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Measuring Inequality of Access

Modeling Physical Remoteness in Nepal

Robert Banick
Yasuhiro Kawasoe

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Abstract

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This paper is a product of the Poverty and Equity Global Practice and the Social Protection and Jobs Global Practice. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at http://www.worldbank.org/prwp. The authors may be contacted at rbanick@worldbank.org and ykawasoe@worldbank.org.

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R41, R53, 021

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Accessibility, remoteness, GIS, Nepal

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Introduction

Unequal access to services is a major barrier to sustainable development. The United Nation's 1984 Universal Declaration of Human Rights (UDHR) declares "Everyone has the right of equal access to public service in his country". Half a century later, ensuring this right remains a challenge in much of the world. The Sustainable Development Goals adopted in 2015 emphasize the importance of equal and universal access to education, health, social protection, and energy in their goals, visions, and agenda. Working to provide such access will therefore be a crucial component of work to alleviate poverty and boost human development over the next 15 years.

Access is a complex concept that encompasses availability, accommodation, affordability and acceptability (Penchansky,R. et al. 1981). In short, an accessible service is available to all, unimpeded by financial, cultural, and social barriers. Most obviously, an accessible service can be reached without undue effort or loss of time; no serious physical or geographic barriers obstruct access.

Measuring physical accessibility is a serious challenge in Nepal, where traditional linear distance measurements or simple network analysis calculations fare poorly given its rough terrain and underdeveloped, poorly maintained infrastructure. We prepare a more sophisticated method for quantifying physical remoteness and accessibility based on converting various factors into travel time modifiers and merging them into minimum travel times for a given area. We take average speeds for movement off-road and over various types of roads and increase or decrease them according to the underlying slope, land cover, road quality and seasonal effects (monsoon rains) to produce the average time it takes to cross each 30m x 30m cell, referred to here as the travel "cost". This method, popularly known as cost time or travel time analysis, is well developed in the accessibility literature and indeed largely possible to implement through standard toolkits in industry-standard GIS software packages. What sets our approach apart is the difficulty of the application area, the relative quality of data inputs used, and the high-resolution output over a large spatial scale.

This study aims to develop a methodology for quantifying physical accessibility in Nepal, produce corresponding data sets for use by researchers, development practitioners and government officials and summarize accessibility to critical services at every administrative level. Crucially, the resulting methodology, tools and geospatial data sets are not application specific and open to reuse and refinement by other researchers and development practitioners.

Because the output data are high-resolution and national in scale, they enable localized analysis of accessibility challenges, remoteness and their impact on developmental indicators. Thus, our research not only solves a critical measurement problem but creates foundational data sets for more accurate analysis of accessibility and remoteness in Nepal. As a basic demonstration of value, we have prepared descriptive analysis and visualizations of accessibility to critical services at every major administrative level under Nepal's new federal structure. In this report we present examples of such analysis summarized across provinces and geographic regions. Where possible, we compare them to government accessibility standards for key services, to better assess where progress has been made and where attention is needed. Our intent is to plug evident data gaps for new municipal and provincial administrations, for whom much previous data are inapplicable, in a visually accessible manner and so improve the quality of planning under Nepal's new federal structure.

We found that accessibility patterns varied widely according to services and administrative areas, with many outliers from observed trends. Generalizing is difficult among the noise, but we found a few consistent patterns. Among administrative areas, mountainous and Far Western provinces and municipalities demonstrated far worse patterns of accessibility. Among services, hospitals, financial institutions and district headquarters showed the poorest levels of accessibility. The observed shortfalls in accessibility are particularly worrisome in a countryside increasingly feminized by male rural outmigration. As women generally report lower comfort with overnight stays beyond the home, women in remote areas may forego access to faraway services. To address these gaps, we recommend improving mechanisms for provincial or inter-municipal planning mechanisms to address accessibility gaps for costly services like hospitals, promoting alternative delivery mechanisms for access to finance, investment in high-quality rural transportation infrastructure and investment in municipal administrative service delivery.

It is important to note that this study focuses exclusively on better measuring *physical* accessibility and its inverse, remoteness. A more holistic analysis of accessibility in Nepal would also capture social and economic constraints to access. Such constraints are pervasive in Nepal and absolutely worthy of study, but currently impossible to consider comprehensively given the challenges of modeling physical travel across Nepal's geographic extremes. Our hope is that our model's data will be a crucial input to more methodologically sophisticated analyses of accessibility in Nepal going forward.

Background

Accessibility theory

Transportation researchers have developed a copious literature for defining and measuring accessibility. Modern travel research recognizes accessibility as essentially multi-dimensional and composed of social, gender, economic, physical and political dimensions. That is, a key service may be physically close, but if cost and/or social marginalization block a person from using it then it is not accessible. Basic metrics of distance or travel time are therefore increasingly treated as inputs to more comprehensive diagnostics incorporating all these factors. Not all these measures are quantitative, but of those that are, Paez *et al.* (2012) note three broad classifications:

1. Gravity-based models
2. Cumulative opportunities
3. Utility-based models

More theoretically sophisticated models may also consider temporal constraints, service capacity, individuals' preferences and other relevant inputs and generate composite measures of them. But as noted by Geurs and Wee (2004), these more theoretically satisfying measures are difficult for policy makers to interpret and less used in practice. The full scope of proposed models is well beyond the scope of this paper; interested readers should look to the work of Paez *et al.* (2012), Curtis and Scheurer (2010), Geurs and Wee (2004) and Handy and Niemeier (1997) for an introduction to the various perspectives, techniques and outputs.

Physical accessibility as studied in this research is therefore only the starting point to a deeper understanding of accessibility. Our research makes no claim to exhaustiveness in its treatment of accessibility in Nepal, only attempts to solve a pernicious measurement problem in a difficult context.

Accessibility metrics

Economics and development policy researchers have tended to adopt more practical, quantitative, and easily interpreted measures of remoteness and accessibility to critical services. Typical measures include linear (Euclidean) distance, remoteness indices, road density within administrative areas, reported travel times from survey instruments, "economic distances" calculated from transportation and opportunity costs, geospatial network analysis, and geospatial travel time models (Chamberlin 2013). There is no consensus on which measures work best and their sophistication varies widely. The exact measure employed depends on the available data, the context and researchers' inclinations.

A simplistic linear distance to markets, roads or other infrastructure is a common measure favored for its ease of implementation (Ghimire 2015, Kristjanson et al. 2005). Its limitations are discussed below. Others use road density per person or square kilometer, often within a given administrative unit (Thapa and Shilelv 2017, Kristjanson et al. 2005). This reflects the importance of infrastructure but may obscure social aspects of inaccessibility, like women's avoidance of overnight travel. Less common are composite indices built off a combination of the above (Babu et al. 2014).

Reported travel times to specific services from survey instruments, sometimes further divided by travel modality, are very popular measures of accessibility among economists (Babu et al. 2014, Jacoby 2000, Minten 1999).

Questions regarding travel times are common to Living Standards Measurement Surveys promulgated by the World Bank and hence data are available for many countries. Despite their popularity, reported travel times contain serious inaccuracies, biases and limitations. Respondents may misreport times (a.k.a. recall bias) and idiosyncratic household conditions (i.e. disabilities, physical fitness, schedules of nearby bus) create many outliers (Roberts et al. 2006). Assessing Nepal's 1996 Living Standards Measurement Survey, Jacoby (2000) notes that reported travel times within wards vary widely around the ward median value for these reasons. Similarly, when comparing reported travel times to a locally validated cost time model, Ahlström et al. (2011) found responses differed by up to 30% (+/-) of the mean modeled travel time for a given district. These findings imply that while such data are appropriate for household level analysis, aggregation and generalization from them is problematic. Reported times also do not work for assessing new or planned infrastructure and are prohibitively expensive to collect at scale.

Some researchers employ road network analysis within a GIS to calculate travel times along roadways (Delgado and Baltenwick 2000). Such analysis work well where road network data sets are complete, terrain's impact is easy to model and off-road travel is insignificant. Only a few researchers have calculated their own cost time models in a GIS. Notable examples of such models include Kosmidou-Bradely and Blankespoor's national mobility model for Afghanistan (2019), the continent-scale analysis of HarvestChoice in Africa (2016) and the district-scale, locally validated analysis of Ahlström et al. (2011) in Sri Lanka. The former model is particularly similar to ours in terms of context, scale and design and worthy of study by those interested. Both cost time models and reported travel times can be used to compute "economic distances" of financial cost for traveling a given distance, for instance the cost of using transport plus the opportunity cost of time (Chamberlin 2013).

A notable weakness of almost all research, perpetuated here for lack of manageable alternatives, is the tendency to calculate accessibility in terms of the single nearest service location, instead of multiple services (Chamberlin 2013). Transportation researchers' more sophisticated models handle multiple destinations better but at the cost of communicative and analytical simplicity. We favor the simple approach in constructing our model but acknowledge the artificial limitation it imposes and invite further research in this regard.

Accessibility and Development

Remoteness plays a heavy role in human and economic development. Jalan speaks of a "geographic poverty trap" wherein a lack of accessibility perpetuates poverty (Jalan, J. et al. 2002). For example, in several case studies Bird, K. *et al.* (2002) highlight the strong prevalence of chronic poverty in rural areas isolated by distance and/or ecology.

This is particularly so in South Asia, where the UNDP's Human Development Report 2016 states that the population in multidimensional poverty is much higher in rural areas (64%) than urban areas (25%), compared to 29% and 11% globally. In India each additional 10 km from a town is associated with a 3.2% reduction in mean earnings (Asher, S. et al. 2016). In Nepal itself Sapkota (2017) finds that remote, rural villages have higher poverty levels and report lower levels of health, education and happiness after controlling for household fixed effects.

Health, education and market development researchers and practitioners have long recognized the determining role of physical access in conditioning development outcomes. Practical implementations of this intellectual tradition are particularly pronounced in the public health sector, where the WHO recommends using travel times instead of linear distances to calculate accessibility. Indeed, the WHO has developed the AccessMod geospatial analysis software to facilitate such calculations by public health researchers (Ray and Ebener 2008). Consequently, many public health researchers and professionals use travel times to assess the impact of accessibility on health care utilization (Buor 2003, Feikin *et al.* 2009). For example, Munoz and Kallestal (2012) demonstrate the relevance of travel time-based accessibility measures to primary health care coverage and usage in Rwanda.

The economic development literature increasingly considers the role of accessibility thanks to the New Economic Geography championed by Krugman. Among many other things, Krugman suggested improving crude linear distance estimates to incorporate infrastructure quality and market demand (Krugman 1991). Agricultural economists and food security researchers in particular have focused on measuring the importance of market access to determining agricultural production, food prices and food security outcomes. A characteristic application is Baltenwick and Staal's (2007) analysis of commodity spatial price formation in Kenya's highlands, where they concluded that travel times to markets affect different commodities' prices differently. For a helpful overview of such work see Chamberlin's 2013 summary and for Nepal-specific analysis see Jacoby (2000), Fafchamps and Hill (2005) and Thapa and Shiveley (2017).

Children's limited mobility means accessible schools are believed essential to strong educational participation and outcomes. This belief is contested; in his 21-country study Fillmer (2004) concludes that increased access has only a minor positive effect on enrollment. However, individual case studies differ. Lavy (1996) found that large travel times constrained educational outcomes in rural Ghana. Rolleston (2011) extends this analysis to find that improved education access significantly improves poverty rates in Ghana, albeit preferentially for economically privileged households. In Nepal, Shyam (2007) shows that geographic isolation affects school enrollment for primary and secondary school-age children after controlling for other known determinants. He demonstrates that early childhood remoteness has a measurable effect on individuals' lifetime educational performance even when accessibility to schools later improves.

Measuring remoteness in Nepal

Nepali context

Accessibility patterns in Nepal are heterogeneous. Altitudes stretch from roughly 70 meters above sea level in the Terai plains to well over 8,000 meters in the Himalayan mountains, with numerous smaller peaks and valleys falling between. Remoteness analysis is more applicable to the hills than the Terai, where the improved highways and flat terrain make access less of an issue. In the hills steep slopes make linear distance estimates meaningless and fast- moving rivers often prompt long detours, expanding travel times. In some remote mountainous districts, air transport is the only available travel modality other than walking, and outside of the Kathmandu Valley most areas are serviced by unreliable, expensive and irregular private bus services (World Bank 2017, Pokharel, R. *et al*. 2015). For these reasons in 2012 the mean reported time to reach major market centers in rural areas was approximately 2 hours 15 minutes, despite the significant downward influence of households located in the flat and relatively well-connected Terai (CBS 2011). Since only 17% of Nepal's roughly 30 million inhabitants live in urban areas this implies heavy costs from remoteness on the country's economy and society (CBS 2011).

Remoteness is a defining feature of rural life in Nepal due to its incredibly rough topography and diverse ecology and land cover. Yet most studies heavily abstract it, rely on estimates from surveys, or do not quantify it at all due to the complexity of accurately integrating so many different factors into a succinct measure. Data shortfalls pose an additional challenge, as key data sets are scattered across ministries or altogether missing. Even where roads data sets are available, the continued relevance of off-road travel in rural areas frustrates typical network analysis.

Simplistic models of accessibility impose costs, as the failure to measure accessibility in units of time leads to incorrect or vague assessments of service facility catchment areas. Traditional linear measurements do not account for the impact of terrain types, slope, presence of roads, etc. on travel conditions. These factors are especially relevant in rural Nepal where a hypothetical child could live within 2 linear kilometers of a school, but be on the wrong side of a river, valley or mountain, or simply 1000m below the school.

Measurement approaches

Most country-scale research into remoteness in Nepal uses basic weighted indices of subnational units, suitable for high-level analysis but not for measuring localized travel times or facility level accessibility. A recent example comes from Dempsey (2016), who assessed remoteness at the Village Development Committee (VDC) level using a simple weighted linear combination (WLC) model. She graded different input factors by their level of remoteness and weighted them based on expert judgments from staff at the United States Agency for International Development (USAID). Elsewhere, the World Bank has calculated a Rural Access Index for subnational administrative units in Nepal and other countries based on road network coverage and quality (Roberts et al. 2006 / Iimi et al. 2016). Huber (2015) went one step further and created a rasterized cost time travel model for Nepal, even including a separate monsoon model to reflect the sharp seasonal changes in accessibility where roads are poor. But to create this raster Huber interpolated missing values from the results of a network analysis (Rodrigue et al. 2009) of road vector lines, ignoring off-road travel and travel impedances from terrain, landcover, bridges, etc. He also calculated remoteness in terms of travel times to Kathmandu, not in terms of services. Reaching further back, Donner (1972) published a map showing path lengths in units of porter days. All the above studies use incomplete and partial transportation data sets, particularly of pathways, implying a degree of inherent error.

Researchers in Nepal not working off custom models tend to use reported travel times from household surveys, especially the Nepal Living Standards Survey (e.g. Jacoby 2000, Fafchamps and Hill 2005). There are departures from this approach. Thapa and Shively (2017) estimate the relationship between accessibility and agricultural and food security indicators using paved road densities (per km2). Elsewhere, the International Labor Organization (ILO) recommends the use of Integrated Rural Accessibility planning in Nepal (ILO 2005). This is a participatory approach to assessing access and planning rural infrastructure development accordingly. On a local level Devkota et al. (2012) built a gravity model of interactions over trail bridges using network analysis to indicate access to various services and optimum locations for additional bridges. The model is promising for small-scale applications but too reliant on rich local data to easily scale.

The government of Nepal's treatment of remoteness varies considerably between ministries. Traditionally, ministries and development actors capture such metrics using self-reported travel times from surveys or administrative questionnaires sent to local officials (MOE and UNESCO 2015). For instance, the Ministry of Health's Second Long Term Health Plan (2007, pg. 10), called for:

> *"Essential Health Services at the District…[to be] available to 90 percent of the population living within 30 minutes travel time"*

Similarly, the Ministry of Education repeatedly references the number and types of children within 30 minutes walking distance to primary schools and 1 hour to secondary schools in its Consolidated Equity Strategy (MOE 2014).

The Department of Roads (inconsistently) embraces more sophisticated approaches to measuring accessibility when planning new infrastructure. This is largely to comply with the Government of Nepal's 2007 goal to bring the entire population of the Terai and Hills within 2 and 4 hours walking distance of paved roads, respectively. Consultants working for the Department of Roads (DOR) accordingly constructed their own 90 meter resolution cost time model and gridded (raster) population data set for focus areas of the Strategic Road

Network (SRN) (DHV *et al.* 2007). The consultants combined these data sets to calculate populations within 2 and 4 hours walking distance of new and existing paved roads and the total person-hours of travel thus saved by roadway extensions. The DOR's effort was notable as the only technically analogous accessibility analysis to our own in Nepal we encountered in our literature review. Unfortunately, we could not find evidence that this approach was updated or replicated by the DOR for infrastructure Priority Investment Plans after 2007.

Our approach

The traditional measures described above all impose some form of penalty in terms of imprecision, lack of generalizability and/or cost. However, geospatial analysis technologies and increasingly high-quality open data enable more accurate, generalizable and cost-effective alternative measurements of physical accessibility using earth science technology. The major consideration when using a Geographic Information System (GIS) will be the choice of indicator. Some studies (such as S. Hasan, 2017) use distance, whereas recent studies on global accessibility employ travel time (Weiss D.J., 2018).

This paper favors the latter approach, quantifying accessibility and remoteness to services in Nepal by developing a model of travel costs across a surface of Nepal and using it to calculate the minimum travel time to various facilities from every point in Nepal. To do so we adapted a similar recent model produced for Afghanistan by Kosmidou- Bradley and Blankespoor to the Nepali context. The most notable modifications were the inclusion of switchback routes over Nepal's steepest terrain and a separate monsoon season model to reflect the serious impact of heavy rains on movement over Nepal's poor roads. The latter echoes Hubert's work in Nepal and the work of many geographers studying Sub-Saharan Africa (Hirvonen *et al.* 2017).

We convert the terrain and transport infrastructure to raster travel speeds and conduct appropriate analysis in units of time at a 30m x 30m cell resolution. Doing so requires intricate modeling of various travel modalities and modifiers to standard travel times. The accuracy and reliability of the result was tested and improved through consultations with professionals and organizations well-acquainted with travel patterns in diverse locations of Nepal. For additional validation we compared model results to reported service travel times from households surveyed in the Nepal Household Risk and Vulnerability Survey (HRVS).

Finally, we consider the accessibility of various service facilities at national, provincial and municipal scales. We compare modeled accessibility levels for each service at each scale to the published standards of the responsible ministry and highlight areas of significant concern.

Alternative Models of Physical Accessibility

Before describing the methodology underlying our cost time model, we shall justify our belief in its superiority for general usage with a brief discussion of other methods and a comparison of each to cost time models.

The cost time model developed described in this paper is only one of many possible methods of measuring accessibility. Methods must balance thoroughness, data inputs and level of effort, accuracy, generalizability and ease of adaptation / interpretation. In the context of Nepal, we believe our model strikes the strongest balance between these criteria. Other methods emphasize some of these criteria above others, in the process often making them more suitable for specific use cases than general usage (see Table 1 for a summary).

Table 1: Characteristics and Uses of Accessibility Metrics and Models

Characteristics assume a well-executed model with high-quality, complete data inputs

Method / Model	Data gathering requirements	Accuracy	Coverage / scalability / generalizability	Ease of adaptation / interpretation	Use cases
Cost time	High	High	High / High / High	Medium	• Various, highly flexible • Multi-scalar analysis • Areas with significant terrain, landcover and/or road surface impedance • Routing to multiple destinations
Linear Distance	Light	Very low	High	High	• Areas without significant terrain or road surface impedance • Rapid / no-budget analysis
Road Density	Medium	Low	Medium / Low / Low	High	• Econometric modeling • Simple comparisons between areas
Survey response	Medium	Variable *(idiosyncratic to household and survey)*	Low / Low / Low	High	• Econometric modeling • Correlations with household-level characteristics
Network analysis	High	High	High / Medium / Low	High	• Data rich environments • Scenarios without off-road travel • Routing to multiple destinations • Multi-scalar analysis
Weighted Index	Medium	Medium	High / Low	Low	• Comparison between areas • Balancing multiple accessibility criteria
Advanced models	High	High	Variable *(depends on model)*	Low	• Data rich environments • Routing to multiple destinations • Balancing multiple accessibility criteria

Linear distance

Linear distance measurements are simple to compute for non-specialists, even manually without computers, and therefore by far the most inexpensive and data-light accessibility measure. Distance measurements can be calculated at any scale, are very simple to communicate to policy makers, the public and other non-specialists, and are easy to incorporate in any distance-based analysis. In flat or near-flat environments where distance is the main impediment to physical access metric linear distance measurements are a useful tool for analyzing analysis.

However, Nepal's rugged terrain and underdeveloped infrastructure mean linear distance measurements there are grossly inaccurate both in absolute terms and relative to our cost time model. Our model matches linear distance measurements' advantages of providing useful detail at every conceivable scale. While the model's construction may appear complex, we selected units of time as the output to make it approachable for specialists and non- specialists alike.

Road density

Road density summaries per administrative area convey useful information about infrastructure coverage but are inexact proxies for accessibility. These data sets must be collated, sometimes tediously, from individual District Transport Master Plans (DTMPs) in Nepal. Given that many Nepali roads operate poorly or not at all due to bad maintenance, simple roadway lengths may obscure poor accessibility caused by quality issues in the roadways (RAP3 2018). Researchers can ameliorate such problems by more detailed modeling of road quality or reliance on a reliably maintained subset of roads (e.g. paved ones), as with Thapa and Shively (2017). But this raises the burden of data collection, introduces sources of error from erroneously reported road conditions or reduces the detail of the metric. Additionally, such models implicitly discount the importance of off-road travel and the varying difficulty of such travel in different areas.

In any case such a summary measure suffers from the same resolution and repurposing limitations of Remoteness Indices: such summaries enable comparisons between areas but not individual, localized analysis, e.g. calculating the shortest route between a given set of points, or local accessibility to a particular type of service. They also obscure accessibility dynamics within such areas; assessing whether new roads reach an important economic center or just a politically powerful constituency is impossible. Road length summaries *do* communicate facts about remoteness easily to users and a non-technical audience can quickly grasp their means of tabulation. By using a common unit of measure (kilometers) they are also easily incorporated into spatial models. Therefore, they balance well cost, technical complexity and communicative value, and may be appropriate to analyses oriented at non- technical audiences, especially where data is readily available. Overall however they are less detailed, more abstract and more limited in their applications than cost time models.

Survey responses

Reported travel times to services from survey instruments are easy to collect within a standard survey instrument but are subject to such instruments' limitations. To begin, collecting quality survey data is a complex, expensive and time-consuming process vulnerable to various types of survey error (for example, see below commentary on GPS error in the Household Vulnerability and Reconstruction Survey (HRVS)). Any of these sources of error can undermine the reliability and validity of the results. Even when surveys are performed well, reported survey times are heavily influenced by individual household dynamics (Ahlstrom et al. 2013). Controlling for fixed effects can offset some of this error but not all effects can be detected. Even then the findings are impossible to generalize beyond the sample frame employed or outside the study area.

Reported travel times offer the precision of a time-based measure and thus have similar advantages to cost time models in terms of communicative efficiency and analytical flexibility. For this reason, economists commonly employ reported travel times to services from survey instruments to assess the relationship between accessibility and market, household or individual characteristics. Thus, they offer useful but inherently limited looks at accessibility and are most useful when accessibility must be correlated with such characteristics. Cost time models are preferable to reported travel times except where a specific households' characteristics must be correlated with its specific set of reported times.

Network analysis

Network analysis is a method of calculating travel times or distances over a road network in a GIS software, measurements which can then be used to look at accessibility in the same manner as a cost time model. It principally requires an accurate, complete roads data set in the area of interest. Accuracy here specifically references the geo-location of the road centerlines, their surface and quality attributes, and the road speed modifiers attached to these attributes. Where data requirements are met the precision of estimates is high and conveniently scalable to any geographic unit of analysis. By contrast, an incomplete or inaccurate roads data set will yield incorrect routes and misleading distance / time measurements, sometimes dramatically so where some road segments do not connect, and the GIS therefore assigns unnecessary detours. Importantly, network analysis assumes all travel happens over the road network and thus cannot factor off-road travel. Interpolation is required to incorporate off-road travel into network analysis calculations.

Network analysis can calculate travel in units of time or distance, offering an attractive package of analytical flexibility and communicative efficiency. Like cost time models, it can also handle trips spanning multiple destinations and optimize the order of visits. Therefore, where reliable data exist, it is a strong option for policy makers, analysts and researchers alike. For use cases like logistics planning or routing that must manage multiple travel destinations along established road networks it is arguably the default, preferred method.

Network analysis poorly fits our needs given the importance of off-road travel and terrain in Nepal and the frequent inaccuracy of its roads geospatial data. In a preliminary analysis of options at the outset of this project the routes and times returned by network analysis over our road network were visibly incorrect even to researchers unfamiliar with the Nepali context.

Furthermore, we had the good fortune of inheriting a complete governmental roads data set from the Rural Access Index; such fortune is unlikely to repeat, and data availability would thus block updates to our eventual model. This limitation also applies to the cost time model but is less severe given the importance of terrain, land cover and other inputs in it, and the imperfect but easy to manage substitute of OpenStreetMap data. OpenStreetMap (OSM) is an ever-growing open access, volunteer contributed global geographic data set and map, best summarized as "the Wikipedia of maps." OSM data cannot be dropped so easily into a network analysis as it does not align perfectly with governmental roads data sets, requiring significant tedious labor to manually align both data sets on each update.

This is less important in our 30m x 30m grid where 1-5 meters of separation between roadways will generally fit within a single cell and thus cause no impact.

Weighted indices

While not strictly models of physical accessibility, we consider weighted indices here as there are several prominent ones currently used to measure remoteness in Nepal.

Weighted indices simplify accessibility for a facility or area to a relative score by weighting various data points and mathematically integrating them. The data gathering and complex model building required for remoteness indices like the Rural Access Index makes them costly and time-consuming to compute, particularly at finely detailed levels of analysis. The accuracy of these indices is difficult to verify, dependent as they are on assumptions about the relative weights of inputs and the quality of underlying data. Unless re-weighted to account for population, service area or other relevant factors indices are also not applicable beyond their specific level of analysis. Area-based indices for instance obscure local accessibility dynamics when they summarize information at their level of analysis. Dempsey's analysis, for instance, rates remoteness on a scale of 1-9 for each village development committee (VDC, old administrative level 3) in Nepal. It is therefore impossible to assess dynamics at the level of households or wards (the new third administrative level, covering several thousand people).

Accessibility indices are very useful for comparisons between VDCs or higher administrative areas and for balancing multiple accessibility criteria. For example, a quick glance at the Rural Access Index allows a policy maker to identify where in Nepal the need is greatest for additional infrastructure investment. Through weighting indices can look beyond simple physical measures of accessibility to consider social dynamics, historical investment patterns, education levels, and other relevant determinants of overall accessibility (albeit at a greater data gathering cost).

However, the resolution of most indices is inappropriate to local applications like planning the actual placement of infrastructure, calculating remoteness's importance at the household level or analyzing accessibility to individual service facilities. The unitless nature of index measurements also hinders communication to policy makers or adaptation to additional analyses; analysts must explain to a policy maker what a 4 vs. a 7 means on Dempsey's scale, and such numbers cannot be meaningfully incorporated into other models that require physical measurements.

Both cost time models and weighted indices are complex, and their inner mechanics must be explained to users. But by employing a verifiable, commonly used metrics, cost time models give users confidence in their results and the ability to field test outputs for themselves. Additionally, cost time models produce raster outputs that can be scaled to any unit of analysis at or above the resolution of a raster pixel. These advantages make them more generically useful tools for specialists and non-specialists alike that still successfully manage multiple input factors.

Data collection and preparation

Service facilities

We collected geospatial data for various categories of services facility types to objectively calculate travel times and distances to them. Our original intent was to compare these data with the reported distances and times from the survey; we have now moved this analysis to a separate paper. We amassed destination data on 77 DHQs, 7,840 banks, and 4,858 medical facilities. Table 2 summarizes these data sets and their sources.

Table 2: Facility data sets

Service	Number of facilities	Source
District headquarters	77	Survey Department
Banks	7,840	Nepal Rastra Bank (NRB)
Medical facility	4,858	Ministry of Health

The financial and medical facility data sets contained additional information about the specific type of facility (e.g. hospital, health post, etc.). We took advantage of this to repeat our analysis for important sub-categories of services contained within.

Digital Elevation Model (DEM)

DEM data enables accounting for slope when calculating travel speeds and path distances. We used 1 arc-second (roughly 30-meter resolution) Shuttle Radar Topography Mission (SRTM) data for this purpose. Specifically, SRTM tiles N26E084 toN26E088, N27E081 to N27E088, N28E080 to N28E086, N29E080 to N29E084, and N30E080 to

N30E082 were extracted, merged and clipped in the shape of Nepal.

Road network

We employed road network and land cover data to calculate surface speeds. OSM data tagged as a "highway" was merged with Department of Roads (DOR) data collected through the World Bank project on "Measuring Rural Access Using New Technologies" to create a final roads layer. OSM roads not tagged as major roadways (smaller than highway=tertiary) were reclassified as paths. Overlapping roads were ignored as they did not substantially alter reported travel times.

We classified roads into four categories based on expected speed, as seen in Table 3. The classified road network was converted to a raster layer with a 30-meter tile size to use as an input for the Cost Time layer.

Table 3: Road Network Classification

<table>
<tr><th>Road Type</th><th>Abbreviation</th><th>Class</th></tr>
<tr><td>Strategic Road Network</td><td>SRN</td><td>1</td></tr>
<tr><td>District Road Core Network</td><td>DRCN</td><td>2</td></tr>
<tr><td>Strategic Urban Road</td><td>SUR</td><td rowspan="3">3</td></tr>
<tr><td>Urban Road</td><td>UR</td></tr>
<tr><td>District Road Core Network (unpaved)</td><td>DRCN (unpaved)</td></tr>
<tr><td>Village Road</td><td>VR</td><td rowspan="3">4</td></tr>
<tr><td>Others/non-recognized</td><td>NR</td></tr>
<tr><td>Paths</td><td>Paths</td></tr>
</table>

Visual comparison of early model results, road network data and WorldPop population data revealed significant pockets of population uncovered by existing roads geospatial data. Further review using Bing, Google and Digital Globe satellite imagery indicated that in most cases minor roads or paths did in fact reach these population clusters. We contracted Kathmandu Living Labs, a Nepali non-profit organization specialized in open geospatial data, to “trace” major missing roads and major paths from freely available satellite imagery into OpenStreetMap. Tracing work focused on pre-determined priority areas covering roughly 7000 km^2. Tracers were instructed to connect their traced roads or paths to the nearest road or path where possible, to ensure the connectivity of the transport network data set.

Priority areas fit two criteria:

1. Population density greater than 1 person / 100m^2 in the WorldPop data set
2. Travel times to any medical facility greater than 24 hours in the preliminary monsoon model

We employed the medical facility layer as it has the greatest nationwide coverage of all the data sets. The 24-hour cutoff was chosen after a desk review of freely available satellite imagery in these areas; we determined it struck a good balance between highlighting extreme cases of error and appropriately narrowing the focus for a potentially unwieldy assignment.

Land cover and river network

Land cover determines travel times for the off-road travel surface. Our analysis employs the International Centre for Integrated Mountain Development (ICIMOD)’s “Land cover of Nepal 2010” layer as it offered the strongest combination of recentness, completeness and resolution. Additional river network data was extracted from OSM in a vector polyline format, converted to a raster and merged with the ICIMOD data set. Cells were reclassified from eight to seven categories based on expected speeds across each land surface when flat (see Table 6).

Figure 1: Maps of georeferenced data employed

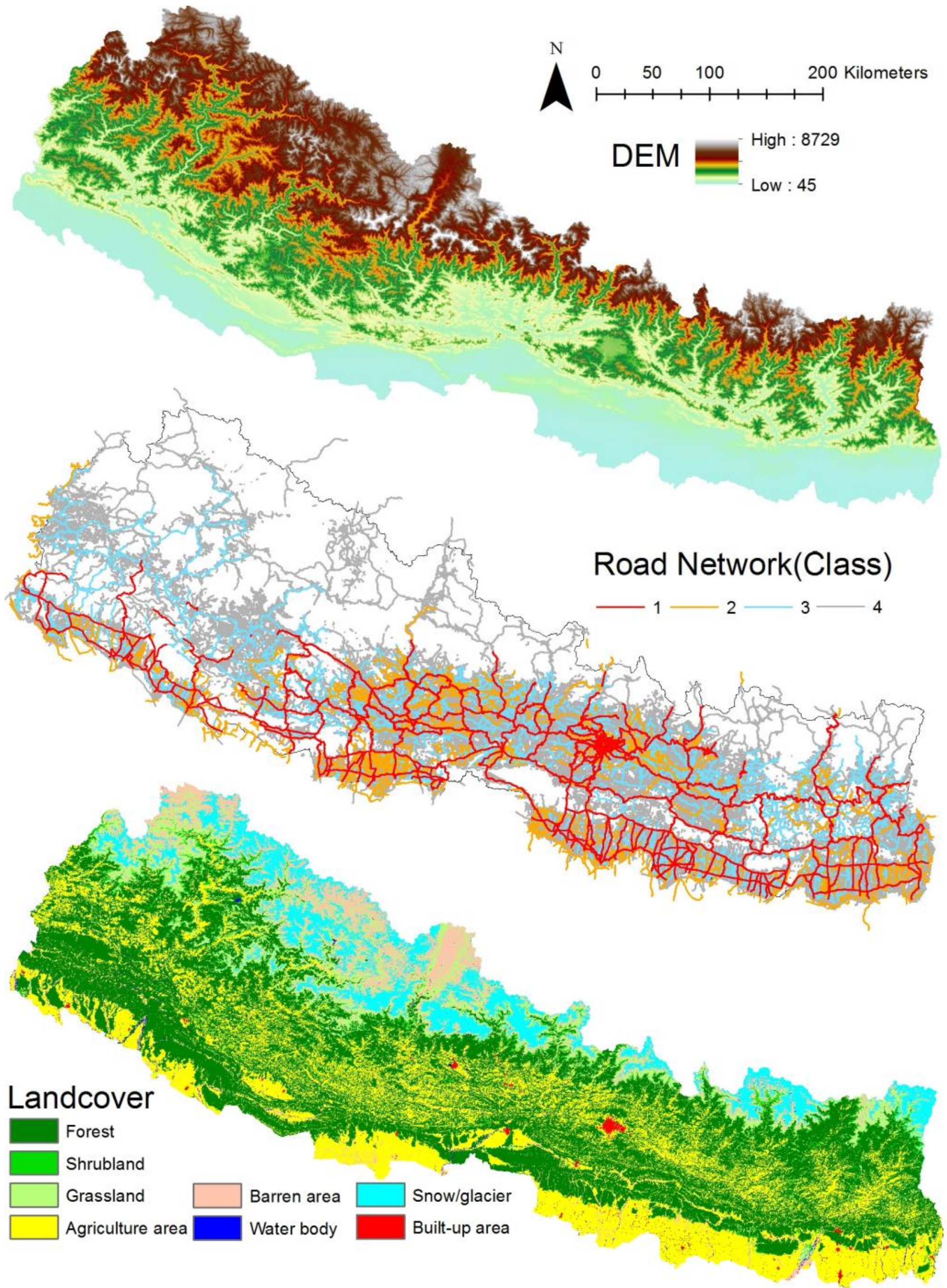
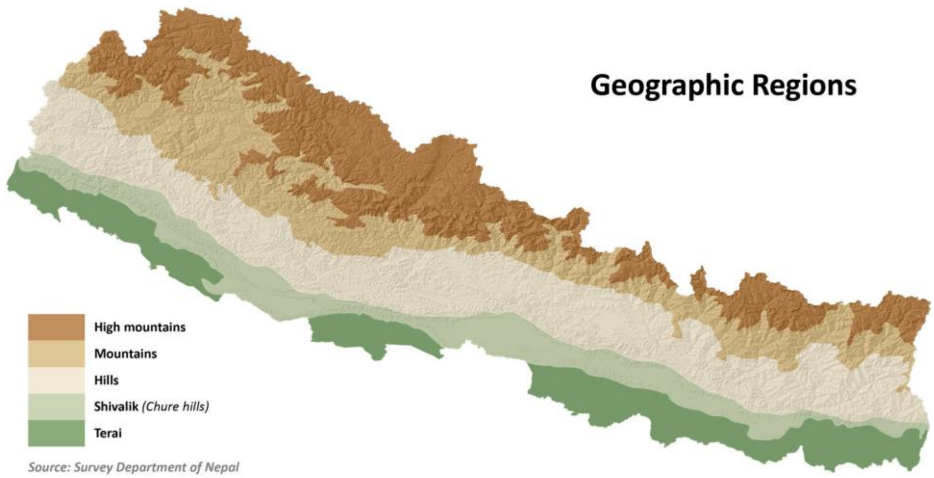


Figure 2: Geographic regions of Nepal



Methodology

Techniques and technology

In traditional geospatial analysis two principal methods are used to calculate facilities' accessibility: network analysis and cost distance analysis. As mentioned before, network analysis works by selecting the shortest path over a road network, while cost distance analysis works by selecting the shortest route over a grid of cost weighted cells.

We performed a basic comparative analysis of the two, framed by our need to rely on secondary data sets. Draft results of Network Analysis showed the routing algorithm mandating long, unnecessary detours to reach facilities due to gaps and inaccuracies in the road network data. Since entirely collecting the missing data was beyond the scope of study and walking outside the road network is an important travel modality in Nepal, we elected instead to use the Cost Distance method and its time-based corollary, Cost Time. Following the resolution of the DEM, a 30- meter mesh resolution is used for all raster calculations.

Trial network analysis calculations were performed with ArcGIS Desktop's Network Analyst. We constructed the cost distance and time models using ArcGIS Desktop's Spatial Analyst extension within a complex multi-stage Model Builder environment (see Figures 1 and 3). QGIS, PostGIS, GRASS GIS and ArcGIS Spatial Analyst were used in combination to calculate aggregate indicators and the population within various categories of travel times for each administrative unit (see next section for methodology description).

1. Calculation of distance

Path distances (in kilometers) from facilities can be calculated using the Cost Distance method. The calculated value in each cell illustrates the Cell Travel Cost in terms of distance to go through that cell. Figure 5 shows the calculation flow chart.

Consideration of Slope

Nepal’s rugged topography requires consideration of slope to understand actual surface distances covered (distances inclusive of vertical distance covered, versus horizontal linear distances). The surface distance of the raster cell can be calculated using the following formula:

Equation 1

$$\mathrm{l} = \frac{c}{\cos\theta}$$

Where:
l: Slope length
c: Raster cell size (~30m)
θ: slope angle (degree)

Traveling over steep slopes in Nepal often requires following zigzagging switchback routes. Normal trail building practices as described in the “North Country Trail Handbook for Trail Design, Maintenance and Construction” by the United State National Park Service hold 16.5 degrees (30%) as the maximum steepness for a trail (Figure 4). Residents and visiting trekkers will readily attest that Nepali trails frequently exceed these limits; therefore, this analysis sets a slope limitation of 30 degrees (57.5%). Thus, raster cells with slopes over 30 degrees adopt zigzag routes and correspondingly higher slope lengths. Equation 2 is utilized to calculate the length of switchback routes when travelers climb up hills/mountains at or over 30 degrees.

Figure 3: Slope degree

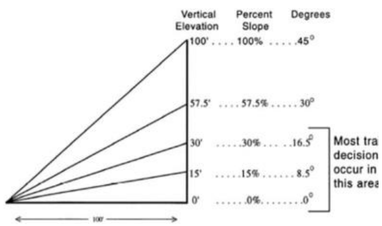
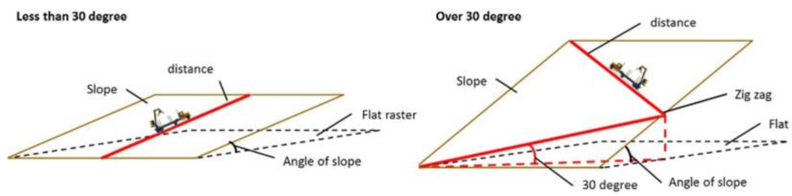


Figure 4: Zigzag route calculation



Source: Pasco., Japan Forest Technology Association (2012).

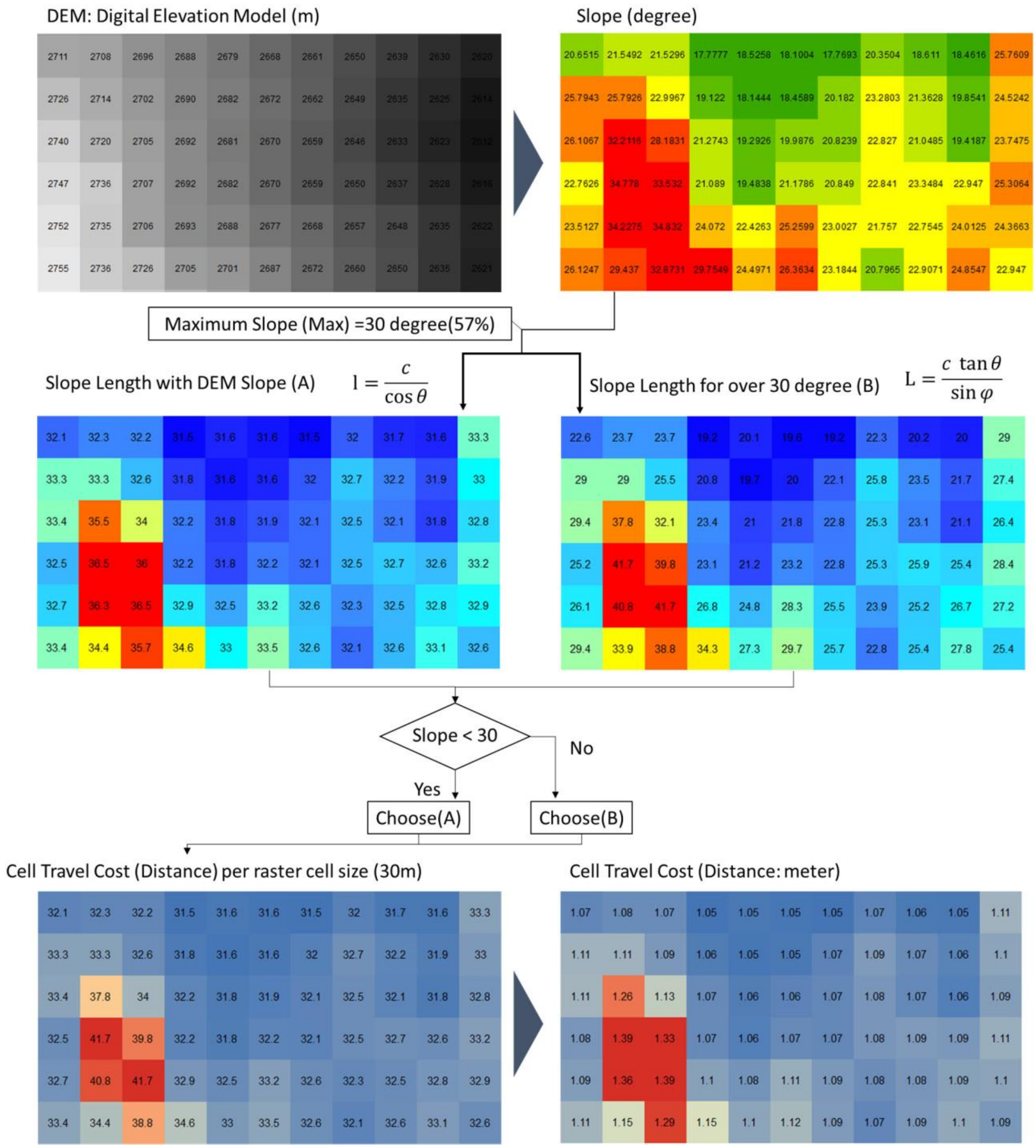
Equation 2

$$\mathrm{L} = \frac{c\ \tan\theta}{\sin\varphi}$$

Where
L: Zigzag route Slope Length
ϕ: Maximum Slope (x30 degree)

Travel distances calculated with this cost distance method cannot distinguish the difference between on- and off-road; this is therefore considered in the calculation of the travel time described below.

Figure 5: Flowchart for calculating Cost Distance



Calculation of travel time

Travel time can show the remoteness of the area/households from facilities, with consideration of the difference of speed due to the surface. Given movement constraints in Nepal this is likely a much more accurate measure of accessibility and remoteness.

Figure 6 shows the calculation flow chart. Because on-road travel is assumed to be faster than off-road travel, the model assigns walking speeds to off-road travel and vehicle speeds to on-road travel. The routing algorithm therefore prefers road network routes when available.

Calculation for on-road travel

Road network type, condition and geographic zone (Plain, Rolling, Hill, Mountain) determine the generic average vehicle speeds for each roadway type. Slope information from the DEM is attached to each element of road network data in order to categorize the speed of the vehicle by a combination of slope angle, road surface and road type.

Strategic Road Network (SRN) and District Road Core Network (DRCN) speeds (model Classes 1 and 2) are derived from the Road Classes II and III (half of the design speed) of the Nepal Department of Roads' "Nepal-Road-Standard- 2070". Class 4 speeds were determined based on reported walking path travel times from consulted organizations and individuals (notably staff from the World Food Programme and Rural Access Programme) (WFP 2018, RAP 2018).

Strategic Urban Roads (SUR), Urban Roads (UR) and unpaved DRCN speeds (model Class 3) were determined using the results of the HRVS survey. The vehicle travel speed for each household was estimated by the below equation 3. The reported distance and time to financial institutions (banks) was employed to maximize the denominator and numerator of the equation and so reduce error. The estimated average vehicle speed was roughly 11 km/hour and the average on-road slope was approximately 27% in Nepal (based on GIS calculations using DEM and road network data). These estimations were approximately half the speed for Class 2 roads in equivalent (mountainous) slopes.

Extrapolating from this, we set the speed for Class 3 to half of Class 2 for all slope categories. These speeds were then confirmed via consultations with partners.

Equation 3

$$V = \frac{\mathrm{Db} - \mathrm{Dr}}{\mathrm{Tb} - \mathrm{Tr}}$$

Where:
V: estimated vehicle travel speed of the household

Db: Distance to bank
Dr: Distance to road
Tb: Time to bank
Tr: Time to road

However, DRCN / SUR / UR / VR road types can mislead as they indicate the relative importance, not the actual size or speediness, of a given highway segment. They may also reflect road future road development plans instead of the current road state. For example, DRCNs in some areas are paved whilst in others they are improved walking paths. The latter case is typical of mountainous areas and the hills and mountains of the Far West region in particular.

Therefore, some manual adjustments were made:

- All road segments above 2400m and all Far Western DRCNs in the Hills were assigned to class 4, walking paths, unless explicitly marked as paved within the RAI data set.
- Planned roads, VR and unpaved OSM highway segments tagged as smaller than "tertiary" were also assigned to class 4, paths.
- Similarly, SRNs in the Hill and Mountain areas of the Far West are usually rough dirt roads instead of paved highways. Therefore, they were assigned to class 3 instead of class 1.

Table 4: Vehicle speed by road type and slope

Class	Road Type	Vehicle Speed, by Slope (%)			
		0-10%: Plain	10-25%: Rolling	25-60%: Mountainous	>60%: Steep
1	SRN	50 km/h	40 km/h	30 km/h	20 km/h
2	DRCN	40 km/h	30 km/h	20 km/h	15 km/h
3	SUR, UR, unpaved DRCNs, Far Western SRNs	20 km/h	15 km/h	10 km/h	7.5 km/h
4	VR, OSM paths, unpaved DRCNs (Far West), >2400m	4 km/h	2.6 km/h	1.7 km/h	0.85 km/h

Monsoon modifications

Heavy rains during the monsoon season drastically impact vehicle travel times on Nepal's poorly built and maintained roads. Travel times can increase greatly depending on the surface material and maintenance quality of the road; some areas become completely inaccessible by vehicles. Therefore, we have calculated a separate monsoon season Cost Time layer by modifying the above travel times according to the road surface and condition. Walking paths are less affected by monsoon rains and are modified accordingly. Where surface conditions are not specified a uniform modifier of 50% has been applied to all vehicular roads and 75% to all paths.

Table 5: Monsoon speed modifications

Reported road condition	% Change in Travel Time (km/h), Monsoon Season			
	Asphalt & Surface Treatment	Gravel Road	Earthen Road	Walking Path
Very Good	100%	90%	50%	90%
Good	100%	70%	40%	85%
Fair	75%	50%	30%	75%
Poor	50%	40%	20%	75%
Very Poor	40%	30%	15%	75%

Because Nepal's poorly built roads erode quickly, maintaining accurate and up to date road condition data is a Sisyphean task. Road conditions change from year to year and the Department of Roads data collection apparatuses cannot keep up, presenting an unavoidable source of error for the monsoon model. Despite this, we elected to continue using the surface ratings provided by the Measuring Rural Access team because the road network data they collected is reasonably recent (2015) and by far the most complete data set available within Nepal. Moreover, IRI ratings may not capture the precise state of the road in a given moment, but they do suggest the priority given by local and regional governments to maintaining a particular road. Therefore, for modeling purposes they are sufficient to indicate generic conditions, with some acceptance of error.

Calculation for off-road travel

Land cover type is a classifying factor for off-road, off-path walking speeds. Initial land cover data was taken from ICIMOD and additional water bodies from the OSM river network data were rasterized and merged into this data set to produce a final land cover raster. The average walking speed from the household survey (distance to the closest road / time to the closest road) was around 4.3 km per hour. We determined the walking speed over a flat surface for each landcover category with reference to similar studies such as Nelson (2000) and Black (2004) (Table 6).

Table 6: Walking speed by landcover

Landcover	Walking speed on a flat surface
Build-up area	5.0 km/h
Barren Area	3.0 km/h
Grassland	4.86 km/h
Scrubland	3.6 km/h
Agriculture area, Forest	3.24 km/h
Water body	0.06 km/h
Snow	1.62 km/h

We merge slope information with the land cover data to calculate a final walking speed. Results from Tobler's hiking function and a model by van Wagtendonk and Benedict (1980)[1] were compared to reported walking times from the household survey. We found Tobler's function yielded results most consistent with survey responses and consequently employed it within the model. Formally, Tobler's hiking function is:

Equation 4

$$W = 6\, e^{-3.5\, abs\, (\tan \theta + 0.05)}$$

Where:
W: Walking speed (km/h)
Θ: Angle of slope

The speed of a level surface is calculated to be around 5.04 by Tobler's hiking function. The following formula is used to combine the walking speed by land cover and slope.

Equation 5

$$\mathrm{V} = v\, \frac{W}{5.04}$$

Where:
V: Modified Walking speed (km/h)
v: Walking speed on flat surface by land cover

Monsoon modification

A uniform 25% reduction in walking speeds has been applied to all off-road surfaces in the monsoon model.

Combining on- and off-road results

We calculated each raster cell's "cost" in units of time by overlapping the separate off-road and on-road speed surfaces and selecting the highest value in each cell. This ensured that vehicle-based speeds are used wherever roads exist, and walking speeds are used where roads do not exist or the monsoon so badly degrades roads that walking is faster. A generic time (in hours) to travel across a cell (surface friction) is then calculated by dividing the cell travel cost (distance) by the cell travel speed (in kilometers / hour). A final travel time raster surface for each facility was computed by applying an algorithm to choose the least travel time route on the resulting Cost Time layer. By extracting these raster values to administrative areas and/or the location of households, the travel time is summarized.

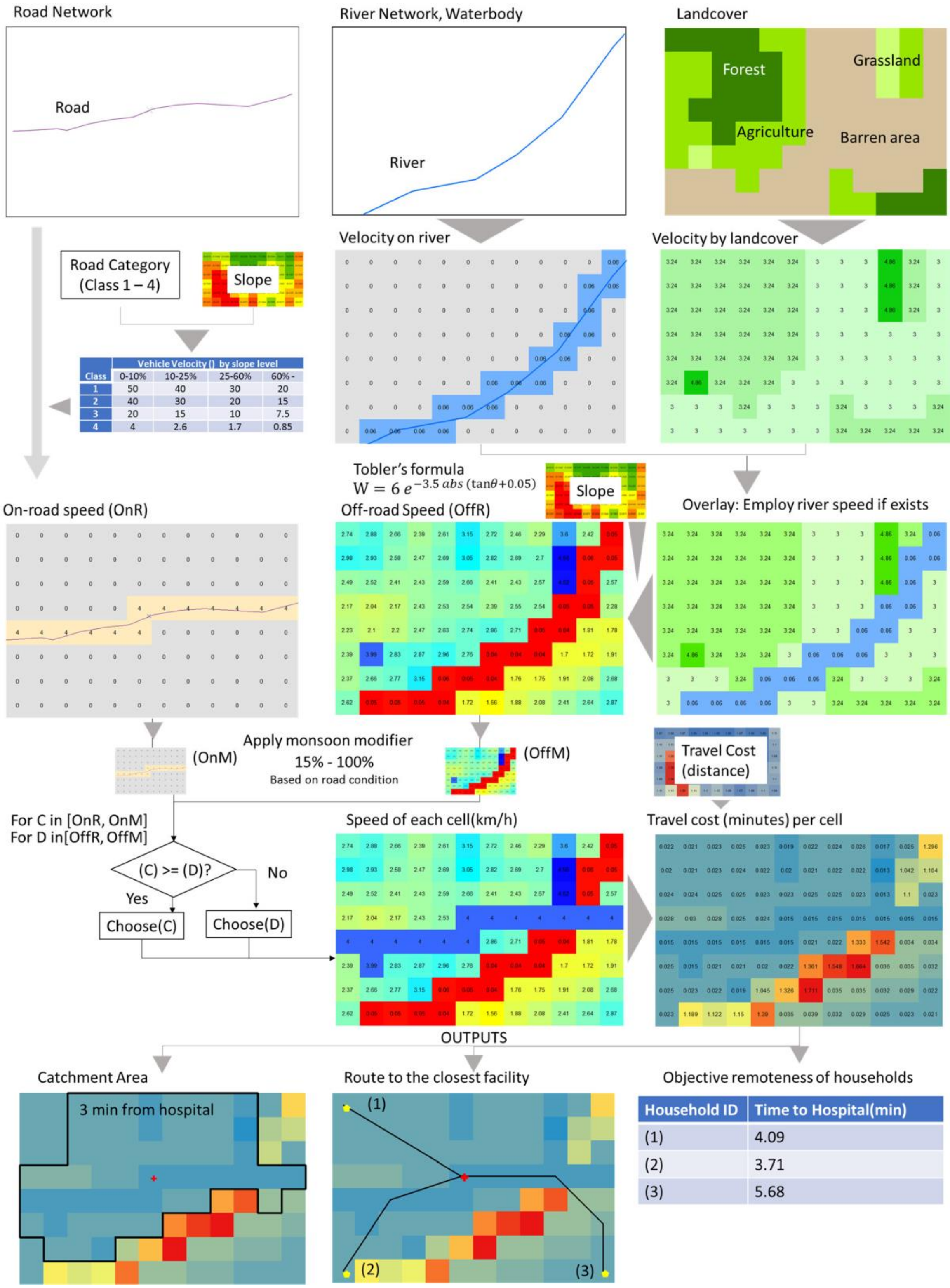
---

[1] $\mathrm{V} = \mathrm{V}_0 e^{-ks}$

Where: v = off road foot based speed over the sloping terrain, v_0 = the base speed of travel over flat terrain, 5km/hr in this case, s = slope in gradient (meters per meter) and, k = a factor which defines the effect of slope on travel speed

For this case we assume a base walking speed of 5km/hr and k = 3.0 and constant for uphill and downhill travel.

Figure 6: Flowchart for calculating Travel Time by Cost Distance



Assumptions and Limitations

Assumptions

Several simplifying assumptions underpin the final Cost Time model. Some, e.g. the absence of snowfall and landslides, are unavoidable over-simplifications given currently available data. These can be modeled in a separate simulation environment but not on a nationally representative average. Accounting for other factors, such as disabilities or encumbered travel speeds, is possible but would introduce greater errors elsewhere in the model. We may address such factors in separate future analysis, as with monsoon and walking travel.

Data accuracy

- All roads are completely accounted for
- All road surface and condition data are accurate and up-to-date
- All service facilities are completely accounted for
- All service facilities in a given category are the same in terms of services and care
- WorldPop population density data for 2015 are accurate

Travel modalities

- Walking individuals travel unencumbered, i.e. without carrying significant loads
- Walking individuals have no disabilities or injuries that affect travel speed
- Vehicles can only move on roads. Some very small roads are only accessible to motorcycles.
- There are no traffic jams.
- Planes and boats are never used for travel
- Individuals *immediately* take the fastest possible means of land transportation in a given cell. (E.g. not only do people always drive on roads, they spend no time waiting for transport to arrive.)
- Landslides, floods, snowfall, road maintenance and other movement-blocking events never occur.

Roadways

- Every travel route above 2400m is an unpaved walking path, *unless* the data set explicitly says otherwise (e.g. in Mustang).
- Every DRCN marked Hill or Mountain in provinces 6 and 7 is an unpaved walking path, *unless* the data set explicitly says otherwise.
- Every SRN marked Hill or Mountain in provinces 6 and 7 is an unpaved road, *unless* the data set explicitly says otherwise.

Limitations

We must note several limitations to this model and the resulting analysis. Localized inaccuracies in our model are inevitable given the contrast between the high resolution of the data set and local shortcomings in input data quality and completeness. Errors in coverage or geolocation from the service data sets, sourced from relevant ministries, would naturally lead to inaccuracies in the model outputs. For instance, we were unable to source a complete, high- quality bridges data set that aligned with spatial data on rivers. Therefore, roadways crossing rivers were the only representation of bridge crossings, which are important chokepoints for transportation in Nepal’s hills. We assumed walkers used these vehicle roads for river crossings, although in reality walkers in rural Nepal commonly use trail bridges and cable-pull tuins. Thus, the model may exaggerate travel times in some areas where walking is the principal modality.

Elsewhere, roads data present a different source of error. Chamberlin (2013) has noted that roads data sets in models are only "snapshots" of present conditions that fail to capture changing dynamics, a charge that applies to our analysis. This is problematic in Nepal, where even a casual observer will note that road quality changes frequently due to poor construction standards and maintenance practices. Deteriorating roads impact travel times, particularly during monsoon season and therefore we anticipate some error where road quality data are out of date.

All service facilities data sets were exclusive to Nepal and the lack of cross-border facilities represents a possible source of error in border communities. However, these communities are either very small in the High Mountains, or usually already well served by Nepal-based services in the Terai. So, the influence of border-based errors on aggregate numbers is likely minimal, though possibly locally impactful in some border municipalities. Care is advised when interpreting numbers from border municipalities with clear roads or paths to China or India.

We also acknowledge the importance of service quality, although our analysis ignores it for lack of data. Frequent staff absenteeism, inadequate supplies and/or poor quality services are common problems for schools, clinics and government offices in Nepal, particularly in remote areas, and impact usage patterns and development outcomes (RAP 2018, IDEA 2018). We therefore caution readers applying our findings in small-scale areas to research the impact of quality on usage of local services.

The assumptions listed above naturally impact the model's accuracy, especially those regarding unencumbered travel and waiting for vehicles, both of which would slow down travel times in practice. Conversely, local residents tend to walk faster than visitors on local paths, somewhat offsetting these factors (RAP 2018). Users should remember that details of the local context like bus schedules and the frequency of landslides will cause departures from the model findings; we recommend careful analysis of such conditions when applying our findings on a small scale. Road-blocking landslides in the monsoon and snowfall in the winter can have particularly dramatic effects on local transportation conditions.

Model validation

Consultations

We performed a thorough desk review of the model results to verify their general accuracy, consulting with peer organizations where necessary to ensure objective and comprehensive feedback. Our own knowledge of travel times in various locations was used to spot check the initial model results and make adjustments. After revisions, we consulted outside parties. The World Bank's Far West Nutrition Program team provided us with detailed feedback on the accuracy of modeled travel times in the Far West using pre-recorded point-to-point travel times from their trips to the region. Externally, we separately consulted with engineers and logistics specialists at the World Food Program's Nepal Country Office and managers at the Rural Access Programme (RAP) to compare model travel times with actual travel times in areas where they work.

Based on these conversations, several adjustments to the draft models were made, for example reductions of walking path speeds and reductions of roadway status above 2,400 meters and in the Far West. Our consultations revealed that model travel times were usually 15-20% too fast in most areas, especially over footpaths, and the model was consequently adjusted downwards. WFP logisticians also provided the principal inputs for monsoon season travel speed modifiers.

Comparison to household survey data

Data from the "Nepal Household Risk Coping and Vulnerability Survey" (HRVS), a geo-referenced nationwide survey, were used as a reference to estimate travel speeds and to validate model results. This survey randomly sampled 6,000 households from 500 primary sampling units (PSU) nationwide.[2] The survey collected considerable locational information from households: GPS locations, names of villages and estimated average travel time and distance to markets, hospitals, banks, schools, and vehicle roads. To ensure the accuracy of the GPS data, this study employs data from three successive years from 2016 to 2018. For the purposes of this analysis GPS locations that fall outside the boundary of the listed village were eliminated from that year's data set. This process narrowed the data set to 6,250 households from 6,367. If the GPS of more than a year fall within the boundary, we compute the household location as the geographic average of the GPS data.

Table 7 summarizes the mean and median time to the facilities based on HRVS result and the developed model (regular and monsoon). To comparing the modeled remoteness with the survey results, households with travel times over 8 hours are dropped, expecting that people will not walk over 8 hours per day and will take a long rest overnight, where the time for resting is not captured in the model. Roads are most accessible to households, while banks are least accessible. The final model results for the location of a household GPS point were spatially joined to the HRVS data and regressed against reported times to validate the final results. Figure 7 plots the regression results.

Table 7: Comparison of model times to Reported travel times (HRVS)

	Road *(excluding path)**			**Medical Facilities**			**Bank**		
	HRVS	**Normal**	**Monsoon**	**HRVS**	**Normal**	**Monsoon**	**HRVS**	**Normal**	**Monsoon**
Mean Time *(min)*	30.18	28.62	32.94	38.88	39.9	44.52	86.4	62.4	67.2
Median Time *(min)*	10.02	9.54	10.92	25.02	20.82	22.2	45	28.2	29.52

** Road excluded path and VR, as the HRVS questionnaire asked about time to drivable or black-topped road*

The results show a rough but inexact convergence between reported travel times and model results. This can also be seen when comparing the sample charts of provincial aggregates in Figures 8 and 9. Our analysis is that this reflects both model and survey error. As alluded to above, there are known localized shortfalls in the quality and completeness of our model input data that present unavoidable sources of error. These are most notable for bridge crossings, road categories and conditions, and some service locations (e.g. private health facilities). Unfortunately, gathering the outstanding data at a sufficient level of detail was impossible given the uneven conditions of data generation and sharing in Nepal.

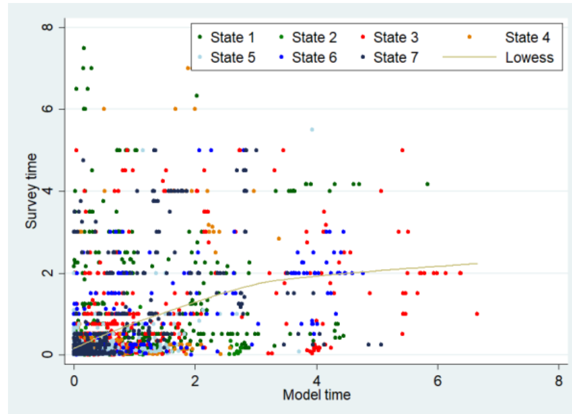
[2] The HRVS sample frame was all households in non-metropolitan areas per the 2011 Census definition, excluding households in the Kathmandu valley (Kathmandu, Lalitpur and Bhaktapur districts). The country was segmented into 11 analytical strata, defined to correspond to those used in the Nepal Living Standards Survey (NLSS-III: excluding the three urban strata used there). To increase the concentration of sampled households, 50 of the 75 districts in Nepal were selected with probability proportional to size (the measure of size being the number of households). PSUs were selected with probability proportional to size from the entire list of wards in the 50 selected districts, one stratum at a time. 5,835 households out of 6,000 in the survey 2016 were re- surveyed in 2017 and an additional 170 households were surveyed only in 2017. Similarly, an additional 197 households were surveyed in 2018 only.

Figure 7: Final model results for HRVS households regressed against reported travel times

Regular season model | Monsoon season model

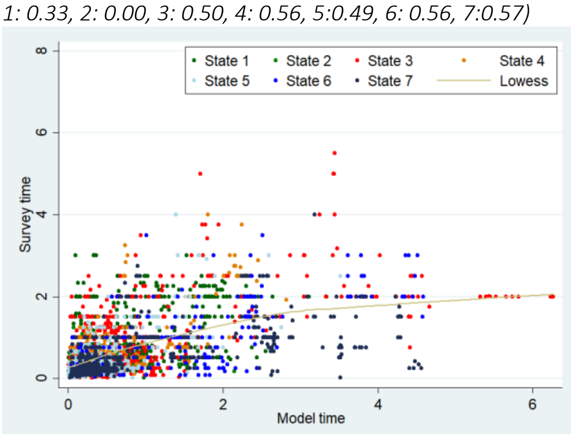
Road: R=0.47

(By state:
1: 0.33, 2: 0.00, 3: 0.50, 4: 0.56, 5:0.49, 6: 0.56, 7:0.57)



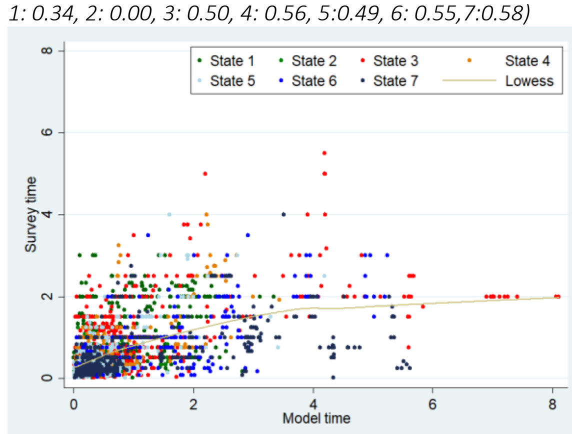
Road: R=0.48

(By state:
1: 0.34, 2: 0.00, 3: 0.50, 4: 0.56, 5:0.49, 6: 0.55,7:0.58)



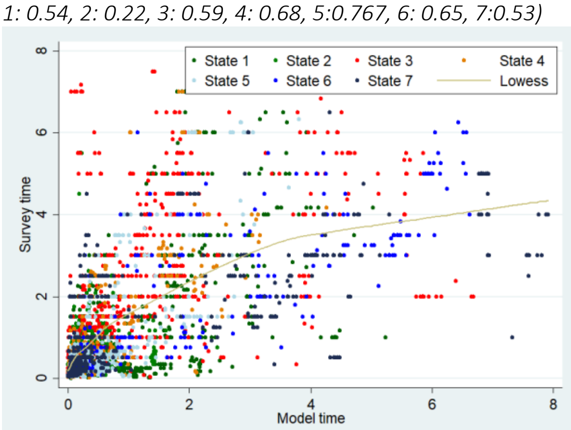
Medical Facility: R=0.59

(By state:
1: 0.54, 2: 0.22, 3: 0.59, 4: 0.68, 5:0.767, 6: 0.65, 7:0.53)



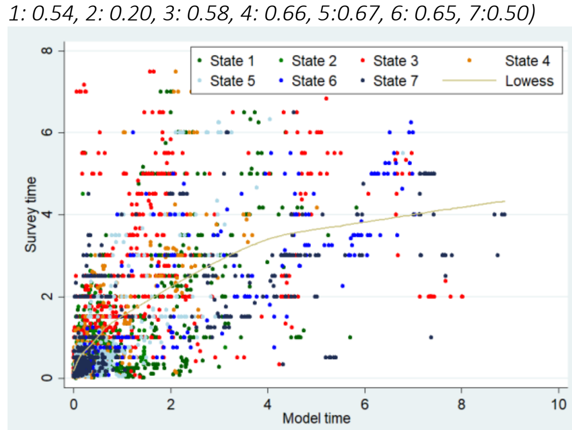
Medical Facility: R=0.57

(By state:
1: 0.54, 2: 0.20, 3: 0.58, 4: 0.66, 5:0.67, 6: 0.65, 7:0.50)



Bank: R=0.63

(By state:
1: 0.60, 2: 0.13, 3: 0.57, 4: 0.75, 5:0.79, 6: 0.77, 7:0.73)



Bank: R=0.63

(By state:
1: 0.61, 2: 0.12, 3: 0.56, 4: 0.76, 5:0.79, 6: 0.76, 7:0.72)

More importantly, reported travel times from surveys are both unreliable and idiosyncratic. In the case of the HRVS data set we believe the variable accuracy of recorded GPS locations disproportionately influenced the rate of convergence where average travel times were low. GPS error within the HRVS data set was high and inconsistent due to the use of multiple tablet models when collecting survey data. As reported above, we discarded 117 GPS points (2% of the total) that fell outside the reported village (ward) boundary, deeming them erroneous. However, we could not assess the quality of points that fell within ward boundaries, many of which may have fallen far from the actual household location.

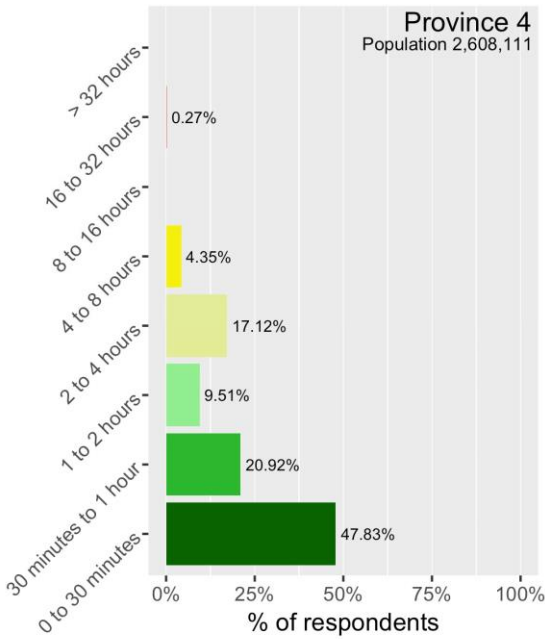
We believe this led to dramatic relative differences where average travel times were low. For example, 12 minutes modeled and 2 minutes reported yields a 600% difference in results, whereas 130 minutes modeled and 140 minutes reported elsewhere yields only a 7% difference. When assessed comparatively the former will return a poor coefficient of correlation even though in absolute terms the difference is insignificant.

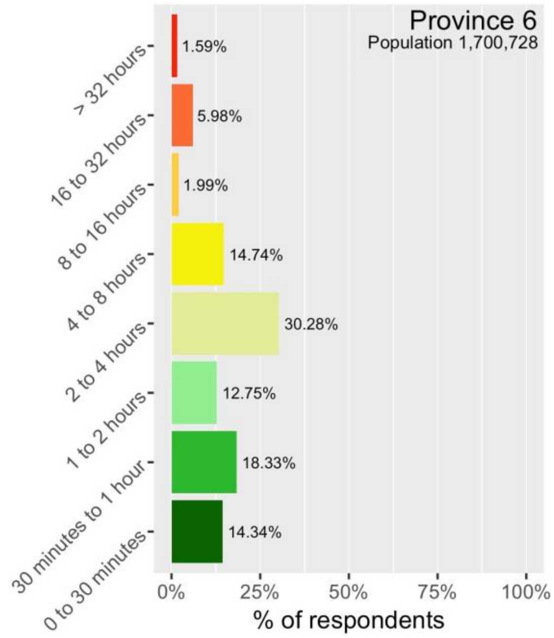
This explains the substantially poorer R value for Province 2, where mean and maximum travel times are much shorter than in other provinces. Subdividing by geography (see Table 14 and Figure 28, Annex III) reinforces this analysis; correlations for households in the Terai are low, yet Terai data clusters close to the regression line in absolute terms. Explaining the low coefficient of correlation in mountain areas is more difficult. It may be that erroneous points there are more likely to return very high travel times because the majority of mountainous areas are very remote. Maps of model results clearly show islands of good access to services clustering near the very few roads and paths in mountainous areas, amidst figurative seas of high travel times (see Figure 27, Annex III). A misplaced GPS point in this environment could easily return an extreme value.

Paradoxically, in Figure 7 the estimated Loess regression lines and a 45° line are close in *absolute* terms for short distances (roughly 30-45 minutes). This indicates that survey based data may be used confidently in this range (for example, for analysis of accessibility to schools) but researchers and policy makers should employ alternative data, such as our model, for analysis of larger distances. Importantly, this finding does not appear to hold for banks.

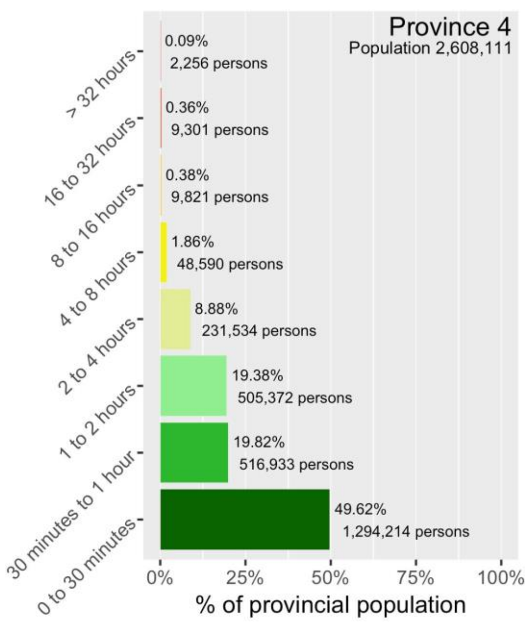
When survey-specific shortcomings are considered alongside the household idiosyncrasies noted in the literature review, the reported coefficients of correlation for model data vs. the HRVS data appear reasonably strong. The clearest point of comparison is a study in Sri Lanka, where comparison between cost time models and surveyed travel times using a ground-validated model and GPS points still yielded 30% variation in reported travel times around the model mean for the area of study (Ahlström *et al*. 2011). Despite limited ability to validate model inputs and household survey points, and the above-mentioned GPS inaccuracies, our reported R values do not greatly exceed this 30% band. Therefore, while it is impossible to guarantee the accuracy of the model at every point in Nepal, we are confident in its analytical validity.

Figure 8: Dry season accessibility to financial institutions in Provinces 4 and 6 Reported (HRVS) accessibility





Modeled accessibility



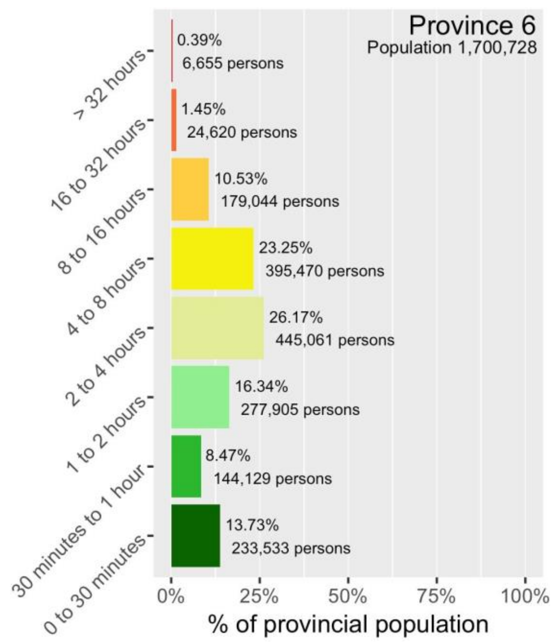
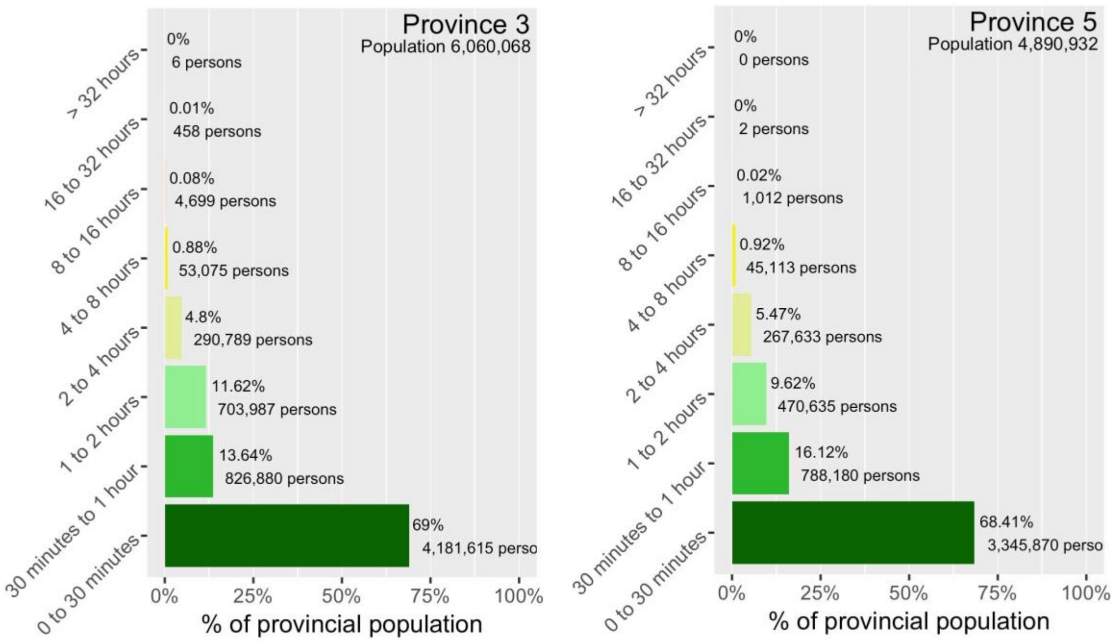
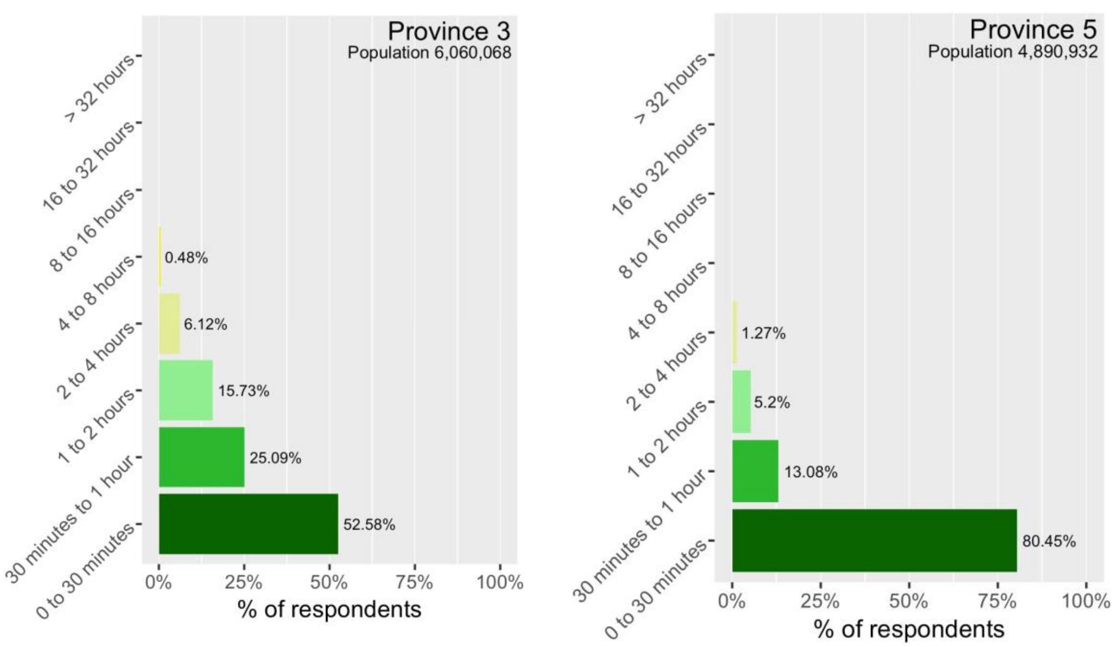


Figure 9: Dry season accessibility to health facilities in Provinces 3 and 5 Reported (HRVS) accessibility



Modeled accessibility



Analysis Process

Generic cost distance and cost time raster travel surfaces enable powerful analysis of accessibility and remoteness in relation to specific individuals, areas or types of features. Travel times to specific locations and services can be quickly computed and updated as new data become available. Because of its fine scale the model generates useful information at almost any scale. However, it is important to stress that this model should be understood as an overview, a means of generating estimates and comparing them across areas. For any small-scale area, we recommend validating these estimates locally.

Table 8: Service facilities

Category	Sub-category
Health facilities	*All*
	Health posts and sub-health posts All hospitals Government / Private hospitals
Financial institutions	*All*
	Class A - B
District headquarters	*All*

Below we briefly summarize the process for and results from a descriptive analysis of model indicators at various administrative levels for the services listed in Table 8. We produced two types of analysis: summary statistics and population breakdowns within travel time categories. We discuss the methodologies for producing these in turn, then provide descriptive analysis.

Summary statistics

Within a GIS software point vector, data for each facility type were overlaid onto the generic cost time surface to generate facility-specific least cost travel surfaces (see Figure 10). Further layers were created for relevant sub-categories of facilities, e.g. health posts and hospitals or primary and secondary schools (see Table 8). This analysis was repeated for the monsoon season using the monsoon travel modifiers described above, and for both normal and monsoon seasons at walking speed. The latter analysis is included in the annex for use by researchers but not described in this report.

For each combination of service type, season and travel modality we calculated two summary statistics:

1. The cumulative person-hours to reach that service, aggregated across that administrative area.
2. The average travel time for the average resident

We first calculated the cumulative person-hours of travel by downsampling the cost time rasters from 30 meters resolution to WorldPop's 100m resolution, then multiplying the WorldPop gridded population density data set by the cost time raster for the service and season in question. This yielded the total travel hours to reach the given service for each grid cell. The results were then summarized for each administrative level using a Zonal Statistics function. In producing this metric, we closely followed the methodology of the Department of Roads' 2007 Priority Investment Plan (PIP) (DHV *et al.* 2007).

Cumulative hours of travel strike an effective, easily interpreted balance between inaccessibility indicators and population density. For example, multiplying 10 hours times 1 person will produce the same results as 1 hour times 10 persons. However, an area with a population density of 0.001 times 100 hours will only yield 0. 1 cumulative hours. The formula thus mitigates the impact of largely unpopulated areas, common to hill and mountainous areas of Nepal. When aggregated by an administrative unit (municipality or ward), this metric allows planners to visualize where accessibility-enhancing investments would be most impactful.

Following these operations, we divided the cumulative hours of travel for an administrative unit by its population to calculate the average hours of travel per person to the service in question. These averages provide useful headline indicators of municipal accessibility and another data point for rapid comparison between administrative units.

Equation 6: Cumulative travel times

$$C_{sa} = \sum_{i=1}^{I_a} (PD_i * TT_{si})$$

Equation 7: Average travel times

$$A_{sa} = \frac{\sum_{i=1}^{I_a} (PD_i * TT_{si})}{Pop_a}$$

Where,

a = administrative unit

s = service, season and modality

i = grid square

I_a = total grid squares in administrative area *a*

PD_i = Grid square population density

Pop_a = administrative unit population

TT_{si} =*Travel time from grid i to service location s*

A_{sa} = Average travel time to service *s* in administrative unit *a*

C_{sa} = Cumulative person-hours of travel to service *s* in administrative unit *a*

Isochrone analysis

We analyzed isochrones, a.k.a. travel time categories, to detect variations in accessibility *within* administrative units and ensure remote populations were not obscured by administrative aggregates. Isochrones are areas enclosed by an isoline representing an equal travel time from a given point, in this case a service facility. We classified isochrones for each facility or facility category layer according to the following rubric:

Table 9: Travel time classifications

Single day	
Class	**Time** *(in hours)*
1	0 – 0.5
2	0.5 - 1
3	1 – 2
4	2 – 4

Multi-day	
Class	**Time** *(in hours)*
5	4 - 8
6	8 - 16
7	16 – 32
8	32+

A further analysis routine followed. Each facility-specific cost time raster file was converted to a polygonal vector data set with each travel class forming one polygon. We then imposed provincial and local government unit boundaries onto these polygons. Finally, we aggregated the population per travel class per administrative area based on the WorldPop 2015 UN Adjusted population density data set. To show the percentage population breakdown for each travel class in each area we divided each polygon's population by the total population for its administrative or physio-geographic area. Figure 10 illustrates this process in detail. Simple bar charts were then prepared to visualize the results and accompany the maps in Figure 11.

Figure 10: Analysis process for calculating population coverage by administrative unit

The output layers of this analysis enabled cartographic visualization of accessibility at various spatial scales and data- driven analysis of remoteness by administrative area, as visualized in Figures 8 to 27 and described below. Overview charts and maps were generated for every municipality, province and physio-geographic area (as defined by the Department of Survey). Because national and provincial boundaries cut across mountains, hills and plains, aggregate national and provincial numbers mask significant variation between local government units. Therefore, alongside aggregate bar charts, we prepared a series of scatterplots showing the dispersion of population in each travel category across local government units. We overlaid cumulative line charts on these to contrast individual LGU indicators with aggregate provincial or physio-geographic trends (samples shown in Figures 18 to 26).

Illustrative examples of the resulting maps and charts are shown below. A complete set of these visuals can be found in a separate web page, to be published soon. Tables of average travel times per administrative or physiogeographic area, for each facility type or sub-type, in every season are provided in Annexes I and II. Accompanying shapefiles and raster files are published on the Nepal GeoNode[1].

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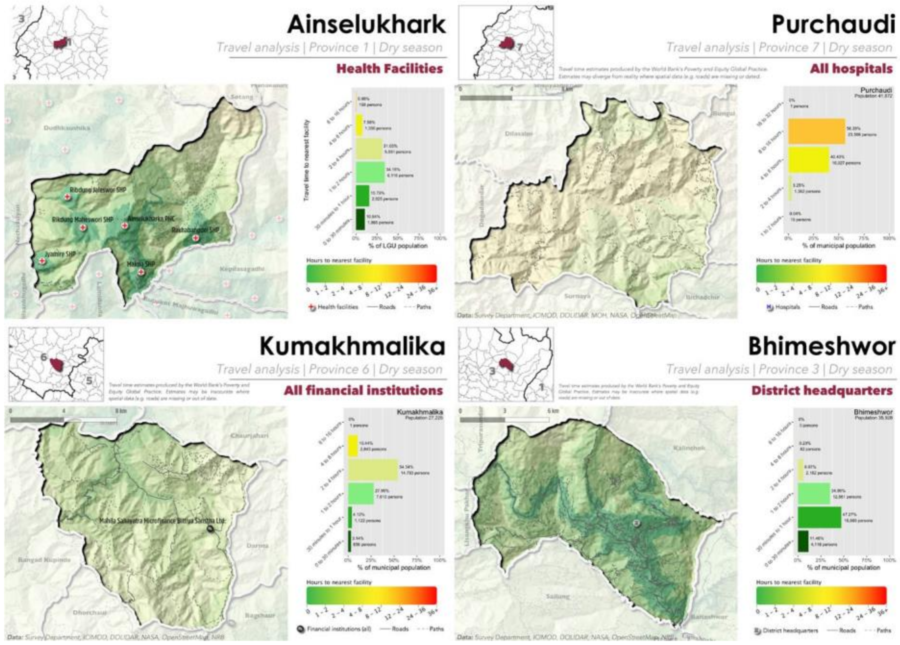
[1] The GeoNode is a geospatial data sharing platform being set up by the World Bank and others in Nepal. A draft version can be accessed at https://geonepal.info

Figure 11: Example travel cost map for municipalities, by administrative area



Results

Based on the outputs of the above analysis route, we prepared a high-level descriptive analysis of physical accessibility trends at the national, regional, local and geographic levels. We used a combination of charts, maps and statistical tools to do so. Given the size and complexity of the data set this is meant as a useful overview rather than a comprehensive treatment of the subject and we invite those interested to further probe the data or visuals. We also note that this analysis can be reproduced with alternative, custom data sets, assessed in more limited areas of interest within Nepal or pushed down to the ward level and we encourage interested parties to do so. The necessary code, scripts and data are published on Github and the Nepal GeoNode (https://geonepal.info).

Our analysis references a number of tables, charts and maps. For the sake of readability and narrative flow the majority of these are contained in the Annexes to this paper.

When assessing these results, we make two critical assumptions:

- Travel over 4 hours (one way) entails an overnight stay in the destination location.
- Travelers will travel a maximum of 10 hours per day.

We recognize that these assumptions oversimplify travel decisions that depend greatly on the individual, season and circumstances. In particular, individuals may travel well in excess of 10 hours per day when necessary. Nonetheless, our consultations with local actors experienced in transport planning indicate these are reasonable, sufficiently accurate general-purpose standards (RAP 2018).

National and geographic areas

Average travel times

At a national level average travel times for all services increase steadily, rather than sharply, from the dry to monsoon seasons (see Figure 13 and Table 10). Population weighted average travel times across all municipalities, for all services, are at or under 2 hours travel in dry and monsoon seasons and mostly fall well below that. The differences between all financial institutions and commercial and development banks (classes A & B) only are marginal and largely indistinguishable. Private hospitals are on average less accessible than government hospitals.

The geographic breakdown of these averages in Figure 13 and Table 11 nuances our findings. Travel times again increase steadily across all services from the dry to monsoon season. As expected, there is a strong deterioration in accessibility moving upwards from the flat Terai into Nepal's rugged highlands. Average travel times increase gently at first into the hills and then exponentially so in the mountains and high mountains, in many cases averaging full day round trips to services. An additional finding is the relative inaccessibility of services within the Shivalik region when compared to the Terai. Nepal's south is commonly treated as one geographic unit, yet indicators in Shivalik municipalities fall slightly closer to those of Nepal's middle Hills than the Terai. Lumping the Shivalik in with the Terai therefore obscures notable service accessibility challenges for the approximately 3.5 million Nepalis (8% of the total population) living there.

A few notable geographic trends for specific services stand out. Average travel times to health facilities and health posts increase much less dramatically in the hills and mountains than travel times to other services. By contrast, travel times to hospitals and district headquarters are much higher in the hills and mountains, averaging multi-day round trips. Financial institutions fall roughly between these two extremes. An interesting finding that we cannot explain is that private hospitals are marginally *more* accessible in the Shivalik than government hospitals, in contradiction of the general pattern of greater accessibility of government services.

Isochrone times

Comparing Figures 15 to 17, administrative and financial services are less accessible than health services, particularly administrative services. However, while basic health care appears accessible to many, access to advanced hospital-based medical care is considerably poorer: almost 10% of the population requires overnight travel to access a hospital. The implied difficulty and opportunity costs are troubling given that chronic or severe medical conditions may require multiple visits and/or travel while in pain or partially incapacitated. Without adequate overland access remote Nepalis may have to use financially ruinous helicopter evacuation for time- sensitive critical medical care. Additionally, almost 40% of the population lives more than 30 minutes from a health post or sub health post (SHPs), far beyond the Department of Health Services' goal of under 10% from its 2016-2017 strategy (DoHS Annual Report 2072-2073).

Almost 40% of Nepalis live more than 30 minutes away from a formal (class A-D) financial institution. Research indicates that small formal and informal local providers meet most financial services needs in remote areas; diseconomies of scale mean that their users usually pay more for fewer and worse quality services (Shakya *et al.* 2014). For those willing to travel finance companies and micro-finance institutions (Class C and D financial institutions) are reasonably accessible throughout the country but commercial and development banks (Class A and

B) can require overnight travel in some areas. The heavy opportunity cost of accessing more advanced financial services likely acts as a brake on economic activity and business expansion in remote areas. More worryingly it complicates the delivery of remittances and cash-based social assistance to marginalized areas. Given that remittances constitute over 30% of Nepal's GDP this is a pressing economic issue (World Bank 2018).

As seen in the analysis of average travel times, geography heavily determines remoteness. For example, the percentage of population within the Ministry of Health's standard of 30 minutes travel to a health post falls from 81% to 46% to 14% in the Terai, Hills and Mountains respectively. More broadly, the percentage of population within a full day's round-trip travel of any health facility falls from roughly 99% in the Terai to 98% and 87% in the Hills and Mountains respectively. The contrast between access in the Terai/Hills/Mountains to financial institutions and district headquarters is starker, with <1/6/39% and <1/14/60% of the population outside a full day's travel for each. Clearly residents of the Mountains suffer from both relative and absolute extremes of remoteness for administrative and financial services. Also, indicators for the Shivalik again fall slightly closer to hill than Terai indicators, underlining the importance of assessing the Shivalik separately from the Terai itself.

Comparison with charts subdividing normal season averages by geography (Figures 22 to 26) nuances these findings. Populations with low accessibility to services are concentrated in the Hill, Mountain and High Mountain physiogeographic regions, sometimes dramatically so. Provincial averages thus offer an incomplete picture, as municipalities in the Terai and Shivalik offset poor accessibility indicators in hilly and mountainous municipalities of provinces 1 & 3-7. The distinctly better aggregate indicators for province 2 described below make sense in this context. Furthermore, aggregate accessibility patterns for geographic regions are distinct and persistent across all services, without the natural clustering observed for provinces 1, 3-5 and 6-7, also described below. Figure 20 illustrates both these trends: geographic splits are replicated across provinces and even within high-performing province 2, indicators for municipalities in the Shivalik region are notably worse.

Cumulative travel times

Since the cumulative hours of travel are a somewhat abstract measure, we have emphasized spatial analysis for understanding the outputs in comparative terms. Mapping reveals interesting nuances to the spatial patterns described elsewhere in this paper.

Most notably, cumulative needs are as great or greater in areas of the middle hills than in the more physically remote mountain areas. The much higher populations of hill municipalities appear to balance or outweigh the elevated remoteness of mountainous municipalities when comparing relative need. Even some areas of the western and central Terai show surprisingly high levels of comparative need for health facilities, hospitals and district headquarters, despite the better infrastructure, easier terrain and relative abundance of services in these areas.

Health facilities are relatively well dispersed across the nation with only a few pockets of concern in the Far West. Indicators for district headquarters and hospitals are notably higher, alarmingly so for hospitals given their irreplaceable function in the health care system. Financial institutions and class A and B banks in particular fall somewhere in between, with moderate-high cumulative hour totals peaking in several concentrated areas in the Far West.

Accessibility indicators deteriorate steadily across the country during the monsoon season, with elevated levels of deterioration in hilly and mountainous areas of the Far West. When comparing dry and monsoon season maps, viewers should keep in mind that the chromatic scale employed is exponential, with progressively larger ranges. Therefore, visible shifts in category from dry to monsoon season reflect substantial deteriorations in accessibility, particularly at higher levels.

Provinces

Average travel times

Visible in the data are three distinct groups of provinces for average travel times. Aggregate accessibility indicators are best in province 2, worst in province 6 and 7 (the Far West) and in between for provinces 1 and 3-5. Within the middle group itself provinces 1 and 4 consistently have similar, slightly poorer indicators than provinces 3 and 5.

At a service level the provincial breakdown illuminates a few subjects. The trend for private hospitals to be less accessible than governmental hospitals is reversed in provinces 3 and 4, likely reflecting their excessive concentration in the richer, more lucrative Kathmandu and Pokhara metropolitan areas. District headquarters, already the least accessible on average of all services, are dramatically less accessible in the Far West than elsewhere, averaging roughly a full-day round trip even in the dry season. Otherwise service-level trends are much the same as in a national analysis and must be explored through isochrones and cumulative indicators for further insights.

Cumulative travel times

Cumulative hours of travel are consistently higher in municipalities in provinces 6 and 7 across all services, and also spike in some parts of the middle hills and Shivalik regions of provinces 3 and 5. This is surprising in province 3, given the proximity of these areas to the services in and transport arteries around the capital Kathmandu, and warrants further investigation. Beyond these broad impressions, cumulative travel analysis is best conducted at the municipal or ward level as differing populations and diverse local dynamics make provincial indicators too broad to impart meaningful information to planners.

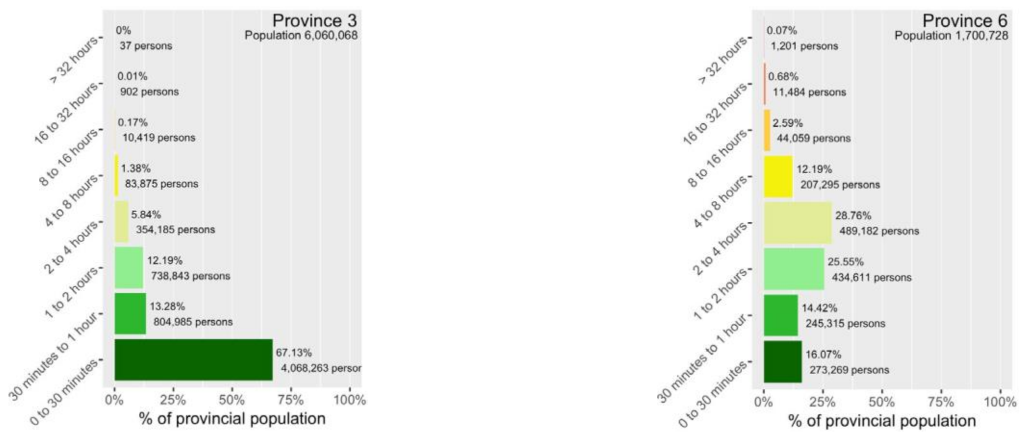
Isochrone analysis

The national averages shown in Figures 15 to 17 mask diverse patterns of accessibility at the provincial government level, for example in monsoon season access to health services in provinces 3 and 6 (Figure 12). Across all services Far Western provinces 6 and 7 generally fare worst and the Terai-based province 2 best. Similarly, monsoon conditions impact the Far Western provinces most and the central, relatively urban province 3 least.

Figure 18 - Figure 26 highlight these patterns by overlaying cumulative population totals for each travel time category, per geography or province, onto scatterplots of municipal population figures across the same categories.

Former district headquarters require over two hours of travel for 10-20% of individuals in provinces 1, 3, 4 and 5 and an outright majority in provinces 6. In province 7 the *majority* of citizens will require an overnight trip to reach a former district headquarters. Given that critical government services continue to cluster in former district headquarters due to staffing and equipment shortages, and many new municipal staff find excuses to work from their relative comforts, this suggests that the opportunity costs of accessing governmental services are steep for many Nepalis (IDEA 2018).

Figure 12: Comparing monsoon season access to heath facilities in provinces 3 and 6



In province 2, the only province entirely within the flat Terai, the vast majority of the population falls within two hour's travel of all services in dry and monsoon seasons. The other, more mountainous, provinces have poorer and more diverse levels of overall remoteness, as well as greater variation between average travel times to different service facilities and average travel times in dry and monsoon seasons. Services in Nepal's eastern province 1 are slightly less accessible on aggregate than in central provinces 3, 4 and 5, and services in western provinces 6 and 7 are markedly less accessible than elsewhere. In particular residents of the Far West experience much greater average travel times to commercial and development banks, hospitals and government administrative services.

Municipalities

Average travel times

Dividing municipalities into quintiles by average travel times to various services (see Table 10) reveals extremes ranges of physical accessibility indicators. Most services show very low average travel times for all services in the 1st and 2nd quintiles, low averages in the 3rd quintile, medium to high averages in the 4th quintile and exponentially worse averages in the 5th quintile. Results are notably poorer for district headquarters and all types of hospitals. The high standard deviations imply considerable variability in averages between municipalities, as illustrated by Figure 18 - Figure 26. The deterioration in average travel times from dry to monsoon season is steady but relatively undramatic, even in the higher quintiles. Mapping the results shows a predictable, exponential rise in average travel times from Terai municipalities up to northern mountainous municipalities.

Cumulative travel times

Cumulative travel times for individual municipalities are highly idiosyncratic and frequently contradict geographic or provincial averages. Figure 14 reveals some spatial autocorrelation in cumulative inaccessibility, for example clusters of adjoining municipalities with high cumulative hours of travel to hospitals in the Far Western hills and Terai. But these maps also show a number of outlier municipalities where services are significantly more or less accessible than surrounding municipalities, likely due to isolating geography. Extrapolating trends in this context is impossible and we recommend analysts and planners reproduce these maps in their area of interest to isolate local cumulative travel dynamics.

Isochrone analysis

In Figure 18 - Figure 26 the wide spread of municipal averages for every travel time category, in every figure, underlines the diversity of travel patterns at the municipal level and the tendency for well-served population centers to obscure serious localized shortfalls in remote areas. The results are diverse and mostly specific to the facilities observed, but a few patterns emerge. Wide spreads between municipal averages are most common for travel times under 4 hours (single day round trips). Significant numbers of outliers are clearly visible for most facilities between 4 - 16 hours, with far fewer outliers above 16 hours. These indicate significant service inaccessibility in some remote areas and extreme levels of inaccessibility in a few.

Figure 21 reinforce several trends observed in Table 12 and Figures 15 to 17. Travel times to hospitals and district headquarters are generally higher than travel times to financial institutions, health posts and all health facilities. Drops in accessibility during monsoon season are modest but consistent across all services. The categories of provincial accessibility observed in Table 12 repeat in these figures, with province 2 and provinces 6 & 7 visibly diverging from provinces 1 and 3-5.

The contrast between the municipal averages and the national/provincial averages shows the dangers of complacent use of the average figures, the importance of investigating local context for small-scale projects and the need for a policy focus on remote municipalities and areas. Significant populations in a minority of municipalities face large, overnight travel to access key services. This localization concentrates the impacts on inaccessibility discussed above on specific communities, with possible multiplier effects on human development outcomes where the cumulative effects of inaccessibility to multiple services interact.

Figure 13: Average hours of travel for various services

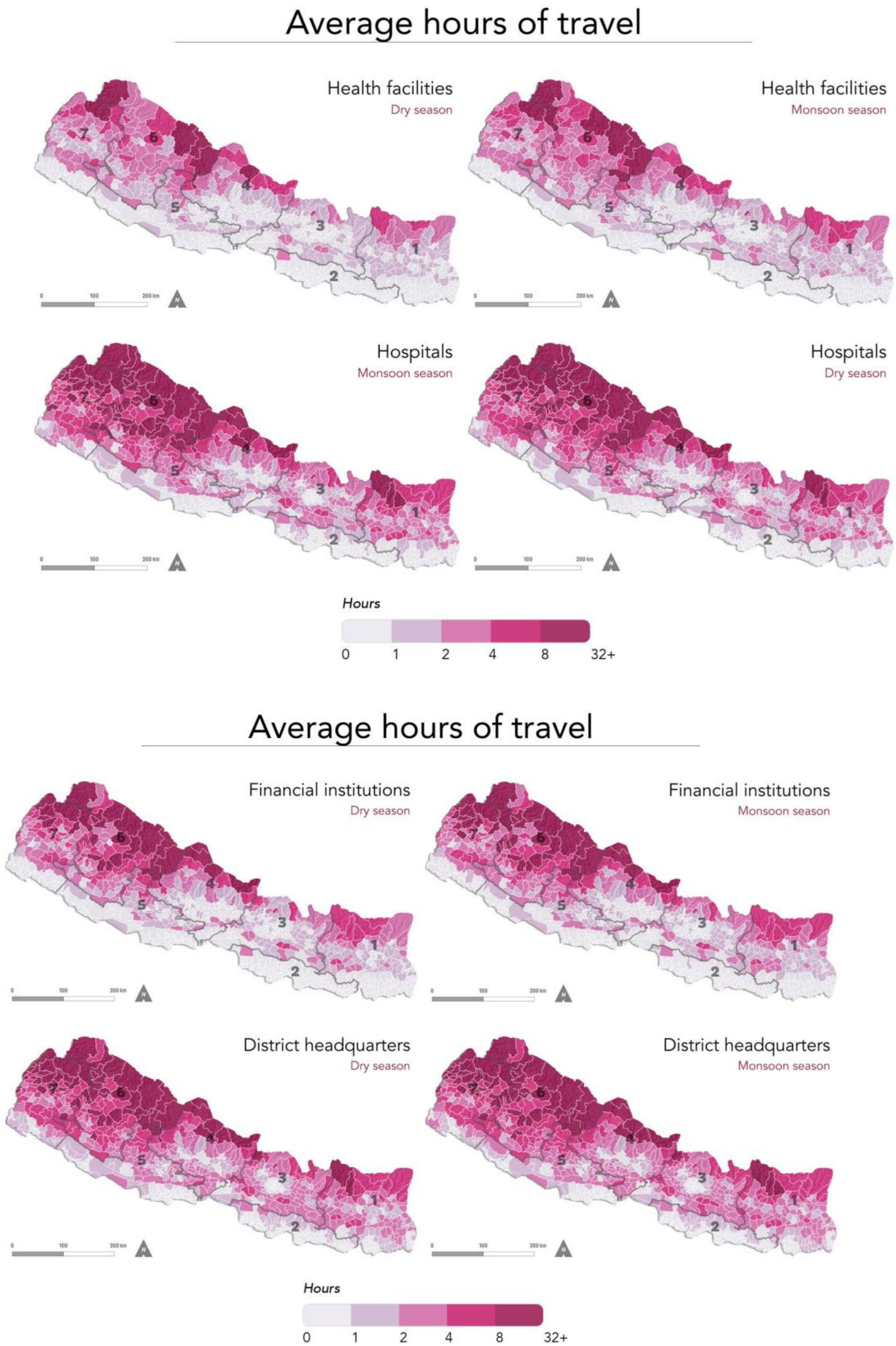
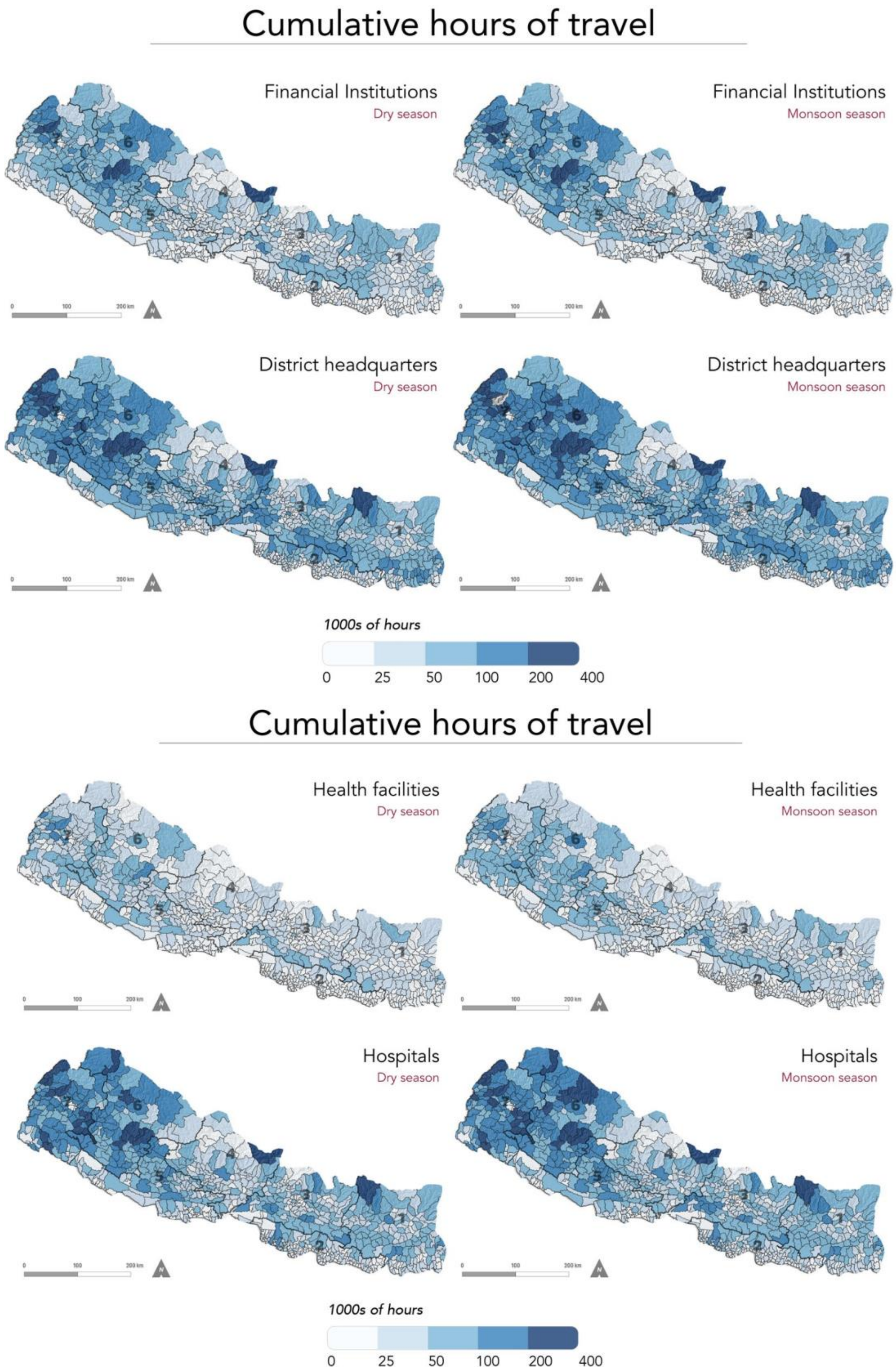


Figure 14: Cumulative hours of travel for various services



Conclusion

Extreme remoteness and widely varying access to key services are facts of life in Nepal and acknowledged strong determinants of development outcomes. Yet despite this recognition, in practice policy makers and researchers in Nepal rarely quantify these factors and rely on anecdotal, household-centric or heavily simplified representations of remoteness. As noted in the literature review, existing models are unsatisfactorily abstracted from the travel time- based measures commonly employed by Nepal's government and citizens themselves, while reported travel times from survey data are difficult to generalize because of sampling constraints and highly idiosyncratic besides. This has limited the breadth and rigor of quantitative research based on remoteness and accessibility in Nepal, despite its uniquely strong role in shaping Nepal's society, governance and economy. Other methods of quantifying accessibility exist, some promising and powerful, but none offered the same mix of analytical power, national coverage, scalability and communicative simplicity of a cost time model, particularly given available data.

The diversity of model inputs and challenge of collecting sufficient data frustrated previous attempts at geospatial modeling of travel times in Nepal. Addressing these challenges required a combination of technical research, consultations with interested partners, persistence in data gathering and tedious data cleaning better suited to our long-term, country office-based program than a typical short-term research project. We were greatly assisted by World Bank staff on the ground and collaboration with the GeoNode open geospatial data sharing project, for which World Bank staff had amassed a considerable amount of geospatial data for Nepal. Despite the overall success of the effort, it must be noted that we could only incompletely collate several important data sets, most notably for education and markets, and therefore exempted them from this analysis.

A mixture of analysis imperatives and policy opportunities guided our research. As this research grew out of the HRVS survey work, we initially intended solely to assess remoteness as it interacted with HRVS survey data.

However, Nepal's recent transition to a federal administrative structure and the creation of 7 new provinces and 753 new local governments, all without baseline data sets, presented a clear need for quantifying and visualizing accessibility challenges at these various administrative levels. Based on this, we prepared the series of maps, charts and tables accompanying this report. Keeping in mind the sometimes rudimentary state of office infrastructure in remote areas and new government offices in Nepal, we prepared products that were equally useful in digital or print form.

Analysis

Our research indicates that low average levels of access to services geographically cluster in hill and mountainous regions and the Far West. Population-weighted shortfalls in cumulative access cluster in the hills and some mountainous areas, especially in the Far West, although pockets of inaccessibility exist in the Shivalik and Terai. The impact of the monsoon is apparent but not as dramatic as feared, suggesting access to essential services deteriorates but does not collapse during the monsoon season. However, we observed a high degree of variability in accessibility patterns across individual local government units; a significant minority of LGUs were outliers from their regional or geographical trends. We therefore encourage readers interested in regional or local implications of this research to consult the appropriate tables, charts and maps for their focus areas from the annexes to learn about the local context.

Making detailed recommendations to rectify these accessibility challenges requires sector-specific knowledge that is beyond the scope of this paper. Nevertheless, we can make some high-level observations on possible responses. For instance, the Nepal Rastra Bank recognizes that financial services have clustered around urban and semi-urban areas and barely reach the Mid-Western and Far-Western areas (Pant 2016). Promoting alternative delivery channels (e.g. mobile banking) and streamlining the remittance transfer process to avoid multiple visits (and fees) would improve access to essential financial services in remote areas. Given the low capital base of many remote municipalities placing a bank in each municipality will be financially difficult and alternative delivery channels are a more sustainable mechanism for financial inclusion (Shakya *et al.* 2014). Sakcyham's Branchless Banking Initative and UNCDF's Mobile Money for the Poor (MM4P) project are the most prominent existing examples of this approach.

For medical services, the Nepalese government will need to continue expanding its network of health and sub-health posts if it is to reach its goal of 90% coverage within 30 minutes travel. More urgently, expanding the public hospital network or incentivizing private hospital construction in less developed areas is justified given the widespread inaccessibility of advanced medical services. Tax breaks or other inducements to private hospital construction in less developed areas could encourage this.

Given the high costs of building and maintaining infrastructure in mountainous areas, raising human development indicators and planning new services will present a stiff governance challenge for new municipal governments in remote municipalities. Provincial and municipal governments can enhance administrative access by enhancing infrastructure connections to municipal headquarters, localizing essential administrative functions and enforcing staff attendance in municipal headquarters. These moves would reduce dependence on far away district headquarters and thus raise overall access. This may require significant investment in staff training and the necessary offices and equipment, in addition to improved bridges, trails and roads.

At a more advanced level, policy mechanisms that streamline collaboration among neighboring municipalities and municipalities and provinces would enable more economical solutions to shared accessibility challenges that are beyond the resources of any one municipality. Hospital siting, for example, may best be addressed at the provincial level. Such expensive services will require strong planning coordination between local and provincial governments, as well as between neighboring local governments facing similar service shortfalls. In this light the new Provincial Planning Commissions are a positive governance step.

Finally, we must note the strongly gendered implications of the above accessibility challenges. Many women will avoid overnight stays outside their or a relative's home, implying inaccessibility for many services over 4 hours' travel away (RAP Nepal 2018). In the context of high and predominantly male international migration to India, the Persian Gulf and Malaysia this is a particularly acute problem; the majority of remittance receivers are women, who may be the effective heads of households, yet unable or unwilling to access distant services (Shakya *et al.* 2014, RAP 2018). In any case, they may be unable to forego one or more days of agricultural labor. Seen through this gender lens long travel times to financial, hospital and governmental services are worrisome. Access to banks is necessary to collect remittances from relatives abroad and ANC/PNC medical services important to maternal health and child mortality. Women may therefore pay extra to access remittances from local, informal financial services providers and/or skip essential maternal health services for lack of access.

Looking forward

The importance of travel times to understanding remoteness in Nepal, and the versatility of the raster-based data set, suggest a number of follow-up analyses. Examples include:

Planning and administration

- Establishing relationships between accessibility to services and household development indicators using existing survey data (e.g. DHS, NLSS, HRVS)
- Objectively calculating remoteness bonuses and travel stipends for government and development project staff working in remote areas

Agriculture and food security

- Econometric analysis of agricultural price and production variation based on accessibility to markets
- Econometric analysis of food insecurity based on accessibility to markets
- Identifying areas ecologically suited for high-value cash crops but poorly connected to markets
- Researching what degree of development project success is due to accessibility challenges vs. program design flaws

Transportation and infrastructure investment

- Optimizing facility and road placement using accessibility criteria
- Calculating improvements in accessibility (cumulative person hours) and health/economic impacts from proposed new facilities or roads
- Integration with global accessibility modeling tools like OpenRouteService for more automated, interactive modeling of accessibility in Nepal
- Extending the model to reflect the quality or reliability of services
- Detecting road condition deterioration by comparing recorded GPS speeds over roadways to modeled speeds

Governance

- Modeling facility catchment areas to assess overuse/ underuse of facilities based on populations within them
- Detecting possible corruption or misreporting using the above
- Breaking down accessibility to various services by ethnicity, caste and/or religion

Health care

- Assessing the impact of accessibility on health care utilization and outcomes, by health care service type

Economic development

- Overlapping access to financial institutions with population disbursement and poverty rates to highlight areas where mobile banking may be more financially sustainable than brick-and-mortar formal institutions

Disaster response

- Highlighting areas where cash-based assistance for disaster relief may underperform due to low access to formal financial institutions

We intend to address some of these topics in follow-up research. As a first step, we are in the process of regressing HRVS data sets related to recovery from shocks on the remoteness data.

We recognize that the data resulting from this research are just as important as the analysis. Providing others useful tools to address accessibility quantitatively was an explicit aim of this research given its foundational importance in Nepal. To this end, we are publishing all output spatial data on the Nepal GeoNode, the code and ArcGIS toolboxes used for analysis on Github, and the resulting maps and charts via a series of provincial dashboards. We can also provide the charts and maps in bulk on request; interested parties are encouraged to contact the authors. We therefore hope to advance the state of understanding accessibility in Nepal and enable more precise analysis of its impacts on economic and developmental challenges. It is our sincere wish that other researchers, policy makers and development partners use, adapt, improve and offer feedback on the model data outputs. We look forward to the results of these efforts.

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Annex I: Tables

Table 10: Average travel times for municipalities, in hours, nationally and by quantile

Dry season							
Service	**Average**	**1st**	**2nd**	**3rd**	**4th**	**5th**	**SD**
All health facilities	0.71	0.06	0.33	0.89	1.59	24.96	*1.93*
Health posts	0.76	0.07	0.35	0.93	1.61	24.96	*2.03*
All hospitals	1.62	0.07	0.71	1.67	3.39	35.75	*4.48*
Government hospitals	1.87	0.12	0.90	2.03	3.72	35.75	*4.56*
Private hospitals	2.63	0.07	0.89	2.18	5.49	50.80	*7.25*
All financial institutions	1.02	0.03	0.40	1.02	2.28	35.41	*3.47*
Commercial and development banks	1.10	0.03	0.46	1.08	2.41	35.43	*3.59*
District headquarters	1.88	0.12	0.93	2.07	3.75	40.79	*4.44*

Monsoon season							
Service	**Average**	**1st**	**2nd**	**3rd**	**4th**	**5th**	**SD**
All health facilities	0.83	0.06	0.36	1.02	1.87	26.40	*2.18*
Health posts	0.87	0.07	0.39	1.08	1.89	26.40	*2.30*
All hospitals	1.75	0.07	0.76	1.81	3.68	37.74	*4.88*
Government hospitals	2.01	0.13	0.95	2.17	4.00	37.74	*4.96*
Private hospitals	2.76	0.08	0.92	2.30	5.78	52.45	*7.63*
All financial institutions	1.14	0.03	0.44	1.14	2.55	36.49	*3.80*
Commercial and development banks	1.22	0.03	0.50	1.22	2.67	36.51	*3.93*
District headquarters	2.02	0.14	0.97	2.20	4.04	43.89	*4.91*

Table 11: Average travel times for municipalities, by geography

Dry season

Geography	All health facilities	Health posts	All hospitals	Government hospitals	Private hospitals	All financial institutions	Commercial and dev. banks	District HQs
High Mountain	3.37	3.53	10.10	10.54	14.92	6.66	6.81	9.38
Mountain	2.13	2.18	1.79	6.12	10.60	3.87	4.25	6.19
Hill	0.87	0.92	5.84	2.04	3.07	1.19	1.27	2.09
Shivalik	0.62	0.68	1.08	1.54	1.37	0.66	0.72	1.49
Terai	0.30	0.32	0.71	0.88	0.97	0.36	0.40	0.89

Monsoon season

Geography	All health facilities	Health posts	All hospitals	Government hospitals	Private hospitals	All financial institutions	Commercial and dev. banks	District HQs
High Mountain	3.98	4.16	11.00	11.47	15.80	7.43	7.59	10.40
Mountain	2.53	2.59	6.39	6.67	11.13	4.36	4.74	6.85
Hill	1.00	1.06	1.94	2.20	3.21	1.32	1.40	2.25
Shivalik	0.71	0.77	1.17	1.64	1.46	0.74	0.80	1.59
Terai	0.34	0.36	0.74	0.92	1.01	0.39	0.43	0.93

Table 12: Average travel times for municipalities, by province

Dry season

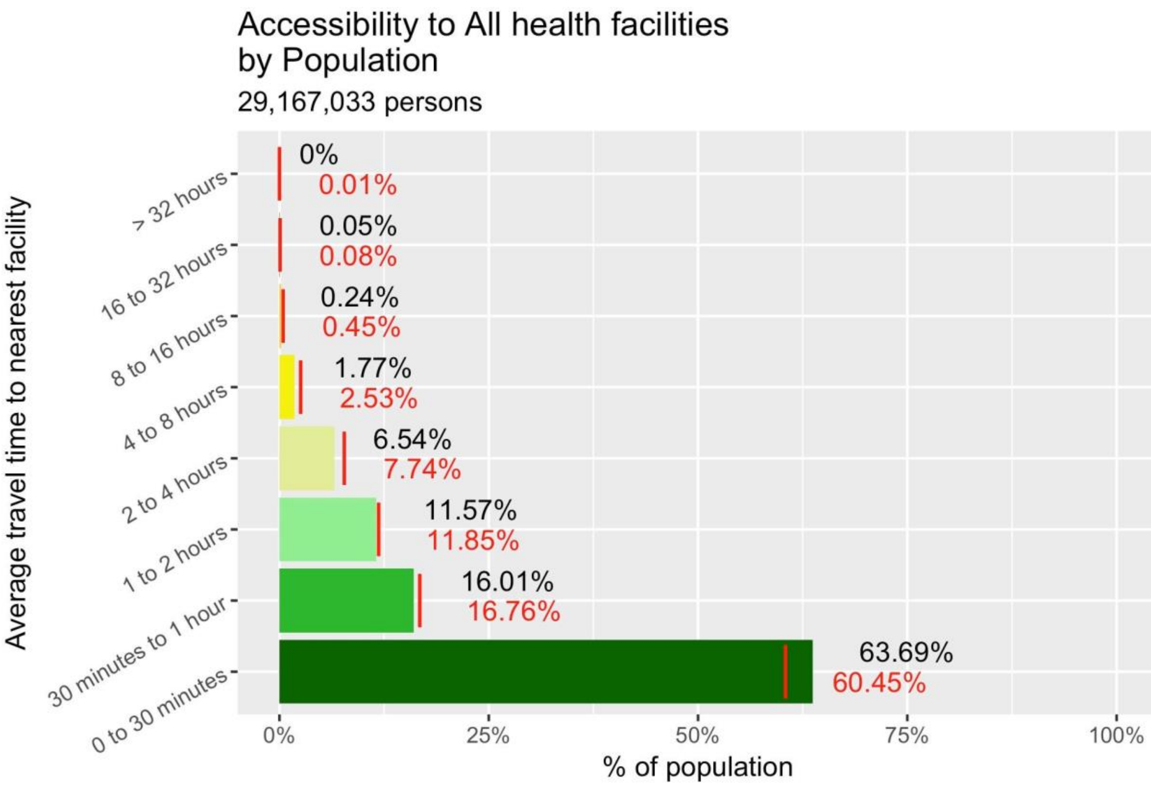
Province	All health facilities	Health posts	All hospitals	Government hospitals	Private hospitals	All financial institutions	Commercial and dev. banks	District headquarters
1	0.70	0.74	1.43	1.67	2.06	0.89	0.94	1.72
2	0.27	0.29	0.67	0.78	0.93	0.40	0.45	0.80
3	0.54	0.59	0.95	1.27	1.18	0.64	0.68	1.27
4	0.75	0.83	1.44	1.85	1.81	0.99	1.02	2.03
5	0.59	0.63	1.15	1.34	1.38	0.71	0.75	1.30
6	2.07	2.14	5.39	5.93	11.01	3.97	4.24	5.72
7	1.46	1.50	4.19	4.35	8.46	2.24	2.51	4.35

Monsoon season

Province	All health facilities	Health posts	All hospitals	Government hospitals	Private hospitals	All financial institutions	Commercial and dev. banks	District headquarters
1	0.80	0.84	1.55	1.80	2.16	0.98	1.04	1.83
2	0.31	0.33	0.71	0.83	0.97	0.44	0.49	0.84
3	0.61	0.67	1.02	1.35	1.25	0.70	0.74	1.35
4	0.86	0.94	1.55	1.96	1.93	1.09	1.13	2.16
5	0.68	0.72	1.23	1.43	1.46	0.78	0.83	1.39
6	2.44	2.52	5.89	6.44	11.47	4.44	4.71	6.31
7	1.73	1.77	4.55	4.72	8.81	2.54	2.84	4.77

Annex II: Charts

Figure 15: Access to health facilities *(monsoon season in red)*



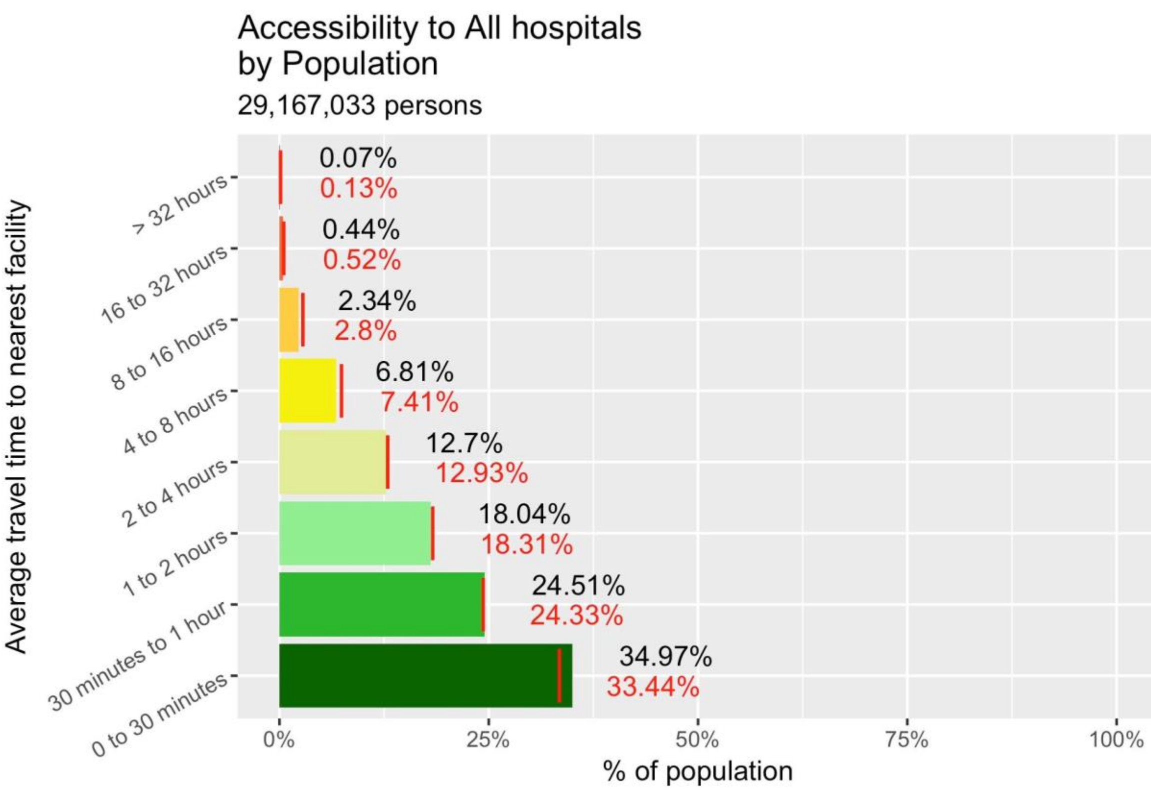


__Figure 16: Access to health posts and district headquarters__ (monsoon season in red)

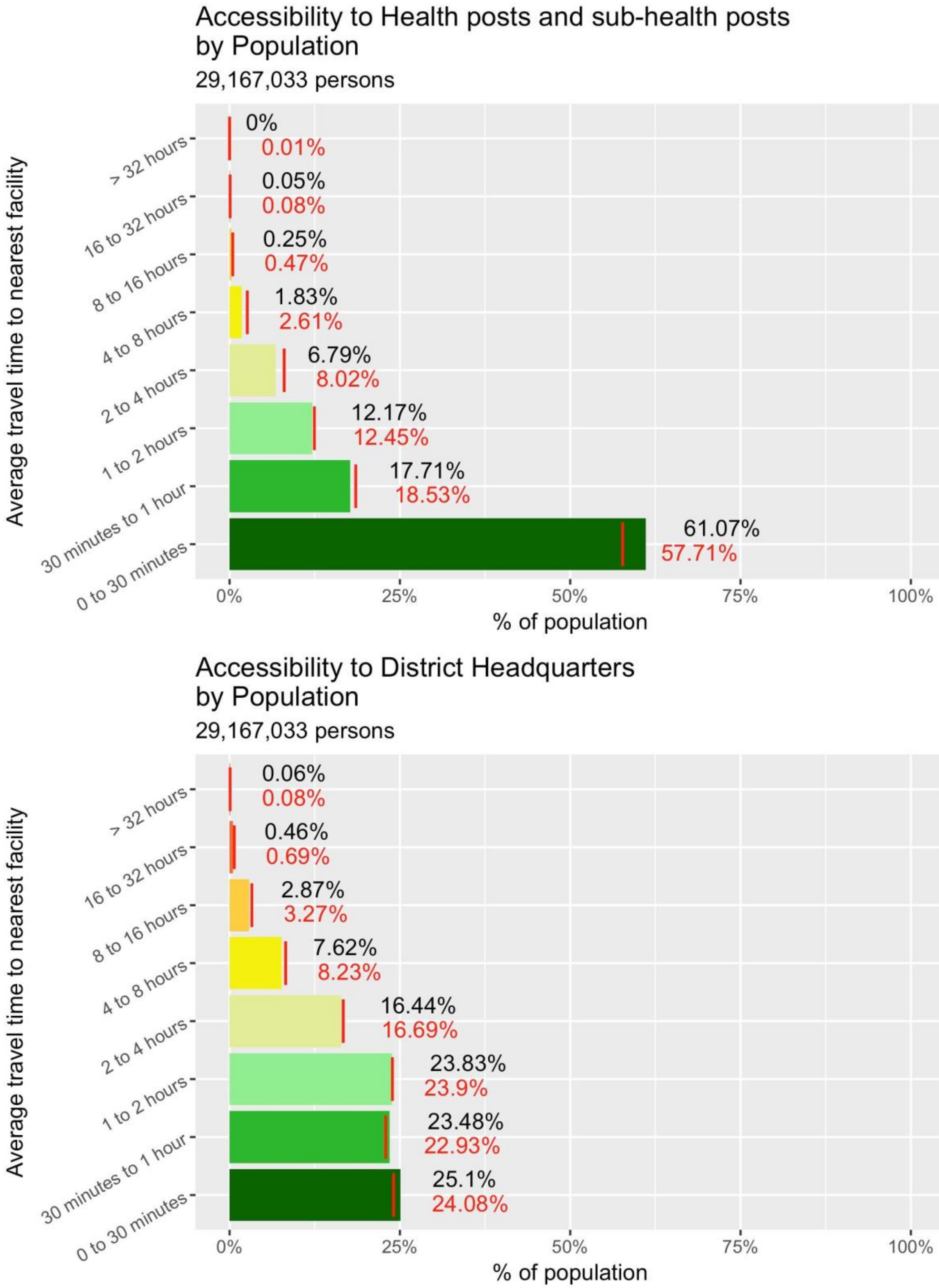
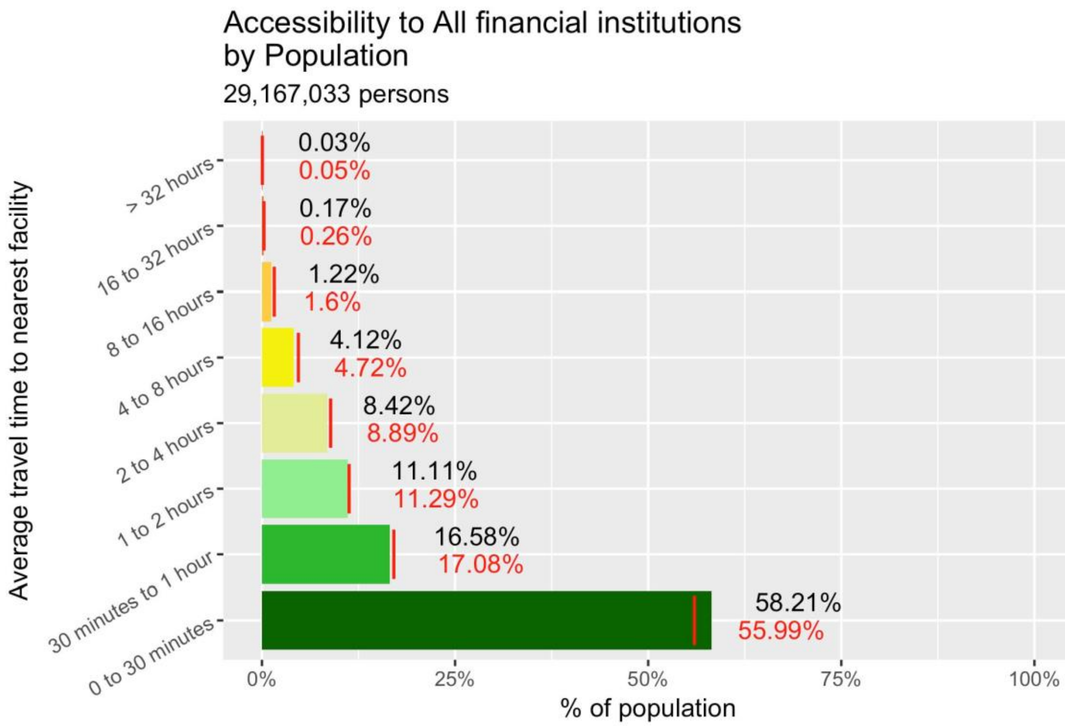
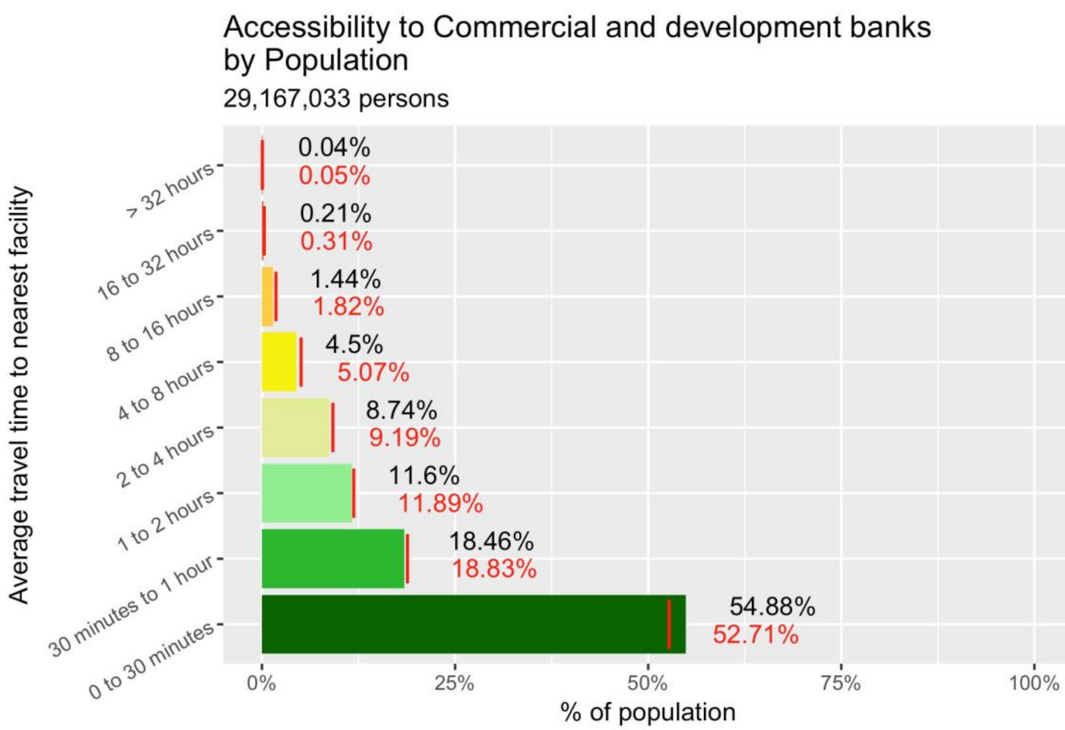


__Figure 17: Access to finance__ (monsoon season in red)





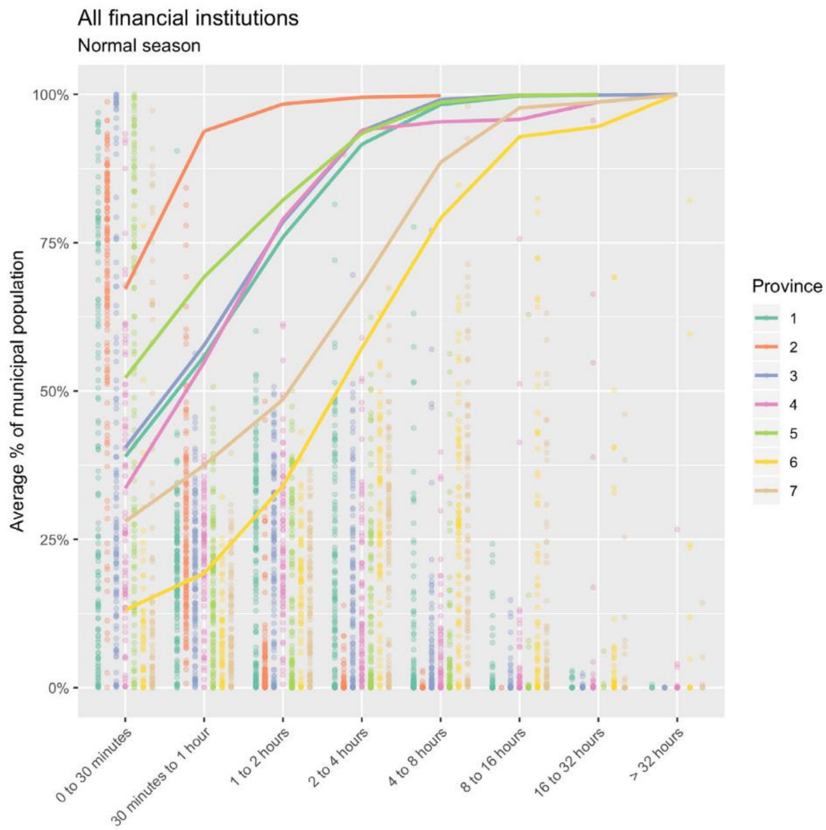


Figure 18

Accessibility to financial institutions, by province and local government unit

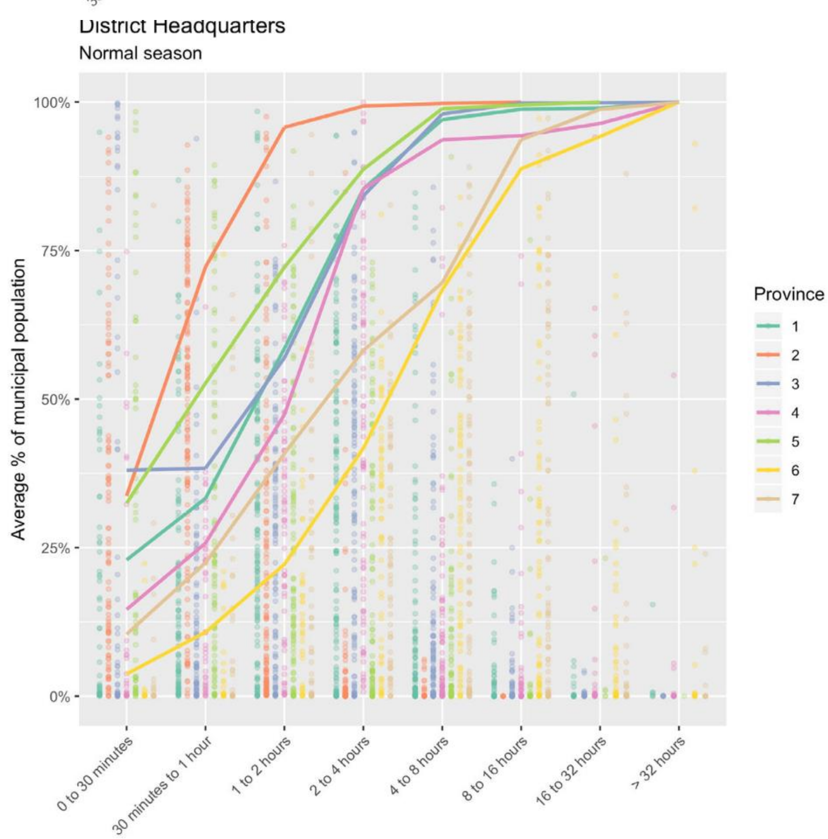


Figure 19

Accessibility to district headquarters, by province and local government unit

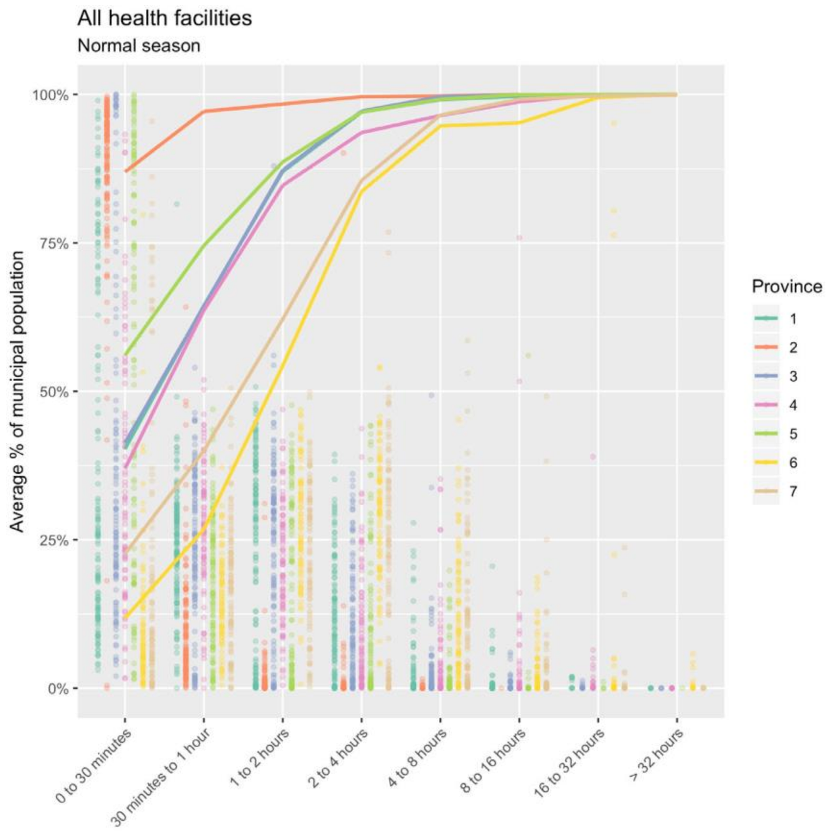


Figure 20
Accessibility to all health facilities, by province and local government unit

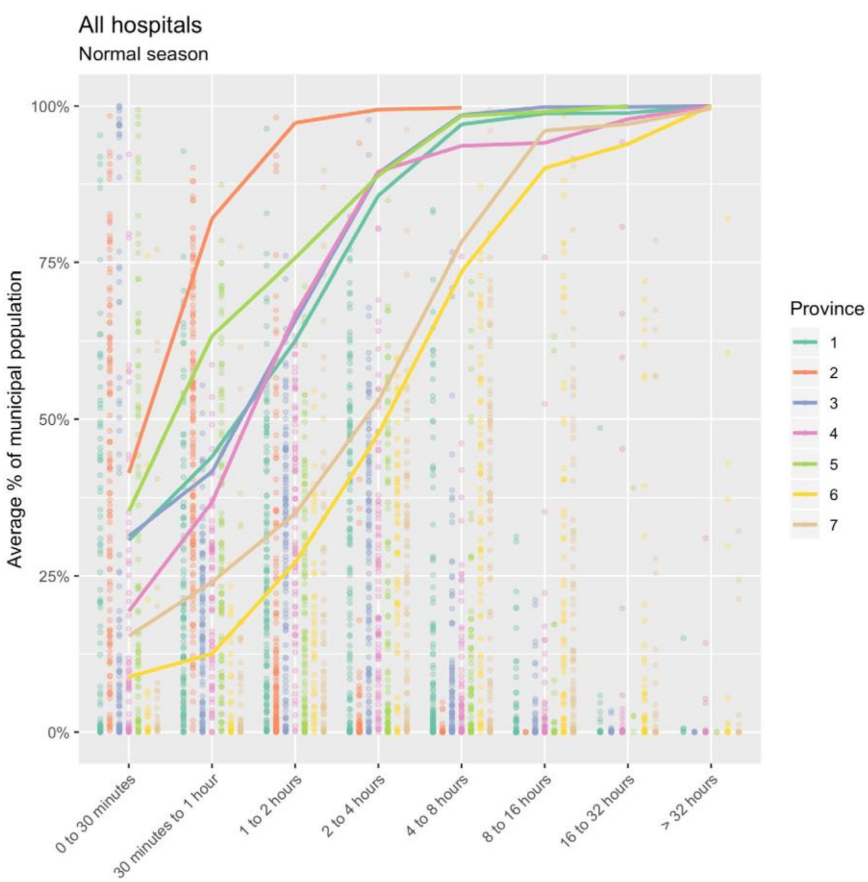


Figure 21
Accessibility to hospitals, by province and local government unit

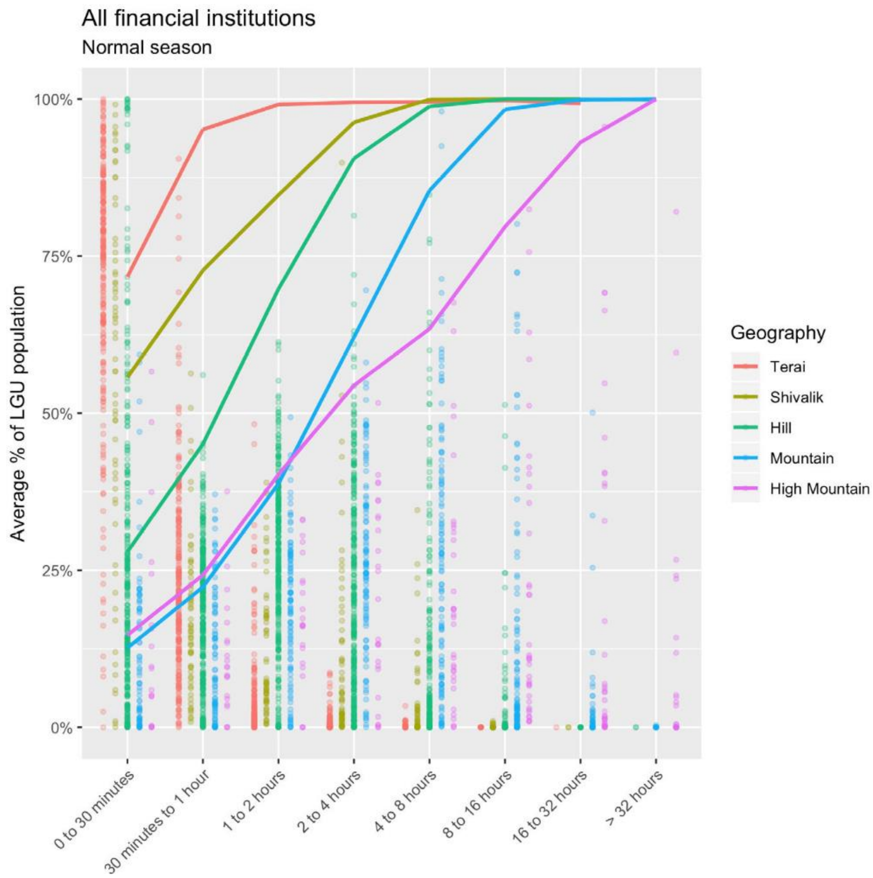


Figure 22
Accessibility to all financial institutions by local government unit and geography

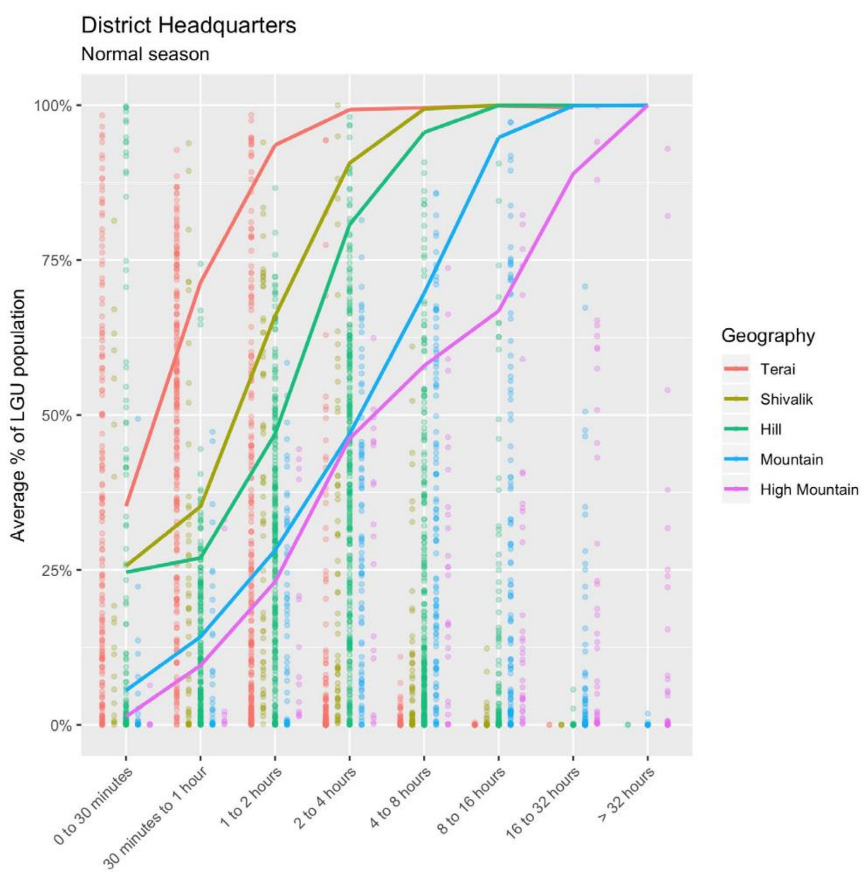


Figure 23

Accessibility to district headquarters, by local government unit and geography

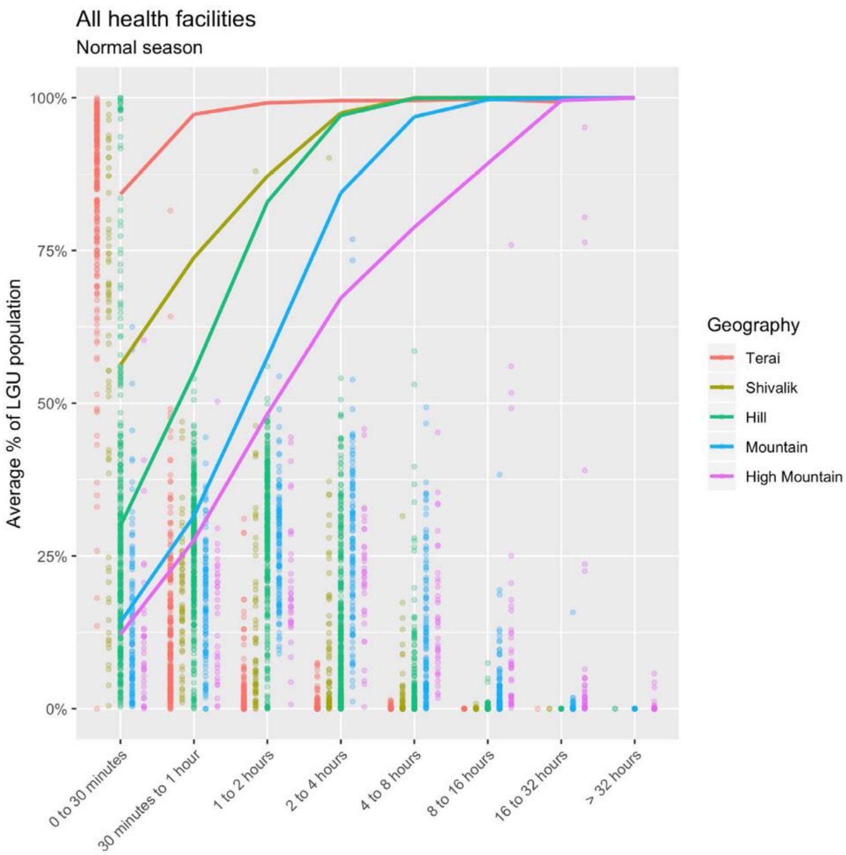


Figure 24

Accessibility to all health facilities, by local government unit and geography

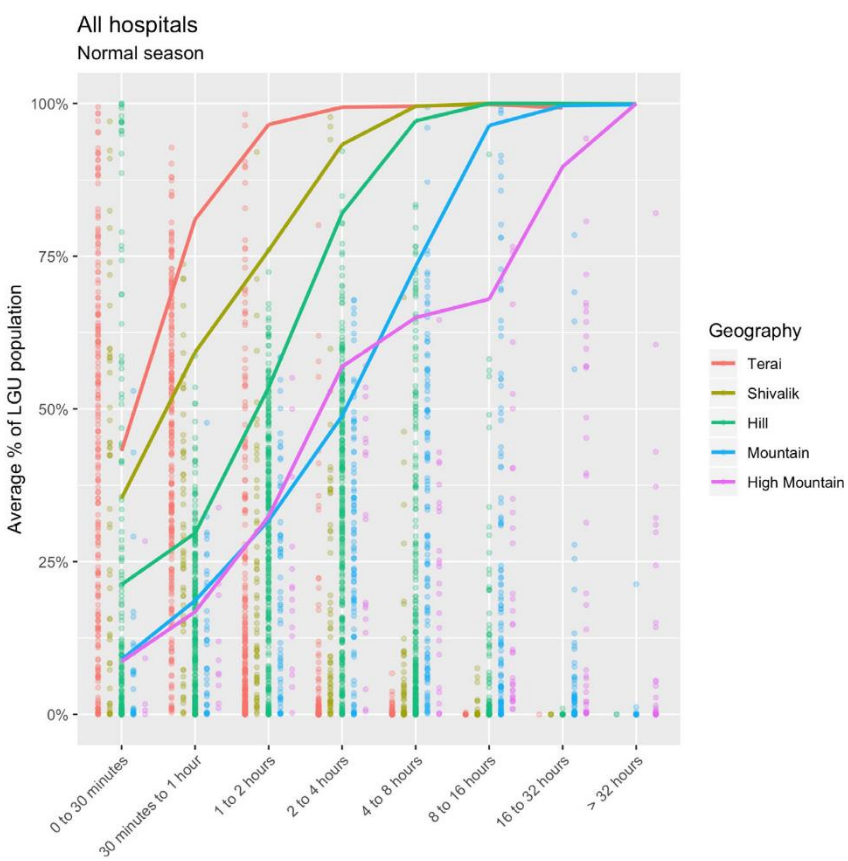
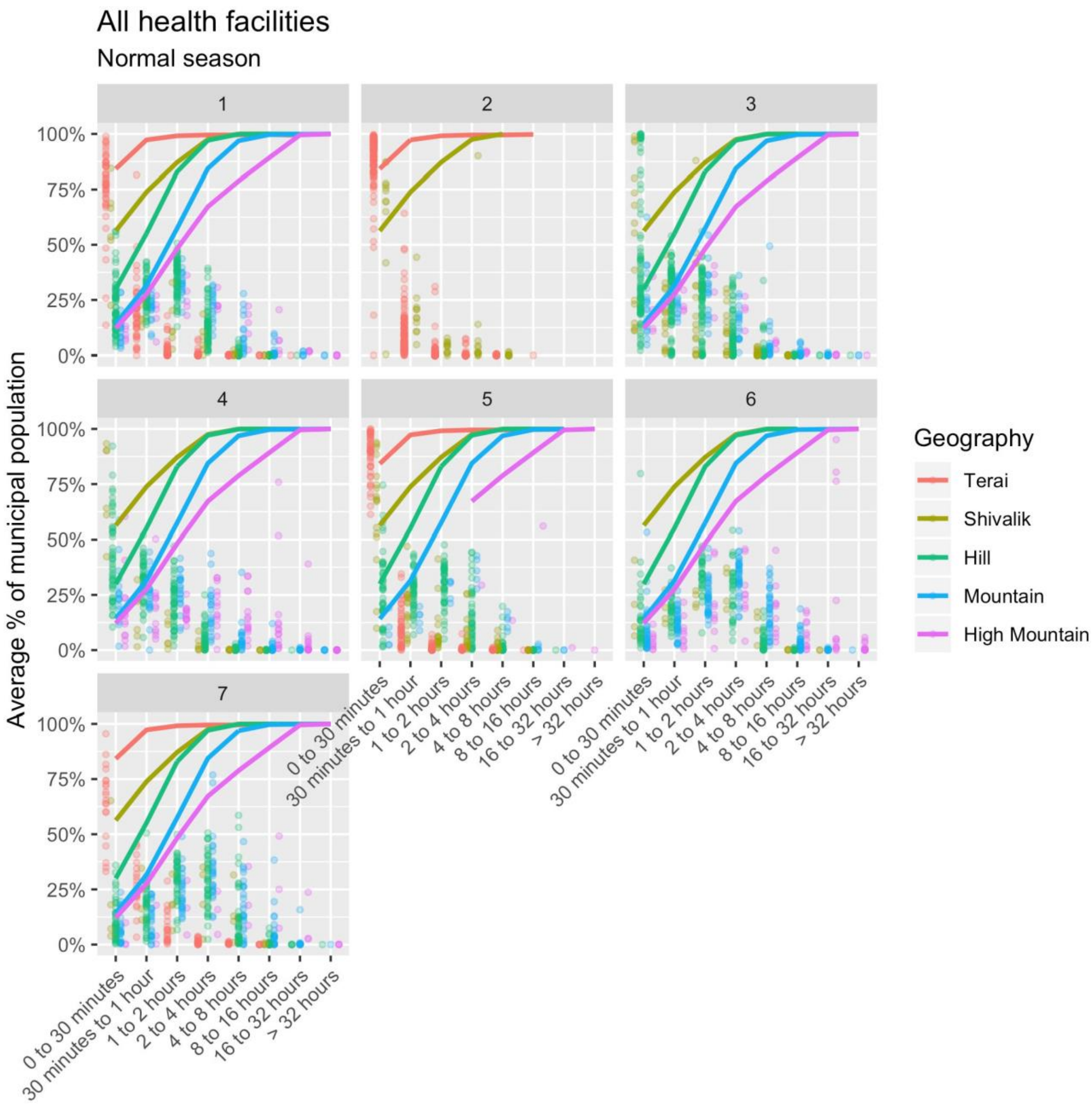


Figure 25

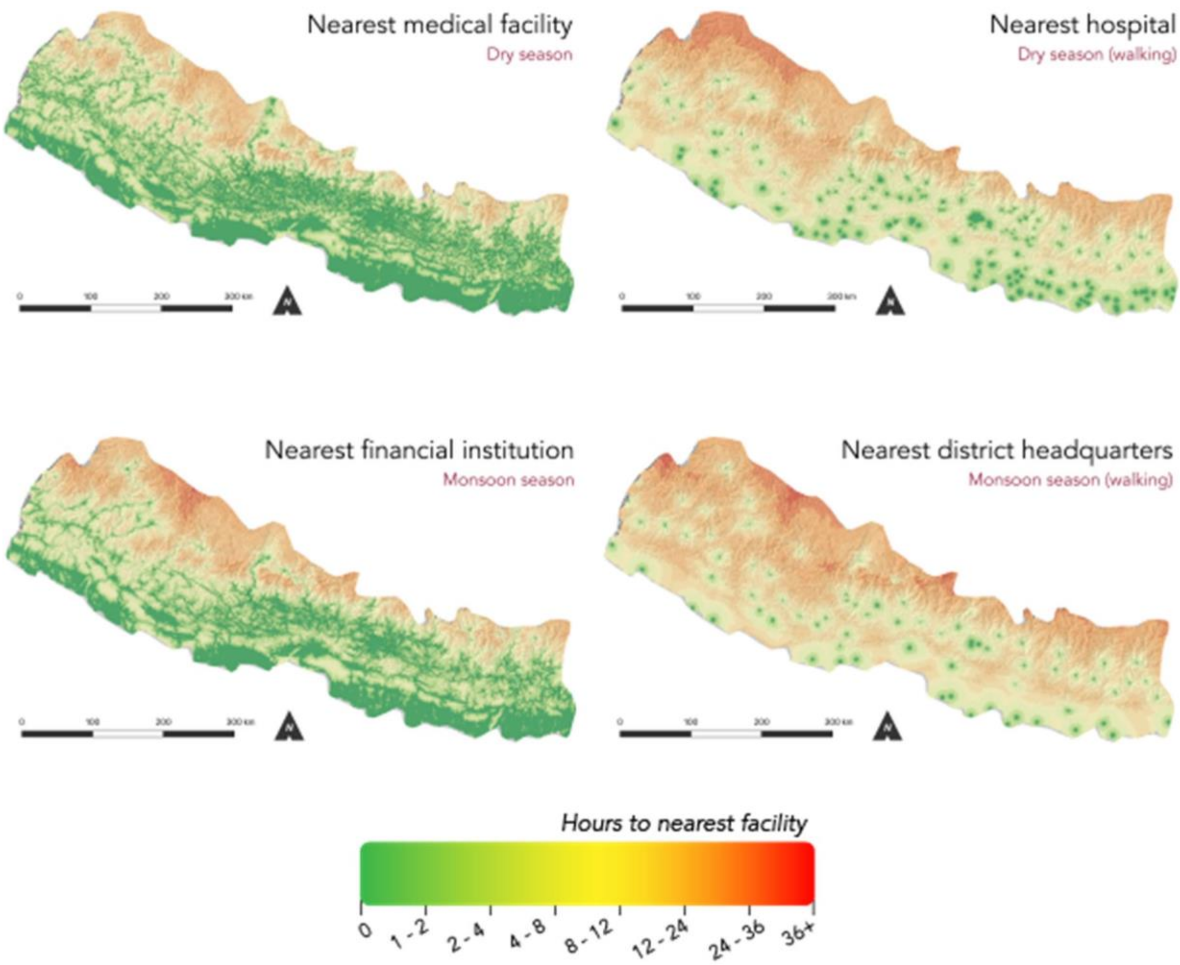
Accessibility to hospitals, by local government unit and geography

Figure 26: Accessibility to all health facilities, by local government unit, province and geography



Annex III: Example maps

Figure 27: Example maps of travel times by facility, season and travel modality



Annex IV: Model validation by province and geographic region

Table 13: Comparison of model times to reported travel times (HRVS 2016/2017), by province

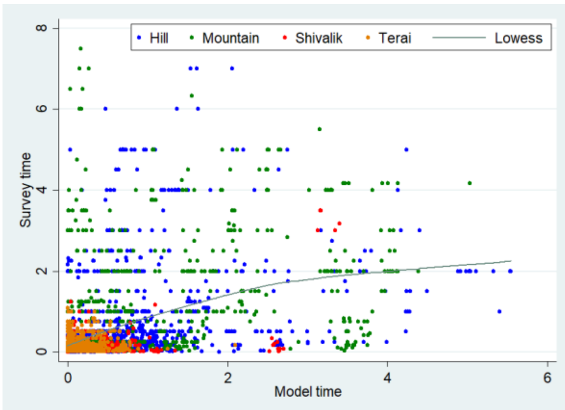
Road	**HRVS**			**Normal**			**Monsoon**		
State	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
1	44.5	12.5	73.9	29.1	8.4	46.3	33.2	9.7	52.7
2	9.8	7.0	9.8	13.1	5.5	23.2	14.3	6.6	24.4
3	32.3	10.0	54.1	41.8	18.2	63.9	48.2	20.8	76.2
4	23.9	6.5	65.9	18.9	5.4	30.6	21.8	6.2	35.4
5	9.1	5.0	21.0	16.5	5.2	27.9	18.7	6.0	32.5
6	56.2	30.0	60.5	66.1	38.1	73.9	75.2	45.0	82.3
7	47.8	15.0	73.7	31.5	14.6	43.1	38.4	17.9	52.7
Total	**29.7**	**10.0**	**57.3**	**28.6**	**9.6**	**47.7**	**32.9**	**10.9**	**55.3**
Medical Facility									
1	49.0	30.5	39.4	33.2	19.6	33.1	36.8	21.0	38.0
2	16.7	15.0	10.5	13.8	9.4	14.7	14.8	10.1	15.9
3	49.2	30.0	45.7	49.7	30.2	61.8	55.9	32.2	75.0
4	40.9	30.0	43.6	33.8	20.8	36.2	37.0	22.9	39.9
5	25.0	15.0	27.3	26.1	14.8	31.9	28.3	15.7	36.0
6	59.1	45.0	48.3	82.2	68.9	66.3	91.0	75.1	73.5
7	38.7	30.0	36.3	68.5	31.0	73.4	79.0	36.6	87.8
Total	**38.6**	**25.0**	**39.1**	**39.9**	**20.8**	**50.9**	**44.5**	**22.2**	**59.3**
Bank (Class A-D)									
1	84.4	32.0	98.8	56.8	28.0	66.6	61.0	29.9	72.1
2	55.2	45.0	47.0	22.1	19.3	18.0	23.3	20.4	19.1
3	127.2	90.0	110.7	73.9	38.4	83.1	80.8	41.2	95.7
4	73.2	37.5	88.3	44.7	29.4	46.5	47.9	30.8	51.0
5	43.2	20.0	67.9	37.4	16.1	53.8	39.6	17.3	57.6
6	141.2	120.0	100.8	136.9	111.7	115.7	145.8	122.4	121.7
7	101.3	60.0	92.8	115.5	36.1	129.4	121.1	37.3	133.7
Total	**86.0**	**45.0**	**94.6**	**62.6**	**28.0**	**83.6**	**66.7**	**29.5**	**89.4**

Table 14: Comparison of model times to reported travel times (HRVS 2016/2017), by geographic region

Road	HRVS			Normal			Monsoon		
	Mean	**Median**	**SD**	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
Hill	33.5	15.0	58.6	32.5	15.0	47.0	38.1	17.4	56.0
Mountain	82.9	57.5	88.8	71.0	43.4	71.8	81.1	48.3	81.4
Shivalik	8.5	5.0	18.3	15.1	5.3	29.6	16.7	6.1	33.6
Terai	8.2	5.0	9.1	8.3	3.3	11.0	9.3	3.9	12.3
Total	**29.7**	**10.0**	**57.3**	**28.6**	**9.6**	**47.7**	**32.9**	**10.9**	**55.3**
Medical Facility									
Hill	51.5	40.0	42.8	49.0	31.3	53.5	55.3	34.7	63.7
Mountain	55.7	45.0	45.4	83.6	62.4	68.8	93.6	67.5	79.5
Shivalik	25.5	19.0	30.4	22.1	14.0	27.1	23.7	14.9	31.0
Terai	17.4	15.0	10.9	13.9	10.5	11.3	14.9	11.1	12.6
Total	**38.6**	**25.0**	**39.1**	**39.9**	**20.8**	**50.9**	**44.5**	**22.2**	**59.3**
Bank									
Hill	107.1	75.0	99.5	75.0	47.4	80.0	81.5	50.9	88.6
Mountain	179.6	180.0	106.6	161.7	159.2	112.1	169.9	157.3	116.0
Shivalik	37.6	20.0	53.8	21.6	12.4	30.2	23.3	13.0	35.5
Terai	35.9	25.0	30.0	17.5	12.7	14.9	18.5	13.5	15.8
Total	**86.0**	**45.0**	**94.6**	**62.6**	**28.0**	**83.6**	**66.7**	**29.5**	**89.4**

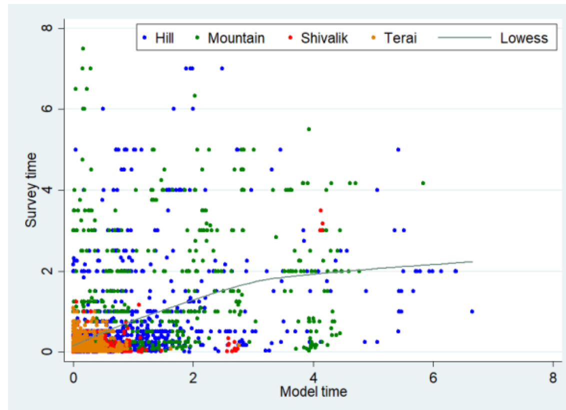
Figure 28: Final model results for HRVS households regressed against reported travel times, by geographic region

Regular season model | Monsoon season model



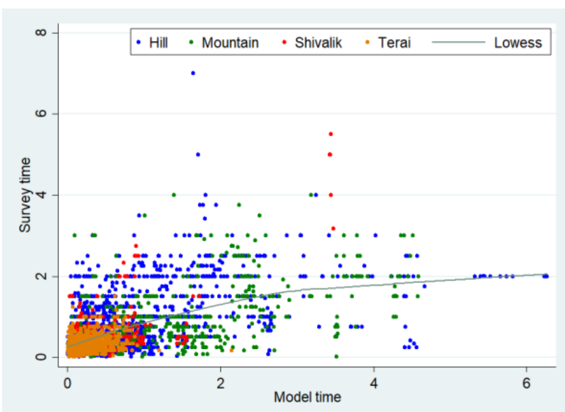
Road: R=0.47

(Hill: 0.38, Mountain: 0.31, Shivalik: 0.54, Terai: 0.09)



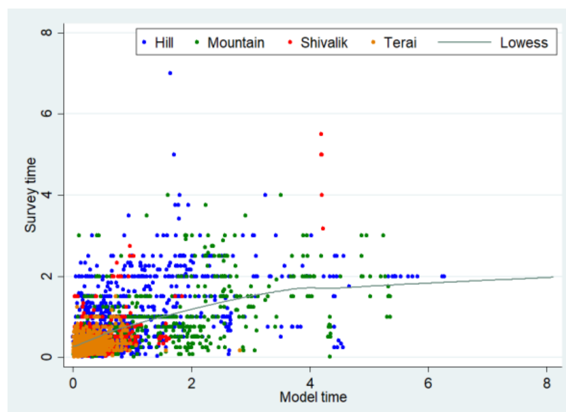
Road: R=0.48

(Hill: 0.40, Mountain: 0.31,Shivalik: 0.61, Terai: 0.08)



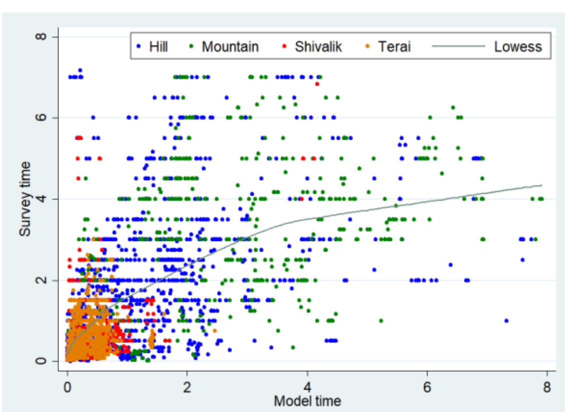
Medical Facility: R=0.59

(Hill: 0.51, Mountain: 0.51,Shivalik: 0.67, Terai: 0.28)



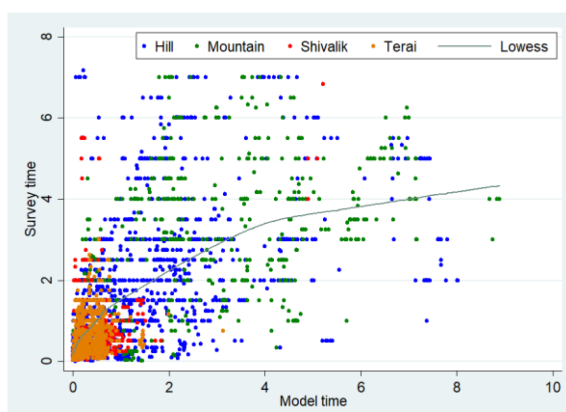
Medical Facility: R=0.57

(Hill: 0.48, Mountain: 0.48,Shivalik:0.69, Terai: 0.26)



Bank: R=0.63

(Hill: 0.52, Mountain: 0.45 ,Shivalik: 0.43, Terai: 0.36)



Bank: R=0.63

(Hill: 0.52, Mountain: 0.46 ,Shivalik: 0.44, Terai: 0.35)