.0	Ruangwa	18.8
Handeni	17.3	Manyoni	12.7	Rufiji	24.6
Handeni Township Authority	3.9	Masasi	28.7	Rungwe	51.0
Igunga	19.1	Masasi Township Authority	37.4	Same	23.9

Tanzania *(continued)*

District	RAI (%)	District	RAI (%)	District	RAI (%)
Ikungi	21.9	Maswa	33.3	Sengerema	22.5
Ilala	58.1	Mbarali	29.2	Serengeti	14.1
Ileje	46.3	Mbeya Rural	45.0	Shinyanga Rural	18.1
Ilemela	32.2	Mbeya Urban	65.3	Shinyanga Urban	50.8
Iramba	34.2	Mbinga	23.3	Siha	45.6
Iringa Rural	13.0	Mbogwe	14.1	Sikonge	16.2
Iringa Urban	56.2	Mbozi	41.8	Simanjiro	13.0
Itilima	10.0	Mbulu	24.8	Singida	37.9
Kahama	17.9	Meatu	4.4	Singida Urban	39.9
Kahama Township Authority	41.8	Meru	53.0	Songea Rural	11.7
Kakonko	15.2	Micheweni	n.a.	Songea Urban	34.4
Kalambo	19.2	Missenyi	44.6	Sumbawanga Rural	23.3
Kaliua	10.9	Misungwi	24.0	Sumbawanga Urban	24.5
Karagwe	21.9	Mjini	n.a.	Tabora Urban	14.7
Karatu	11.4	Mkalama	32.0	Tandahimba	23.4
Kaskazini A	n.a.	Mkinga	9.7	Tanga	7.3
Kaskazini B	n.a.	Mkoani	n.a.	Tarime	33.6
Kasulu	9.8	Mkuranga	23.4	Temeke	42.3
Kasulu Township Authority	15.0	Mlele	5.4	Tunduma	77.2
Kati	n.a.	Momba	22.7	Tunduru	5.2
Kibaha	3.0	Monduli	22.8	Ukerewe	46.0
Kibaha Urban	9.3	Morogoro	14.8	Ulanga	7.6
Kibondo	12.6	Morogoro Urban	37.6	Urambo	6.2
Kigoma Municipal-Ujiji	55.2	Moshi	56.0	Uvinza	15.4
Kigoma Rural	48.8	Moshi Municipal	87.1	Uyui	1.5
Kilindi	10.3	Mpanda Rural	2.2	Wanging'ombe	17.9
Kilolo	15.2	Mpanda Urban	2.7	Wete	n.a.
Kilombero	24.2	Mpwapwa	4.6		
Kilosa	24.2	Mtwara Rural	20.7		

Uganda					
District	**RAI (%)**	**District**	**RAI (%)**	**District**	**RAI (%)**
Abim	44.4	Kalangala	35.3	Mbarara	35.1
Adjumani	74.9	Kaliro	93.2	Mitooma	45.2
Agago	36.7	Kalungu	69.7	Mityana	32.1
Alebtong	56.2	Kampala	92.6	Moroto	44.9
Amolatar	40.0	Kamuli	75.6	Moyo	65.4
Amudat	23.9	Kamwenge	24.2	Mpigi	59.7
Amuria	14.3	Kanungu	45.7	Mubende	28.3
Amuru	51.1	Kapchorwa	83.2	Mukono	66.4
Apac	43.7	Kasese	59.4	Nakapiripirit	31.6
Arua	35.6	Katakwi	15.1	Nakaseke	71.0
Budaka	84.4	Kayunga	72.1	Nakasongola	18.9
Bududa	70.8	Kibaale	34.4	Namayingo	70.5
Bugiri	36.6	Kiboga	46.5	Namutumba	38.6
Buhweju	31.3	Kibuku	80.5	Napak	22.0
Buikwe	60.8	Kiruhura	77.0	Nebbi	22.6
Bukedea	80.0	Kiryandongo	38.4	Ngora	59.9
Bukomansimbi	49.7	Kisoro	47.2	Ntoroko	37.9
Bukwo	67.3	Kitgum	64.3	Ntungamo	77.8
Bulambuli	68.1	Koboko	48.3	Nwoya	41.5
Buliisa	73.8	Kole	42.0	Otuke	38.9
Bushenyi	65.8	Kotido	36.8	Oyam	56.7
Busia	93.7	Kumi	67.5	Pader	32.9
Butaleja	73.8	Kween	44.5	Pallisa	63.4
Butambala	58.0	Kyankwanzi	27.0	Rakai	49.1
Buvuma	0.0	Kyegegwa	28.4	Rubirizi	51.3
Buyende	46.2	Kyenjojo	56.3	Rukungiri	28.4
Dokolo	94.3	Lamwo	30.9	Serere	80.3
Gomba	33.4	Lira	93.5	Sheema	92.8
Gulu	37.3	Luuka	51.8	Sironko	76.4
Hoima	61.8	Luwero	65.3	Ssembabule	36.3
Ibanda	93.2	Lwengo	59.2	Tororo	73.7
Iganga	80.2	Lyantonde	84.8	Wakiso	86.5
Isingiro	16.6	Manafwa	86.7	Yumbe	48.4
Jinja	34.0	Maracha	21.6	Zombo	13.8
Kaabong	1.9	Masaka	44.7	Soroti	77.9
Kabale	44.4	Masindi	49.0	Bundibugyo	51.3
Kabarole	54.1	Mayuge	32.5		
Kaberamaido	64.1	Mbale	93.3		

Zambia

District	RAI (%)	District	RAI (%)	District	RAI (%)
Chibombo	15.4	Chiengi	21.6	Mbala	14.1
Kabwe	49.1	Kawambwa	13.9	Mpika	8.8
Kapiri Mposhi	9.2	Mansa	21.9	Mporokoso	23.6
Mkushi	15.2	Milenge	14.2	Mpulungu	41.2
Mumbwa	9.2	Mwense	19.5	Mungwi	11.5
Serenje	14.1	Nchelenge	16.0	Nakonde	28.7
Chililabombwe	5.0	Samfya	11.7	Choma	29.7
Chingola	16.4	Chongwe	20.5	Gwembe	7.8
Kalulushi	11.3	Kafue	30.7	Itezhi-Tezhi	17.2
Kitwe	25.5	Luangwa	11.9	Kalomo	13.7
Luanshya	19.6	Lusaka	3.9	Kazungula	7.6
Lufwanyama	7.9	Chavuma	3.4	Livingstone	54.3
Masaiti	15.4	Kabompo	10.9	Mazabuka	30.7
MPongwe	13.2	Kasempa	12.7	Monze	21.7
Mufulira	21.2	Mufumbwe	5.8	Namwala	7.8
Ndola	56.2	Mwinilunga	7.9	Siavonga	21.8
Chadiza	36.0	Solwezi	8.1	Sinazongwe	23.8
Chama	4.8	Zambezi	8.7	Kalabo	9.2
Chipata	34.3	Chilubi	8.7	Kaoma	13.5
Katete	27.7	Chinsali	15.4	Lukulu	6.6
Lundazi	14.5	Isoka	22.4	Mongu	17.0
Mambwe	18.5	Kaputa	11.7	Senanga	9.9
Nyimba	25.5	Kasama	21.1	Sesheke	8.1
Petauke	14.3	Luwingu	13.4	Shangombo	5.8

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