IGAD Livestock
Policy Initiative

Accessibility Mapping in the Horn of Africa: Applications for Livestock Policy

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A Living from Livestock

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PREFACE

This is the 11th of a series of working papers prepared for the Intergovernmental Authority on Development Livestock Policy Initiative (IGAD LPI). The IGAD LPI was established by IGAD in collaboration with FAO and with financial support from the European Commission. Its main objective is to enhance the contribution of the livestock sector to sustainable food security and poverty reduction in the IGAD region. The initiative works towards the core outputs of IGAD's programmes on policy harmonization, agriculture and the environment and regionally integrated information systems. The work described in this paper contributes towards making available standardised spatial data to help analyse policy options, to target policy interventions and to evaluate their impact – contributing to the evidence base underpinning pro-poor livestock policies.

The objective of the paper is to review and investigate different approaches to accessibility mapping that are relevant to pro-poor livestock policy development. Access to services and markets are important contributors to poverty, as better access can lead to more efficient agricultural production, better market opportunities, diversification of rural economies and improvement of living conditions. Quantitative measures of accessibility are therefore useful in livestock policy analysis to determine optimal provision of services and to help understand the spatial distribution of markets and market access - and thus to target interventions.

In this paper we describe the data and methodology required to estimate access to markets in the IGAD region (Section 3), then we discuss different measures of accessibility based on varying modes of transportation, different targets and the movement of different livestock products (Section 4). The annex provides step-by-step commands to produce the surfaces using standard ESRI GIS software.

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Keywords

Market accessibility, cost-distance function, friction surface, travel time, livestock, poverty, policy.

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ACRONYMS

AGAL	Livestock Information, Sector Analysis and Policy Branch
CIAT	International Centre for Tropical Agriculture
CIESIN	Centre for International Earth Information Network
DCW	Digital Chart of the World
DEM	Digital Elevation Model
DMA	United States Defence Mapping Agency
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organisation
FEWS-NET	Famine Early Warning System Network
FSAU	Food Security Analysis Unit
GIS	Geographic Information System
GLC	Global Land Cover
GLOBE	Global Land One-kilometre Base Elevation Model
GPS	Global Positioning System
GRUMP	Global Rural and Urban Mapping Project
IGAD	Intergovernmental Authority on Development
JRC	European Union Joint Research Centre
LCCS	Land Cover Classification System
LINKS	Livestock Information Network Knowledge System
LMIS	Livestock Marketing Information System
IGAD LPI	IGAD Livestock Policy Initiative
NGA	National Geospatial-Intelligence Agency
NGDC	National Geophysical Data Centre
NIMA	National Imagery and Mapping Agency
ONC	Operational Navigation Chart
PPLPI	Pro-Poor Livestock Policy Initiative
UNEP	United Nations Environmental Programme
USGS	United States Geological Service

EXECUTIVE SUMMARY

In the spatial analysis of accessibility, the equivalent of a 'poverty line' can be thought of as the distance to a public facility, beyond which the services provided by that facility would not be adequate. This concept has mostly been applied to health facilities but has increasingly been used in the analysis of access to towns and markets. Market access plays a significant role in the wellbeing of a household, as it allows people to buy and sell food, products and services and it contributes to the diversification of economies in rural areas. Quantifying accessibility becomes important, therefore, in investigating possible causes of poverty and inequality, in determining where public services are inadequately provided, and in devising technical and policy interventions to address such problems: targeted improvements to transportation networks or market infrastructure, for example. This paper describes the data and methodology used to develop market accessibility surfaces for the IGAD region and provides a comparative analysis of accessibility in the context of the livestock sector.

The accessibility surface is produced using a cost-distance function, which estimates the travel time to a set of target destinations (e.g. populated places) over a friction surface that takes into account the road network, land cover and slope. Roads and land cover are classified according to estimated travel speeds, while slope is included as a speed-reducing factor. The baseline model used to generate the accessibility surface for the IGAD region assumes on-road travel by motorized vehicle and off-road travel by pedestrian movement. With the objective of generating a regionally consistent accessibility surface (in part as input to a regional poverty model, described in a separate, forthcoming IGAD LPI Working Paper), it was necessary to make a number of simplifications and assumptions, determined largely by the availability of regionally consistent datasets, for example of markets and their attributes and of road networks.

A number of variations of the basic, regional model has been produced for Kenya, using more detailed road and market datasets. In this case, accessibility surfaces have been created based on differential modes of transportation (e.g. car/truck, bicycle, motorbike, donkey and by foot) and based on different types of markets (e.g. populated places above 5,000 people, livestock markets, milk markets and airports). These two factors are closely interlinked and dependent on the type and volume of commodity to be transported. This comparative analysis demonstrates that market access is likely to be highly commodity-specific and that accessibility maps should be constructed using data and settings that are appropriate for particular applications: generalised accessibility maps are not likely to provide a sufficient level of information to be used effectively for commodity-specific analyses.

1. INTRODUCTION

The term 'accessibility' refers to the distance to a location of interest and the ease with which each destination is reached (Goodall, 1987). More recently, it has been defined as the ability for interactions or contacts with sites of economic or social opportunity (Deichmann, 1997). Travel time and destination choice are crucial to the definition of accessibility: the less time required to reach them, and the more numerous and varied destinations are, the higher the level of accessibility (Handy and Niemeier, 1997).

Although factors other than distance or travel time - the quality and cost of services provided, for example - also determine actual use of services, geographic parameters have been shown to be significant in predicting service utilization, especially in rural areas (Bigman and Fofack, 2000). Measures of accessibility, which can be generated relatively easily, can therefore play a useful role in informing policy analysis, for example: 1) in determining gaps in service provision and in specifying optimal locations of new facilities (Bigman and Fofack, 2000; Bigman and Deichmann, 2000); 2) in analysing market interactions and improving market infrastructure; and 3) in addressing humanitarian emergencies and food insecurity (Bartel, 2007; FEWS NET 2007).

Access to markets is particularly important in rural areas, as better access to population centres and markets can lead to diversification of rural economies by opening up markets to villagers who wish to sell their labour, artisanal products or agricultural produce. In the IGAD region, much of which is remote and inaccessible and where harsh environmental conditions and high disease burdens make livestock-keeping a risky business, marketing patterns are crucial to pastoralists' welfare.

There are several ways to measure accessibility (reviewed in Section 2). The simplest way would be to define a circular region with a given facility located at its centre. The radius of the circle would be chosen to reflect the distance within which the population is deemed to have access to that facility. Thiessen polygons[1] provide an alternative approach, but suffer from the same limitation as does the definition of circular catchments: they assume equal travel time in all directions. A more accurate model would take into account information on the transport routes and the terrain. Clearly, travel time to a facility is determined by the existing transportation infrastructure: estimates that incorporate the length and quality of the access roads can vary greatly from those based only on Euclidian distances.

Distance in fact may not be the most appropriate measure of accessibility. Where the quality of the transport network is highly variable or where the cost of using public transport must be taken into account, travel cost or travel time can provide more realistic measures. For these reasons, the terms 'impedance' or 'friction' are sometimes used in the geographical literature rather than 'distance.'

Generally, the concept of market access combines several elements: 1) the distance between a point of observation and some target destination or combinations of destinations; 2) the utility of the target destinations, based on their supply or demand attributes; and 3) the impedance level or quality of the route, in terms of relative ease of movement for goods, services and people.

One of the major drawbacks of most accessibility models is that they are based on the assumption that people travel to the nearest market or facility, when in reality that might not be the case. Furthermore, models that assign weights based on market or

[1] The boundaries of Thiessen polygons are defined such that they demark the area that is closest to each destination point relative to all other points. They are generated from a set of points, and are mathematically defined by the perpendicular bisectors of the lines between each point and its neighbours.

town size assume that people would prefer a larger market, when, especially in the case of smallholder farmers, that might not be the case (see for example in Bigman and Deichmann, 2000). Accessibility may also vary depending on the season and on the type of product or service that is to be traded. Another limitation is that often, especially in developing countries, detailed information on the supply or demand attributes of the markets or services or on costs of transportation is not available.

You and Chamberlin (2004) developed an accessibility model for Uganda that estimated the time taken to travel to places populated by at least 50,000 people. Here, we created a 'baseline' accessibility surface by extending this analysis to the rest of the IGAD region, using the most recent data available but taking a population threshold of 5,000 people to define the target locations, in order to include large numbers of regional markets in addition to the major conurbations. The assumption was made that people would travel to the nearest market along the least costly route. Access to markets was defined using a cost-distance function in which time to access markets is accumulated over a friction surface that takes into account the road network, land cover and slope. Roads and land cover have been classified based on estimated travel speeds, while slope is included as a speed-reducing factor (people walk and cycle more slowly up-hill). For Kenya, where more detailed information was available, we then developed additional accessibility surfaces for alternative types of market (local, major towns, capitals, etc.) and for different types of product or service to be transported (perishable produce, live animals, etc.).

Accessibility can also be used to define 'catchment areas' – frequently used in health applications because they help identify populations at risk, due to their not falling into the catchment area of any facility. Such analyses can then be used to target interventions to improve access to health services. Similarly, catchment areas could be helpful to identify populations beyond the sphere of influence of different markets, or to determine the number of people that could benefit from improvements in access roads, market infrastructure, etc.

In Section 2 of this paper a review is provided of different approaches to accessibility modelling. Section 3 describes the methodology and input data used to produce a generic regional map of market access (which has been developed as an input to regional poverty mapping, reported in a forthcoming IGAD LPI working Paper). Section 4 then takes a more detailed look at different approaches to accessibility mapping of specific relevance to the livestock sector; focussing on outputs that may be relevant to pro-poor livestock policy analysis and formulation.

2. REVIEW OF ACCESSIBILITY MODELS

A simple definition of accessibility is the shortest distance from any demand point in a study area to the closest facility. Formally, the shortest-distance measure can be denoted as follows (see, for instance, Talen and Anselin, 1998):

$$E_i = \min_j (d_{ij})$$

where E_i is the shortest-distance index for location i, and d_{ij} is the distance from the point of origin i to the location of facility j.

The shortest-distance index has two drawbacks when used to determine the demand for and location of public facilities. First, it considers only the spatial relationship between a given location and the service center, but not the services provided at that center. In most cases there are large differences in the services provided at each facility, and the more advanced or expensive services are typically provided only by a small number of the facilities. The shortest-distance index assumes that people will use the closest facility, which might not always be the case: people might choose a more distant clinic or hospital, for example, if it provided better care or cheaper services. Second, distance may not be the most appropriate measure where the quality of the transport network is highly variable or where the cost of using public transport must be taken into account. In such cases, a measure of travel cost or travel time can provide a more realistic measure.

Another way to measure accessibility is through a so-called 'covering index'. This is simply the number of facilities that are located within a specified threshold distance from each demand point (Bigman and Deichmann, 2000). If the different facilities have different sizes or capacities, this index can also be calculated as the sum of a size attribute of all facilities that are located within a specified threshold distance or travel time (hospital beds within an hour's travel, for example). The covering index can be calculated as:

$$C_i = \sum_j \delta_{ij} S_{ij}$$

where C_i is the covering index, δ_{ij} indicates whether or not a destination is within the threshold distance δ (δ_{ij} = 1 for $d_{ij} \leq \delta$ and δ_{ij} = 0, otherwise), and S_{ij} is the size attribute for each facility j. The size attribute can indicate the number of hospital beds, nurses, classroom spaces, teachers, or employment opportunities, for example.

Information on size (or quality) of facilities may also be accounted for by assuming that accessibility decreases in proportion to the distance or travel time to the facility, but increases with the size (or quality) of the facility. Such 'gravity models' have their origins in the idea that interaction between two cities is proportional to the size of their populations and inversely proportional to some measure of distance between them (Isard, 1956). In analogy with physics, Reilly (1931) formulated Reilly's law of retail gravitation (stating that larger cities will have larger sphere of influences than smaller ones), and Stewart (1948) formulated definitions of demographic gravitation, force, energy, and potential, now called accessibility (Hansen, 1959). The gravity model gives rise to a large family of spatial interaction models (Wilson, 1971) that use different pieces of information to estimate the interaction between two points. The gravity models are usually obtained by weighting opportunities in an area with a measure indicating their attraction and discounting them by an impedance measure (for example Geertman and van Eck, 1995; Handy and Niemeier, 1997; Kwan, 1998). In the case of accessibility, these models can be formulated as follows:

$$I_i^c = \sum_j \frac{S_j}{d_{ij}^{\beta}}$$

where I_i^c is the classic accessibility indicator, S_j is a size indicator at destination j, d_{ij} is the distance between the origin i and the destination j, and β is a distance exponent (Bigman and Deichmann, 2000).

This classical model has certain drawbacks, the main one being its steep distance decay function (de Wolff *et al.*, 2006), thus alternative weighting functions have been suggested. The negative exponential model is a commonly used variant that allows for a more gradual distance decay function, in which the influence of a destination with a particular size diminishes gradually at first, more rapidly in the medium range and more slowly again for locations further away (Deichman, 1997; de Wolff *et al.*, 2006). Whilst not generally available as standard functions in GIS software, some potential models are available as bespoke software, for example Liu and Kam (2000) developed an ArcView GIS extension (named ACCESS) that allows users to calculate accessibility with potential models within a GIS environment.

The models described above do not take into account road type, differential modes of transportation, or market attributes other than size, so researchers have calculated composite indices or used simpler indices (such as weighted distance, shortest-path, or cost-distance functions) that incorporate such factors. For example, de Wolff *et al.* (2006) calculated three indices based on different road types to analyze access to milk markets in the Kenyan highlands. Instead of using the total distance as the input distance value, three input distance values were used, based on the stretches of tarmac, gravel and dirt encountered *en route* to a particular market.

The more widely used methodology to calculate accessibility is based on a cost-distance algorithm (reported for example by Juliao, 1999; van Eck and de Jong, 1999; Nelson, 2000; ESRI, 2004; Longley *et al.*, 2005), which calculates the cost of movements between two points on a raster grid. This algorithm is commonly found in commercial GIS products such as in the ESRI Spatial Analyst extension. In such models the cost usually represents the time taken to access destination points (which may be towns, markets, health facilities, etc.), and the distance is calculated on a friction surface that takes into account the road network and, depending on the mode of transportation, environmental factors such as land cover and slope. Roads and land cover are classified according to an estimate of travel speed, while slope is included as a speed-reducing factor. Simple cost-distance models have been used to determine accessibility for a variety of purposes. Applications include estimating accessibility to towns for planning purposes and analysis of population, infrastructure and land use (e.g. Juliao, 1999; van Eck and de Jong, 1999; Nelson, 2000; Nelson and Leclerc, 2007) and emergency service and health care planning (e.g. Wilkinson *et al.*, 1998; Cromley and McLafferty 2002; Noor *et al.*, 2003; Noor *et al.*, 2004; Guagliardo, 2004; Black *et al.*, 2004; Ebener *et al.*, 2005). Accessibility maps have also been incorporated as part of broader spatial analyses, particularly in relation to the analysis of poverty, welfare and development options (e.g. Staal *et al.*, 2000; You and Chamberlin, 2004; Omamo *et al.*, 2006; Rogers *et al.*, 2006; Bartel, 2007; Robinson *et al.*, 2007) and recently in relation to the characterization of population pressure around protected areas in Africa (Hartley *et al.*, 2007).

Noor *et al.* (2006) further developed the shortest-path approach by using a transect algorithm to quantify competition for patients among hospitals, health centers and dispensaries in Kenya. This allowed them to identify the catchment areas for each facility, which were then used to adjust the shortest-path accessibility measure. Their results showed that the adjusted model provided the best fit to actual patient data derived from community surveys, compared to a non-adjusted model and a simple Euclidean model.

Even though accessibility measures can be computed using the common GIS packages, there are few user-friendly, step-by-step models to develop accessibility surfaces and catchment areas. CIAT (2001) developed a bespoke programme that allows users to calculate accessibility surfaces based on a cost-distance algorithm, and to analyze the allocation of services and the least-cost paths to services. The extension also allows the user to explore accessibility to different target points (markets, ports, health care facilities, schools, etc.) or to explore different scenarios such as the season (and its implication on ease of travel) and disaster-type events (such as the loss of infrastructure due to flooding, earthquakes or landslides). Similarly, Black *et al.* (2004) and Ebener *et al.* (2005) developed models for situation analysis, monitoring, and evaluation of the effectiveness of interventions in the health sector. These models allow users to calculate access to health facilities and to generate catchment areas, and thus to determine the population covered by each facility. The models allow optimal locations of new health facilities to be determined in order to prioritize health interventions in areas classified as highest risk (with critical accessibility conditions).

Finally, accessibility measures have been used at regional scales to create models of population distribution (UNEP and CIESIN, 2004; Nelson, 2004). The approach uses information on settlements, transport infrastructure and other features important in determining population distribution to compute a simple measure of accessibility for each node in a network. Such measures, termed ‘population potential’, are the sum of the population of towns in the vicinity of the current node weighted by a function of distance. The accessibility measure is then used to reallocate the population within each region, preserving the population totals from the original census data.

3. ACCESSIBILITY MAPPING

A base layer of access to markets was created with a cost-distance function, using an approach similar to that of Nelson (2000) and You and Chamberlin (2004), which requires a raster friction surface, and a gridded map of targets – in this case population centers with more than 5,000 people. The friction surface takes into account the road network, land cover and slope. Roads and land cover have been classified based on estimated travel speeds and slope is included as a speed-reducing factor. In this model, on-road travel is assumed to be by motorized vehicle, whilst pedestrian movement is assumed off-road. The resulting grids represent, for each 1 km cell, the shortest time (in hours) required to travel to a market.

The first step in the analysis was to reclassify roads and land cover so that the value of each cell represented the speed at which it could be traversed. The friction components were then merged into a single friction surface, and the cost-distance function applied to calculate time to access the specified markets. A catchment area was then produced for each market by re-classifying the cost surface using specified thresholds of access time.

When interpreting accessibility maps, users are warned of the simplifications and assumptions underlying the models, and are minded of the models' sensitivity to the data used. Limitations of the accessibility maps may be 1) inherent to the model itself (e.g. the assumption that people travel to the nearest market); 2) dependent on data availability (lack of detailed information on markets and their attributes, lack of good road databases, inconsistency of data across different countries for regional models, issues of seasonality, security, transport costs, etc.); and 3) related to the classification of data (e.g. estimated traveling speeds over different land cover and road types).

3.1 Data

3.1.1 Roads

Road network data were extracted from the Vector Map Level 0 (VMap0). VMap0, released by the National Imagery and Mapping Agency (NIMA)[2] in 1997, is an updated and improved version of the Digital Chart of the World (DCW). The DCW is a vector base map of the world at a scale of 1:1,000,000, commissioned by the US Defence Mapping Agency (DMA) and developed in 1992 by the Environmental Systems Research Institute, Inc. (ESRI). The primary source for this database was the Operational Navigation Chart (ONC) series, co-produced by the military mapping authorities of Australia, Canada, United Kingdom, and the United States. Some collateral sources have been used to add extra information about road and railway connectivity through selected urbanized areas.

The VMap0 database, also at 1:1,000,000 scale, includes GIS layers for road and rail networks, drainage systems, utility networks, airports, elevation contours, coastlines, international boundaries and populated places. The more recent versions of this database, VMap1 and VMap2, are not yet fully available to the public.

VMap0, available as a National Geospatial-Intelligence Agency (NGA) Vector Product Format, was converted to ArcInfo format and the road layer was classified into three

[2] The National Imagery and Mapping Agency (NIMA) was created in 1996 from the merge of the US Defence Mapping Agency (DMA) and several other agencies. In 2004, NIMA was renamed as National Geospatial-Intelligence Agency (NGA), with the primary mission of collection, analysis, and distribution of geospatial intelligence (GEOINT) in support of national security.

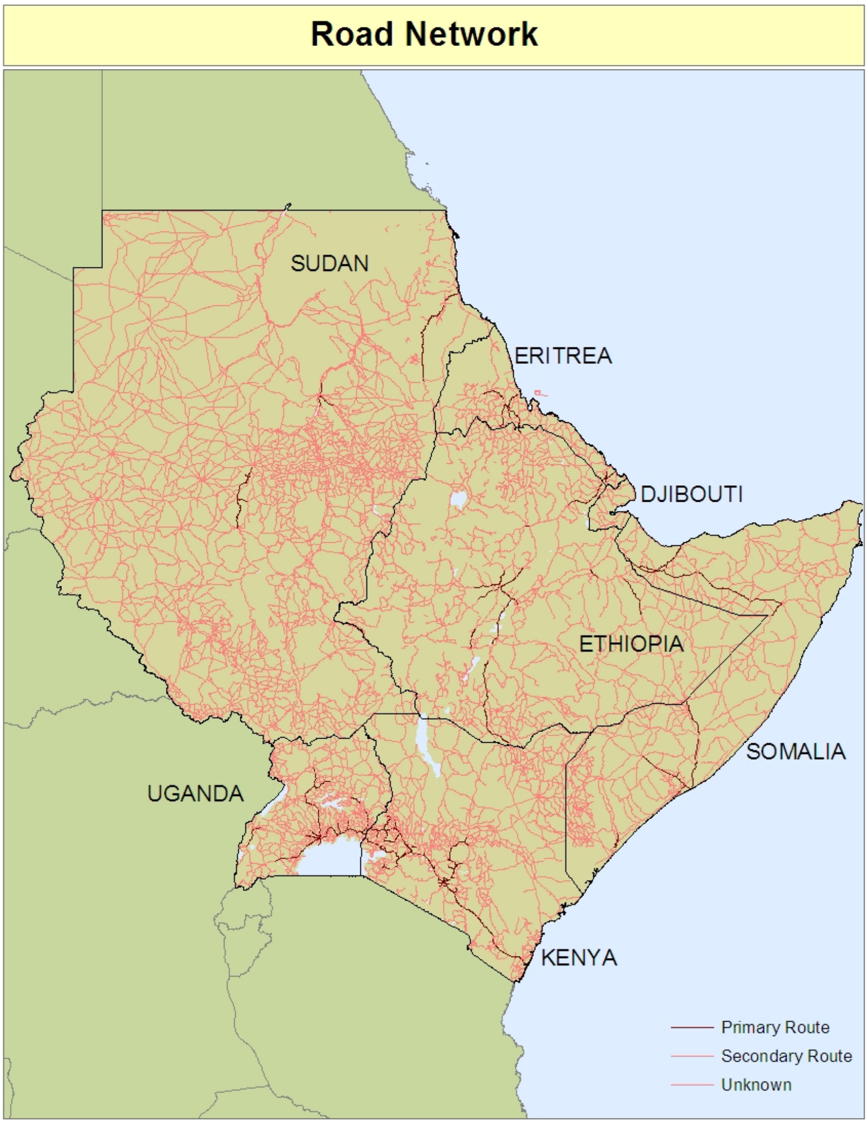
categories: 1) primary; 2) secondary; or 3) unknown. Based on a review of similar studies (Nelson, 2000; Nelson, 2004; You and Chamberlin, 2004; Hartley *et al.*, 2007) and consultation with people in the IGAD region, a travel speed of 60 km hr^{-1} was assigned to primary roads and 30 km hr^{-1} to secondary roads and road segments classified as unknown.

In Somalia and Kenya more detailed road datasets were available respectively from the Food Security Analysis Unit (FSAU) of FAO and the Kenya Ministry of Roads and Public Works. In Somalia the FSAU classification scheme generally corresponded to VMap0, but with better spatial coverage and with the inclusion of tracks, thus providing more detail. In Kenya, the road system was much more detailed and quite different to VMap0. In both cases, therefore, the VMap0 dataset was retained for consistency and to allow cross-country comparison in the regional model. The more detailed Kenyan roads database was used for some of the comparative analyses described in Section 4.

Table 1: *Road Network Classification.*

Road type	Average speed
Primary roads	60 km hr^{-1}
Secondary roads	30 km hr^{-1}
Unknown	30 km hr^{-1}

Figure 1: The Road Network in the IGAD Region.



Source: NIMA VMap Level 0.

3.1.2 Land Cover

Land cover data were extracted from the Global Land Cover map for Africa in the year 2000 (Mayaux *et al.*, 2000). This map was produced as part of the Global Land Cover 2000 project (GLC 2000), organised and led by the Joint Research Centre's (JRC) Global Vegetation Monitoring Unit, in collaboration with a network of partner organizations around the world. The objective of GLC 2000 was to provide a harmonized global land cover database with a reference year of 2000, providing baseline land cover information for a number of international Conventions and Treaties, including the International Conventions on Climate Change, the Convention to Combat Desertification, the Ramsar Convention and the Kyoto Protocol. GLC 2000 makes use of VEGA 2000: a dataset of 14 months of pre-processed, daily, global data, at 1 km resolution, acquired by the VEGETATION instrument on board the SPOT 4 satellite (collected between 1 November 1999 and 31 December 2000).

GLC 2000 is available for download in various formats from the JRC website (http://www-gvm.jrc.it/glc2000/), both for the globe and for different regions of the world.

Each partner in the GLC 2000 project used the Land Cover Classification System (LCCS) produced by FAO and UNEP (Di Gregorio and Jansen, 2000; Di Gregorio and Jansen 2005), which ensured that a standard legend was used across the globe. This hierarchical classification system allowed individual partners to choose the most appropriate land cover classes to describe their region (for example the legend of the Africa map pays special attention to the forest and savannah biomes), whilst also providing the possibility to translate regional classes to a more generalised global legend.

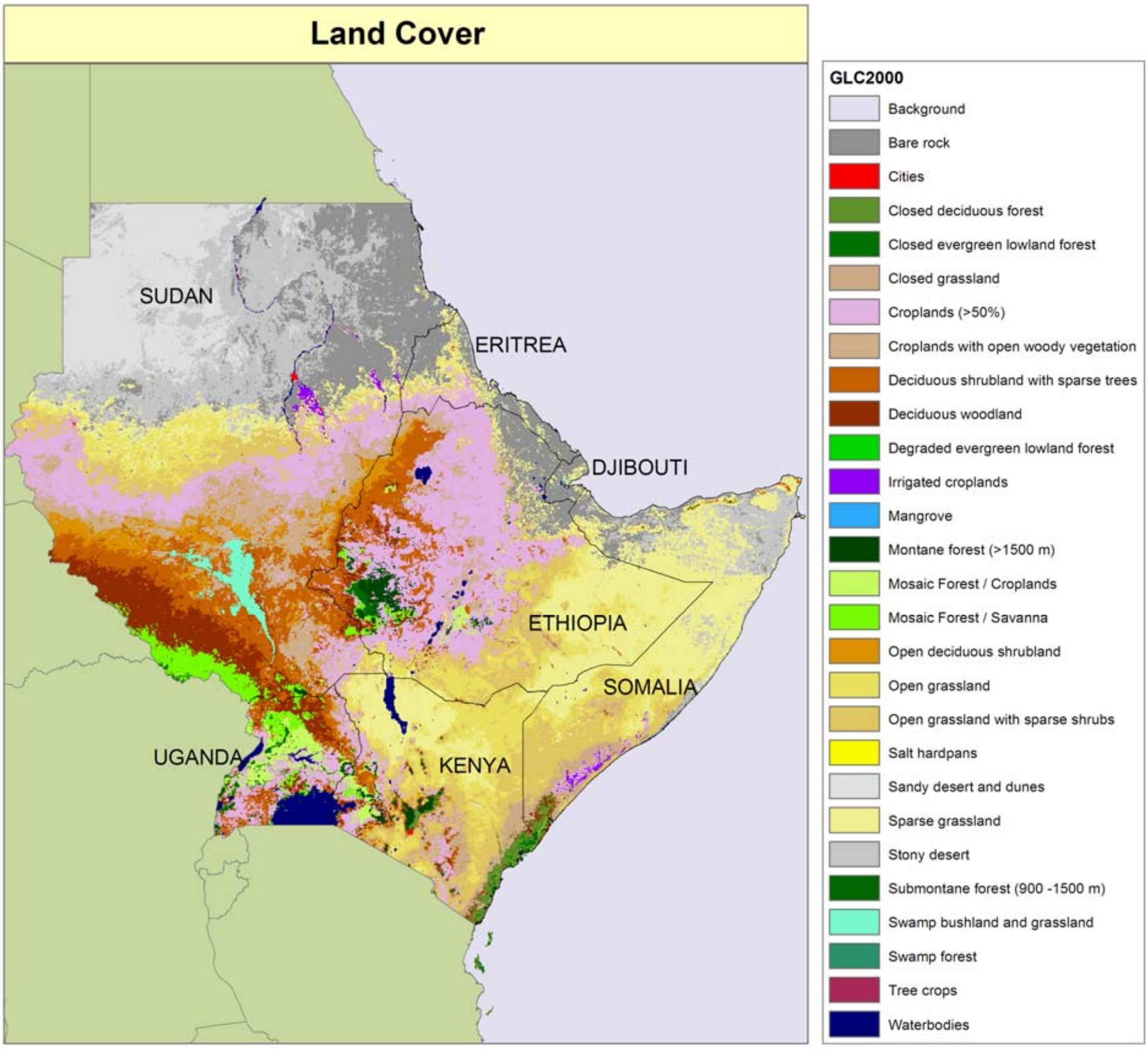
The Africa Land Cover Map (Version 5) was downloaded and reclassified as shown in Table 2. Average speeds for walking across the different land cover types were based on You and Chamberlin (2004) and on Chamberlin (personal communication, June 2006).

Table 2: *Land Cover Classification.*

Land Cover type	Average speed
Open or sparse grasslands, croplands (> 50%, or with open woody vegetation, or irrigated), mosaic of forest/croplands or forest/savannah, urban areas	3 km hr^{-1}
Deciduous shrubland or woodland, closed grasslands, tree crops, desert (sandy or stony) and dunes, bare rock	1.5 km hr^{-1}
Lowland forest (deciduous or degraded evergreen), swamp bushland and grassland, salt hardpans	1 km hr^{-1}
Submontane and montane forest	0.6 km hr^{-1}
Closed evergreen lowland forest, swamp forest, mangrove	0.3 km hr^{-1}
Waterbodies*	-

Note*: It was assumed that water bodies represent a barrier, rather than a means of transportation to markets so a water mask was created and the calculations were performed only over the 'land' types.

Figure 2: Land Cover in the IGAD Region.



Source: The Land Cover Map for Africa in the Year 2000 (Mayaux *et al.*, 2000).

3.1.3 Slope

Slope data were derived from the Global Land One-kilometer Base Elevation (GLOBE), released by the National Geophysical Data Centre (NGDC). GLOBE is an internationally designed, developed and peer-reviewed global digital elevation model (DEM), at a latitude-longitude grid spacing of 30 arc-seconds (GLOBE Task Team, 1999).

The original concept searched for possible sources of DEMs that could populate a 30 arc-second latitude-longitude array. Initial plans were to encourage experiments by the United States Geological Service (USGS) to convert DCW hypsography to 30" grids, and to seek additional contributions of DEMs. NGDC's ETOPO5 was to be used to fill gaps where better data were not forthcoming. Currently there are 11 major contributors to the project – the largest coming from the design and development of a 30" DEM derived from the DCW hypsography by NIMA.

Slope can easily be extracted from any digital elevation dataset, as it is calculated as the ratio of the altitude change to the horizontal distance between any two points on a line. In the accessibility model, slope is used as a speed-reducing factor. For the baseline accessibility surfaces, the slope factor was applied to the cost surface on the assumption that slope would affect both driving and walking speeds. Table 3 shows how slope values were reclassified into to weights (based on You and Chamberlin, 2004 and Chamberlin, personal communication, June 2006). The weights are expressed as the percentage of the potential speed possible within each slope range, and are thus applied to reduce travel speed, or increase travel cost, according to the following formula:

$$trcost2 = trcost1/(slope\_reclass/100)$$

where the trcost1, in this case, is determined by the combination of on-road and off-road travel speed and trcost2 is the resulting friction surface to be used in the cost-distance model (see Section 3.2 and Annex 1 for details).

Table 3: Slope Classification.

Slope (%)	Reclassification (%)
0 - 2	100
2 – 5	80
5 – 8	60
8 - 12	50
12 - 16	40
16 - 32	20
> 32	10

3.1.4 Markets

Obtaining data on markets, including their locations, is challenging, particularly because there is no common definition of a market: there might be different markets for different products or services, there are formal and informal markets, some have permanent infrastructure whilst others are temporary, and so on. Furthermore, data on the different market types, market volumes and market prices are usually not available. de Wolff *et al.* (2006) suggest that markets in the informal sector are governed by one simple rule: wherever there are people there is demand for agricultural and livestock products. Defined along these lines, any population centre will suffice as a destination for smallholder farmers.

As a baseline for the regional accessibility map, markets were represented by towns with a population of 5,000 or more in the year 2000 (Figure 3), selected from the human settlements database provided by CIESIN, Columbia University (CIESIN *et al.*, 2004). The human settlements database is one of many available from the Global Rural and Urban Mapping Project (Balk *et al.*, 2004) and comprises a global dataset of about 55,000 cities and towns with populations of 1,000 or more. Each point has geographical coordinates and associated tabular information on its population and data sources. Population data were gathered primarily from official statistical offices (census data), and supplemented with data from other sources, such as gazetteers. Where the records for populated places did not include latitude and longitude coordinates, those were taken from the NIMA database of populated places.

As shown in Figure 3, the database does not provide a full coverage of cities and markets in the Horn of Africa, leaving areas in Somalia largely uncovered. This naturally does not mean that there are no markets in thise regions, but that data were not available from the database we used. Additional information could be used for country-specific or livestock-specific applications (as discussed in more details in Section 4.2), but have not been incorporated in the regionally-consistent baseline accessibility surface. Market access in fact is likely to be highly commodity-specific and so for commodity-specific applications accessibility maps should be constructed using the appropriate data and settings, estimating access time to specific livestock markets and so on.

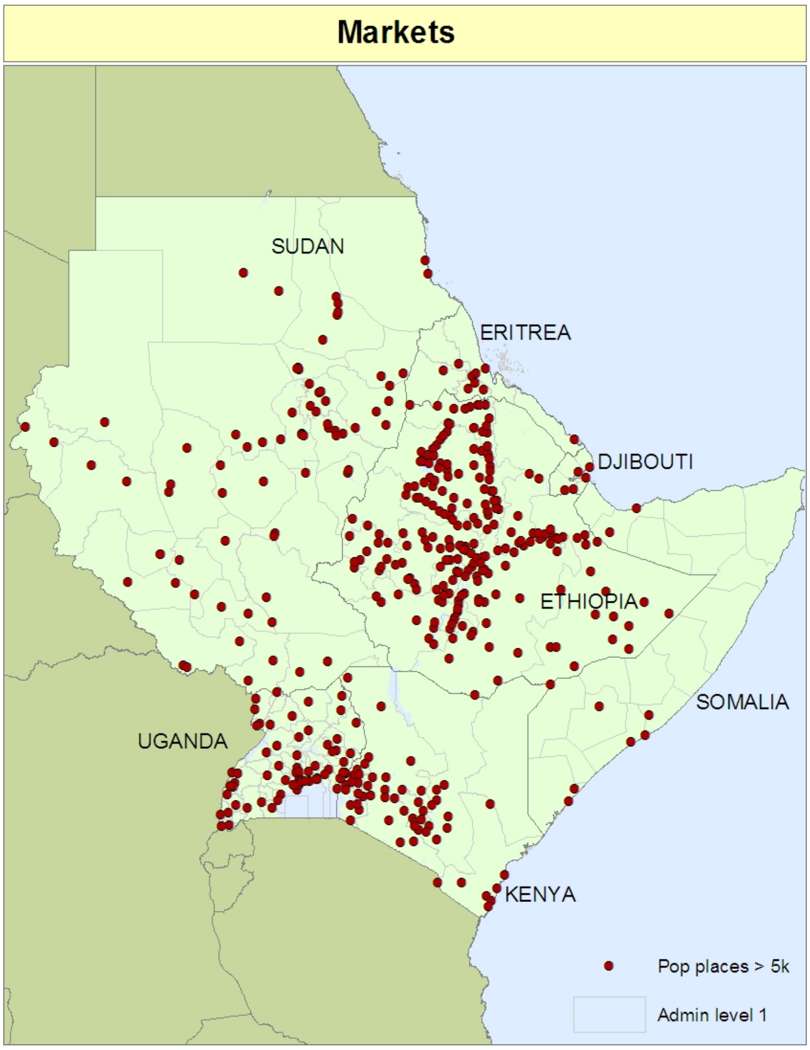
Among the more specific information on markets, two sources of livestock market data in East Africa are the Livestock Information Network Knowledge System (LINKS) and the IGAD Livestock Marketing Information System (LMIS). LINKS provides regular livestock prices and volume information on most of the major livestock markets, along with information on forage conditions, disease outbreak, conflict and water supply to support decision making at multiple scales (LINKS, 2007). Similarly, the IGAD LMIS aims to provide timely and reliable marketing information, in particular livestock pricing and volumes. In reality, however, entries in both databases are limited to the major markets, corresponding to the largest cities or towns.

Country-specific market data were available for Kenya and Somalia, provided respectively by the Kenya Ministry of Roads and Public Works and FAO-FSAU. The Kenya database comprises some 5,400 geo-referenced markets, while the Somalia database includes 39 geo-referenced cereal markets and 56 geo-referenced livestock markets, 15 of which were actually located in Ethiopia and Kenya. FSAU also provided information on market prices for the years 2003 and 2004 for selected markets, which included price data for camels, cattle and goats (and for camel milk). For the regional accessibility model we used the regionally consistent GRUMP data (with the resulting surface shown in Figure 5) and for the comparative analyses presented in Section 4 we used the much more detailed dataset for Kenya. Table 4 below shows the number of markets listed in each of the IGAD member states.

Number of markets by country in the IGAD region. Markets are defined as population centers of 5,000 people or more, derived from the GRUMP database. For Kenya and Somalia, specific market data were also available, as indicated by the numbers in parenthesis.

Country	Number of markets
Djibouti	5
Eritrea	9
Ethiopia	217
Kenya	59 (5,432 from the Kenya Ministry of Roads and Public Works)
Somalia	8 (39 from FAO-FSAU)
Sudan	72
Uganda	64

Figure 3: Markets in the IGAD Region.



Source: Places populated by 5,000 people or more from the Global Rural and Urban Mapping Project (CIESIN *et al.*, 2004).

3.2 Accessibility Surface Modelling

The accessibility surfaces were generated using the cost-distance function in the ArcInfo Grid environment (see Annex 1 for the full commands). The function calculates the least costly path, in this case the quickest, to reach a destination traveling across a raster friction surface. A cost path consists of sequentially connected links that provide the route connecting each cell location to a destination or target. The cost-distance from any cell to a target is the cumulative cost of all links along the cost path. While there are many possible paths to reach each target cell, there is only one least cost path. The least-cost path is calculated for each cell in the analysis window to the target that will be the least costly to reach, based on an iterative allocation (ESRI, 2004; Longley *et al.*, 2005) that accounts, with two different formulae, for both linear and diagonal movements from one cell to the next. It is this value that is assigned to each cell in the array – an estimate of the time required to reach the most 'accessible' market by the quickest route.

All cost-distance functions require a set of targets and a friction surface. Targets are points of interest, such as markets, villages, hospitals, schools, etc. They are represented as a grid with specific characteristics: a village's population, the number of beds in a hospital, for example. If we are simply interested in the location of the target then all points are assigned the same value. The cost grid is a raster dataset where each cell's value represents the cost of traversing that particular cell. The cost grid may represent actual costs, in monetary units, or, more commonly, the time taken to cross the cell, for a specified mode of transport.

Cost-distance surfaces are expressed in units of cost, not in geographical units. The cost values assigned to each cell are per unit of distance measured for the cell. That is, if the cell size is expressed in meters, the cost assigned to the cell is the cost necessary to travel one meter within the cell. If the resolution is 50 m, the total cost to travel either horizontally or vertically through the cell would be the cost assigned to the cell, multiplied by the cell resolution:

$$total\ cost = cost \times 50$$

To travel diagonally through the cell, the total cost would be 1.414 times the cost of the cell, multiplied by the cell resolution:

$$total\ cost = 1.414 \times cost \times 50$$

For consistency with other standard datasets being generated for the IGAD LPI (e.g. for use in regional poverty mapping), the accessibility surfaces were produced at a 1 km spatial resolution.

The steps needed to generate the accessibility surfaces are summarized as follows:

1. Reclassify the road and land cover types according to the established average speed (see Tables 1 and 2) and determine the cell crossing time in min m^{-1} (for example a travelling speed of 60 km hr^{-1} corresponds to 0.001 minutes needed to cross 1 m).

2. Grid the road and land cover layers at the same spatial resolution. The attribute value would be the cell-crossing time.

3. Grid the target points (also at the same spatial resolution). The attribute value could be the population.

4. Since accessibility is calculated across different countries, include a grid of the country boundaries to account for delays at international borders (for this analysis we have estimated a delay of 1 hour, thus assigning a value of 60 min to traverse a 1 km cell, based on Nelson, personal communication, July 2006 and Hartley *et al.*, 2007)[3].

5. Project all the grids to a suitable projection for the calculations. In the present case the Lambert Azimuthal Equal Area projection was used.

6. Prepare the cost surface, by merging the borders, road and land cover grids, according to the following logic:

[3] Note: when working in a raster environment, the impedance values for line features which represent barriers (borders in this case) should be resolution-specific – for example 60 minutes per kilometer may be a reasonable "delay factor" for a national border rendered in 1 km cells, but might not be appropriate for different resolutions, since the pixel value represents the total time to cross that barrier (unlike the other components of the cost surface, where the pixel value represents the average speed)

trcost1 = [merge (border, roads, land cover)]

The <merge> command works on precedence, which means that, cell-by-cell, the value for border takes precedence over that for roads, which in turn takes precedence over that of land cover. Land cover is used to estimate average speeds outside the road network. In the present analysis it was assumed that on-road travel would be by motorized vehicle, with road speed depending on the type of road, whilst off-road travel would be by foot, with walking speed conditioned by land cover. This simplification does not take into account different modes of transportation, seasonality (dry or wet roads, for example), or the fact that people who are walking to a road might keep on walking on the road itself. Nor does it allow for vehicular travel off-road, along un-recorded tracks, for example. The underlying assumption is that a person living at a given location in the study area will travel on foot to the nearest road access point and continue travelling to the closest market using a motorized vehicle. In practice that may not be the case, and it may even be unlikely in many developing countries and especially if transporting livestock. These issues are discussed further in Section 4.

7. Weight the cost surface by the slope factor (reclassified as in Table 3), based on the assumption that increasing slope will reduce travel speed and therefore increase travel cost:

   trcost2 = trcost1/(slope_reclass/100)

8. In this particular analysis, we are assuming that water bodies represent a barrier to movement, so water was masked out before running the cost-distance model, by setting a mask:

   Setmask (igad_water)

9. Run the cost-distance model, based on the following ArcInfo command:

   Access = costdistance (<source grid>, <cost grid>)

   Where the <source grid> is the grid of the markets and the <cost grid> is trcost2 from point 7 above.

   There are two optional outputs: 1) a grid showing the direction to the nearest target, and 2) a grid showing the allocation zones for each target (i.e. pixels for which that target was the least-cost option).

10. Convert the cost-distance outputs to sensible units (e.g. minutes to hours). The resulting grids represent, for each cell, the time (in hours) required to access the nearest market.

11. Re-project the resulting access grid back to the original projection.

Figure 4 illustrates the main steps needed for the analysis.

Figure 4: Accessibility Surface Modelling.

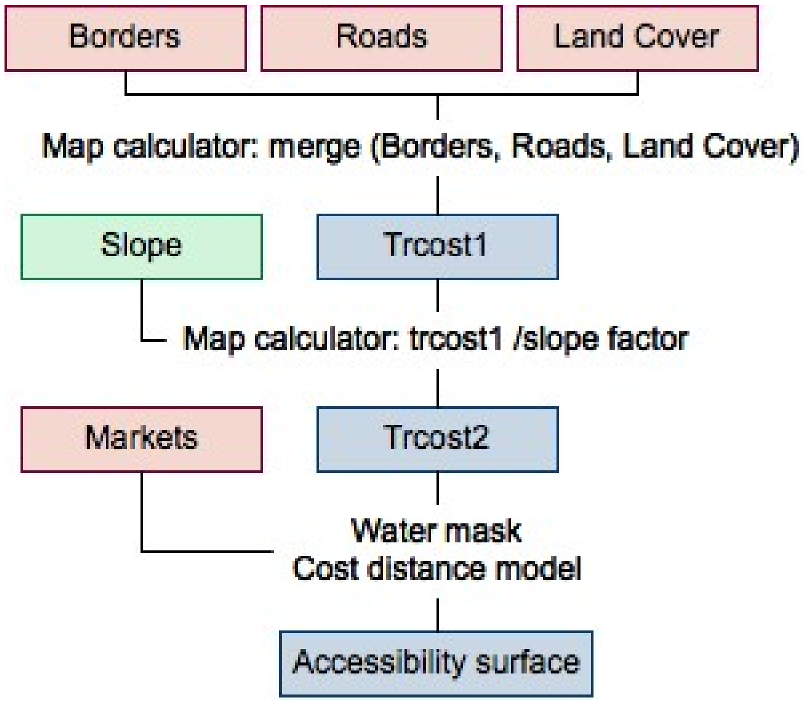
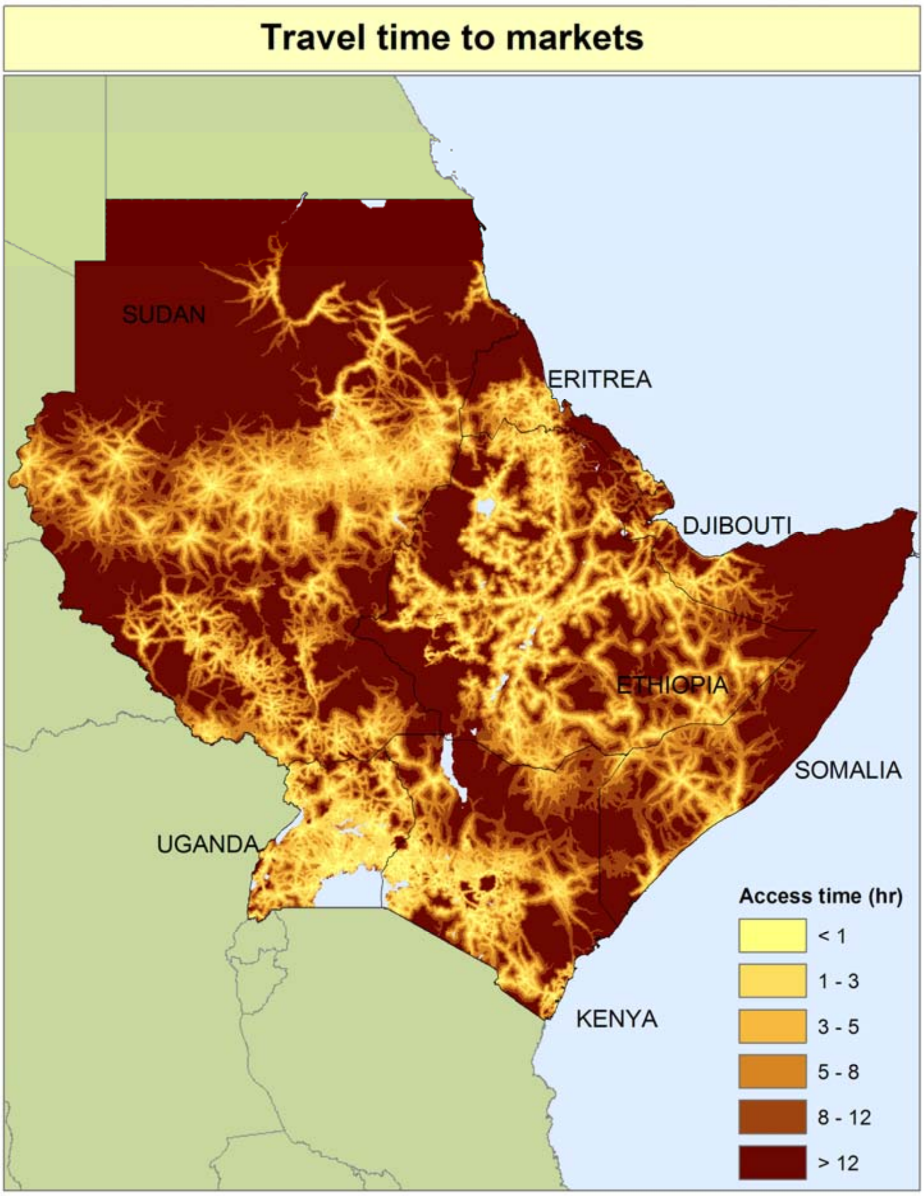


Figure 5: Market Accessibility in the IGAD Region.



Once the accessibility surface is produced, areas can be selected that are within a specified travel time from a market, therefore determining catchment areas. Figure 6 shows the areas within 2 and 4 hours travel distance from a market in the IGAD region.

Table 5 shows the mean population density and the percentage of total population within 2 hours of markets within each IGAD country.

Figure 6: Areas within 2 and 4 hours Travel to a Market in the IGAD Region.

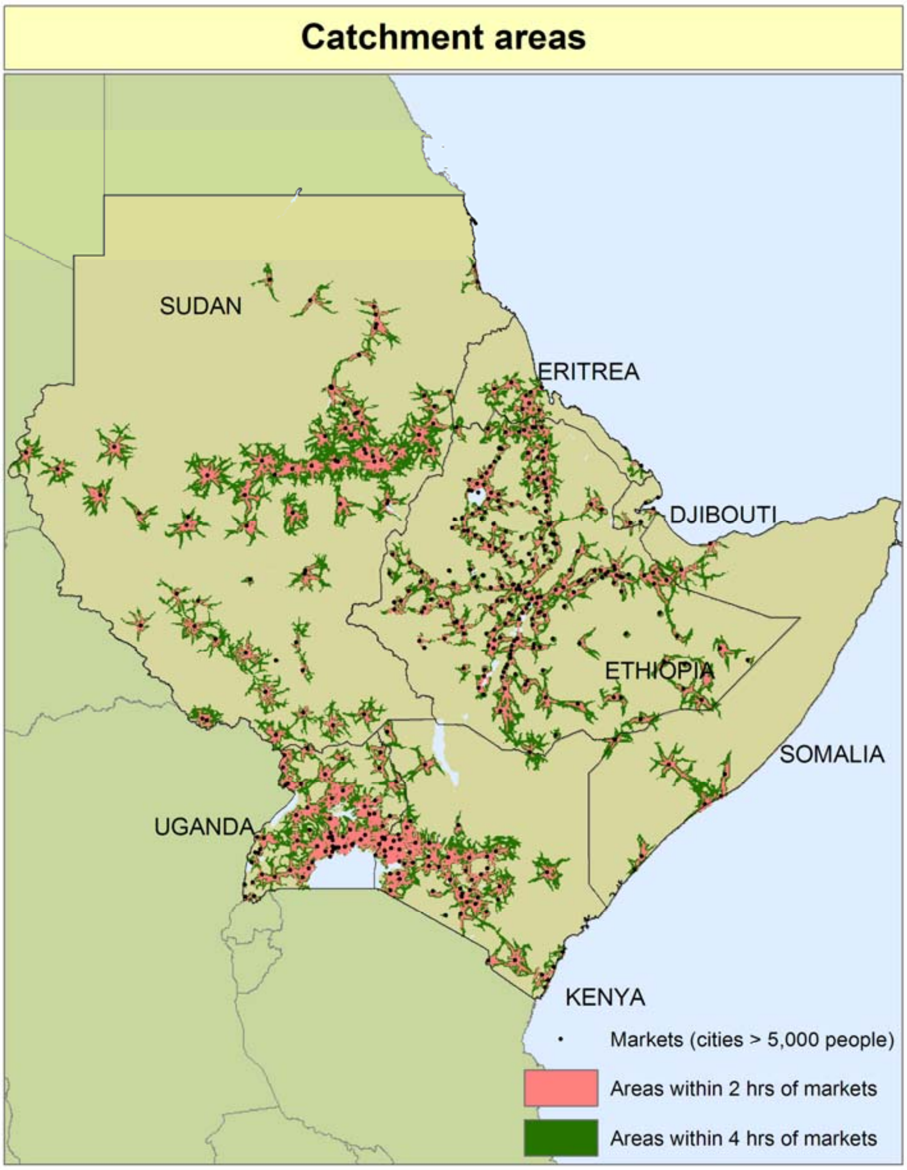


Table 4: *Population Distribution within 2 hours of Markets in the IGAD Countries.*

Country	Total population	Percentage of total population within 2 hours of markets	Average population density within 2 hours of markets (people km^{-2})
Djibouti	632,000	19.40	139.75
Eritrea	3,659,000	16.00	122.51
Ethiopia	62,908,000	22.22	196.53
Kenya	30,669,000	48.81	294.26
Somalia	8,778,000	12.95	177.36
Sudan	31,095,000	11.24	82.52
Uganda	23,300,000	52.54	215.66

Note: Total population is from UN 2000 Statistics, while calculation on population number and population density within 2 hours of markets are produced using the GRUMP database (CIESIN *et al.*, 2004).

4. LIVESTOCK-SPECIFIC APPLICATIONS

The basic market accessibility surface for the IGAD region described in the previous section was developed using a simple model, with regional datasets and some broad assumptions and generalisations. In this section we use essentially the same model, but apply it to more detailed data for Kenya, and conduct a comparative analysis, accounting for different 1) modes of transportation; and 2) types of market. These are closely interlinked and depend on the type and volume of commodity to be transported. Specific markets may exist for different commodities and the choice of transportation will depend on the type and quantity of commodity that is to be transported. Table 5 provides some ideas about the types and quantities of livestock products that can be accommodated by different modes of transportation. In Table 5 large stock refers to animals such as cattle and camels, small stock to animals such as sheep, goats and pigs, and meat may refer to whole carcasses or to cut meat. Obviously the numbers given are only indicative – there will be considerable variability within each category.

Table 5: *Estimated Volumes of Commodities by Different Modes of Transportation.*

Commodity	Units/load	Herding	Walking	Donkey cart	Bicycle	Motor-bike	Car/pick-up	Lorry	Refrigerated transport
Large stock	Head	200	na	na	na	na	2	20	na
Small stock	Head	200	na	na	2	2	5	100	na
Poultry	Number	na	5	50	20	20	50	200+	na
Milk	Litre	na	10	100	20	40	200	1,000	1,000
Eggs	Number	na	200	2,000	400	800	4000	20,000	na
Meat	Kg	na	10	100	20	40	200	1,000	1,000

The cost-distance model cannot account for variations of more than one variable at a time, and so it needs to be 'customized' to address specific questions individually.

4.1 Different Modes of Transportation

In this first analysis we compare models of accessibility based on different modes of transportation. For land cover we used the same database (Africa Land Cover Map, Version 5) that was used for the IGAD-wide accessibility surface. For roads, we used the more detailed database from the Kenya Ministry or Roads and Public Works (Government of Kenya, 2006). The roads were grouped into three classes: 1) paved roads (classified as A through C in the original database); 2) single carriageways with earthen surfaces (classes D and E); and 3) all the others (described as special purpose roads, which normally serve a farm, school etc. and are of poor quality).

Table 6 shows the different travelling speeds estimated for the different road and land cover types, for each mode of transport.

Table 6: *Average Travelling Speeds (km hr^{-1}) by Differential Modes of Transportation on Different Road and Land Cover Types.*

Road or land cover type	Herding	Walking	Donkey cart	Bicycle	Motor bike	Car/pick -up	Lorry	Refrigerated transport
Open or sparse grasslands, croplands (> 50%, or with open woody vegetation, or irrigated), mosaic of forest/croplands or forest/savannah	1.5	3	10	10	10	na	na	na
Deciduous shrubland or woodland, closed grasslands, tree crops, desert (sandy or stony) and dunes, bare rock	1.5	2	6	10	10	na	na	na
Lowland forest (deciduous or degraded evergreen), swamp bushland and grassland, salt hardpans	1.5	2	na	10	na	na	na	na
Submontane and montane forest	1	1	na	8	na	na	na	na
Closed evergreen lowland forest, swamp forest, mangrove	na	1	na	na	na	na	na	na
Urban areas	2	3	6	10	20	30	30	30
Paved roads (Classes A through C)	2	3	10	15	35	70	70	70
Single carriageways with earthen surface (classes D and E)	2	3	10	10	20	40	40	40
Other roads (special purpose roads)	2	3	10	10	20	25	na	na

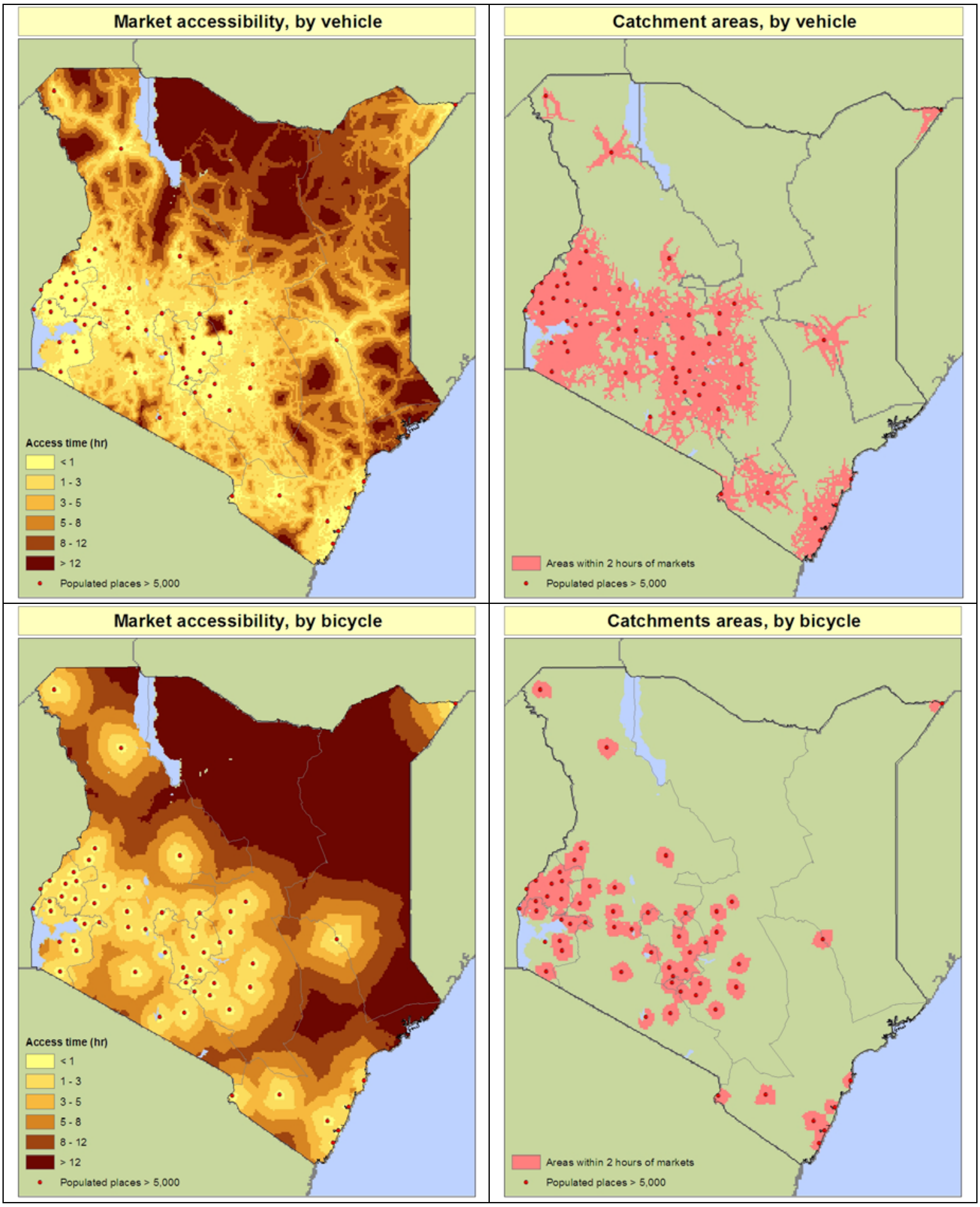
This table tries to capture the different ways livestock and livestock products can be carried to and from markets. Naturally, the choice will depend on the type of livestock or products transported and on availability of the different modes of transportation. For example, depending on the quantity being moved and the distance to be covered, milk may be transported by foot (small volumes over very short distances); by bicycle (medium quantities over intermediate distances); by motorbike (medium quantities over longer distances); by van or truck (large quantities over long distances); or by refrigerated motorised transport (large quantities over even longer distances). With a perishable good such as milk transport time is absolutely critical – and may be tempered by refrigeration or purification facilities at milk collection centres *en route*.

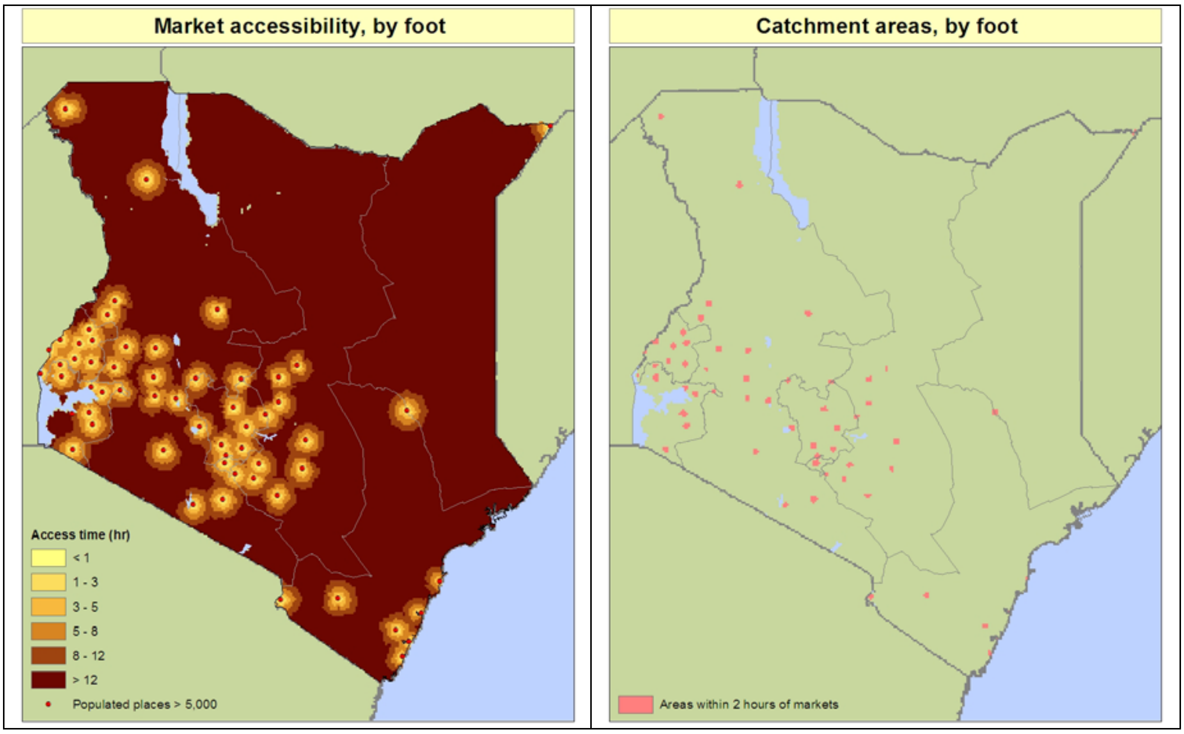
The model has to make a number of additional simplifications about factors that cannot be accounted for in the cost-distance model. For example, livestock are likely either to be trucked or trekked across open country to markets. How these two modes of transport may be combined will depend on many factors, possibly including infrastructure (market and transport), legislation (for example taxes), availability of feed and water resources *en route*, security, demand (which may determine the availability of services to transport livestock), and the market value of the livestock. Though trekking may have high costs in terms of animal mortality and weight-loss, trekker time and greater risk of raiding, the poor road infrastructure and the cost and availability of motorized transport services in Kenya often preclude sellers and traders from trucking livestock (Bailey *et al.*, 1999). Transportation costs are also not accounted for in this model. In Kenya, transport accounts for 25 to 40 percent of the total cost of livestock delivered to a terminal market from the northern pastoral areas, and in some cases traders might choose to trek their animals to save on transportation costs (FEWS NET, 2007).

To compare the effects of differential modes of transportation, a single category for markets was used - populated places above 5,000 people. Figure 10 shows travel time to markets based on three different modes of transportation: 1) walking; 2) cycling; and 3) by car/pick-up, assuming the travelling speeds described in Table 6.

The figure clearly shows the strong linear influence of the road network in accessibility using vehicular transport. The patterns for bicycle and pedestrian transport are similar to one another – and are less strongly influenced by road networks, with travel time increasing rapidly in a more circular pattern with increasing distance from markets. In the latter two cases the market catchments are much smaller.

Figure 7: Market Accessibility in Kenya with Roads Classified based on Driving, Cycling and Walking Speeds. The Right Hand Figures show the Respective Catchment Areas within 2 hours of Markets.





Source of road data: Kenya Ministry of Roads and Public Works (Government of Kenya, 2006). Source of market data: CIESIN *et al.* (2004).

4.2 Different Types of Markets

This section examines how the type of market considered can affect accessibility. Market-type and product- or service-type are closely linked, and an analysis of market access should start by looking at the structure and organization of the marketing chain for the commodity (or service) of interest. In the case of milk marketing, for example, in many developing countries it will be of vital importance to differentiate between formal and informal channels (de Wolff *et al.*, 2006), as different markets are likely to serve each. Cattle will normally be taken to a primary market (by the livestock owner), whence they will transport to secondary, tertiary and ultimately a terminal market by various traders. The different legs of this journey may involve different modes of transport, and an accessibility analysis should be clear whether it is measuring access to primary markets, or to terminal markets.

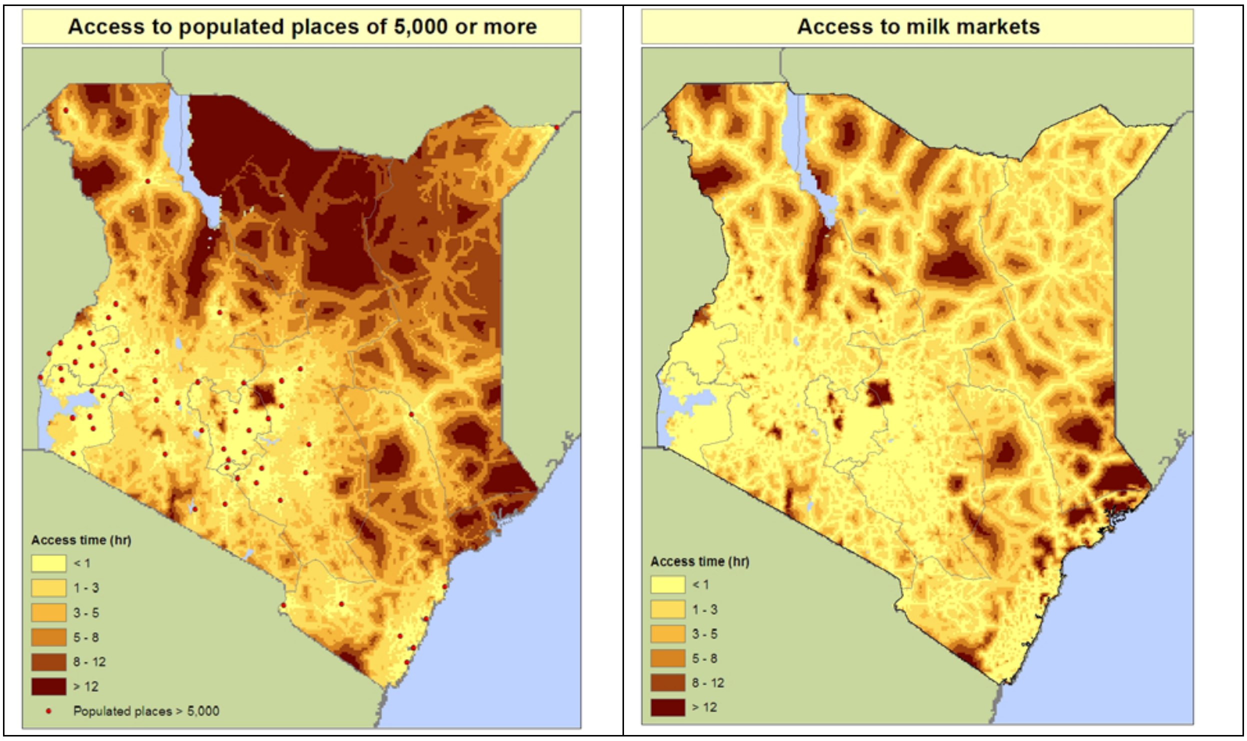
With these caveats in mind, we modelled accessibility to different types of market, running the 'base' cost-distance model in which on-road travel is assumed to be by motorized vehicle and off-road travel by foot. We distinguished the following types of market:

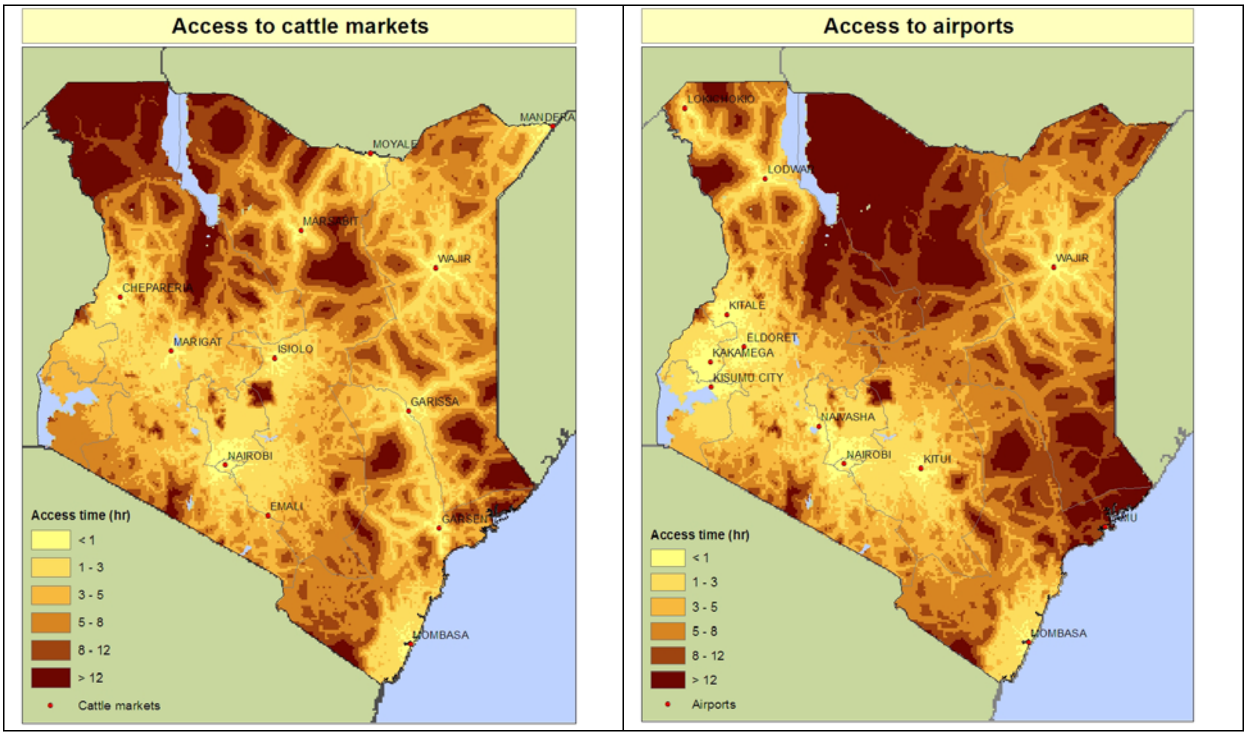
- Places populated by 5,000 or more people, from the GRUMP database (CIESIN *et al.*, 2004) – this is the baseline map as per Figure 5 but not accounting for neighbouring countries (n=59);
- Milk markets, as provided by the Kenya Ministry of Roads and Public Works database (Government of Kenya, 2006) – these market locations were collected alongside the road data by the Roads Department, and thus are not 'official' milk markets. Based on the assumptions of de Wolff *et al.* (2006) - that every place where people could buy and sell milk could be considered a milk market - all locations have been included, which is likely to account both for formal and informal markets (n=5,400);

- Cattle markets, from the Livestock Information Network Knowledge System (LINKS, 2007) – these are the major markets at which cattle are traded (n=12);
- Airports, from the World Aeronautical Database (NGA, 2008) – perishable products such as processed meat, and a wide range of other livestock products (e.g. hides and skins, milk powder, egg powder, etc.) are typically sent to airports for export (n=12);

Figure 11 shows the resulting maps. The importance of the road network is clearly revealed in all cases due to the assumed use of vehicular transport in the accessibility model used. It comes as no surprise that access time decreases as the number of markets increases, and the maps demonstrate that, for commodity-specific analyses, the appropriate inclusion of markets is essential.

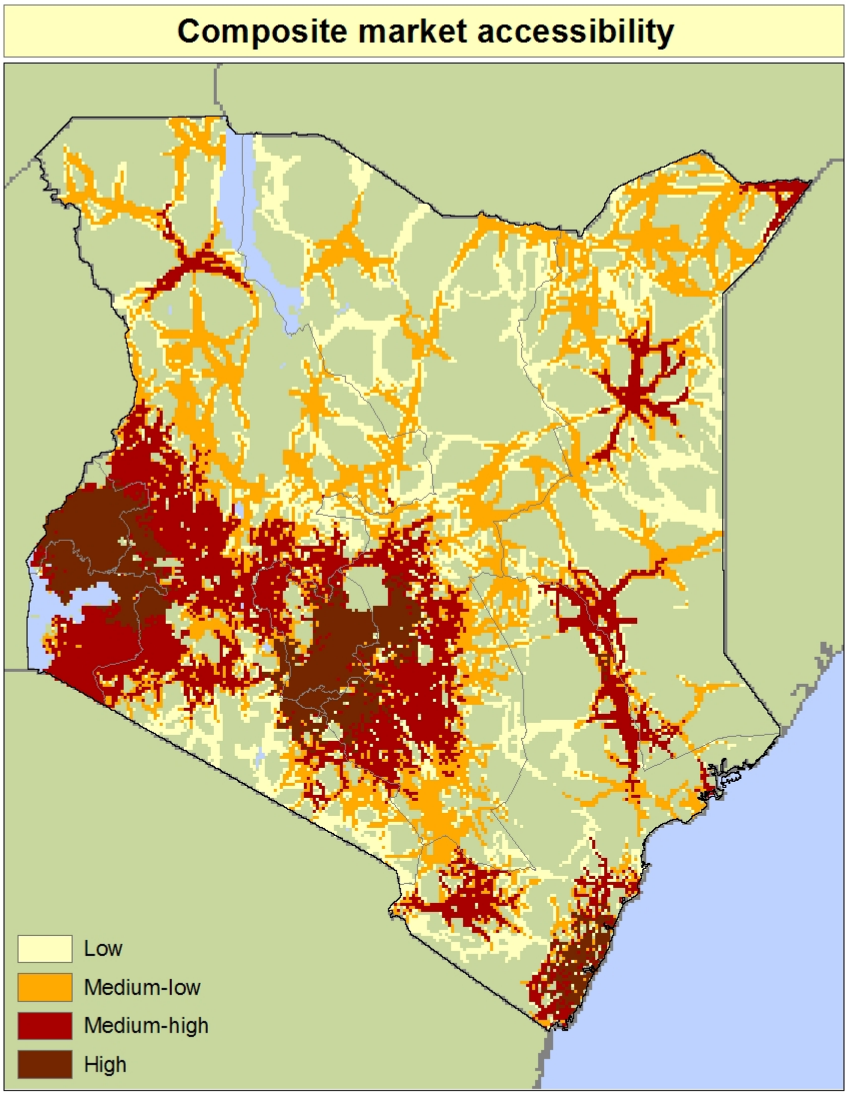
Figure 8: Access time to different types of markets in Kenya.





Following the approach developed by Omamo *et al.* (2006) a composite accessibility index was constructed in an attempt to assess the overall level of market accessibility. The Kenya Ministry of Roads and Public Works database comprises some 5,400 georeferenced markets, classified as divisional, provincial, district and 'other' markets (where the denomination 'other' refers to small markets and trading posts). We first determined areas within two hours of each market type and then, for each cell, counted the number of different types of market within two hours travel. The results, shown in Figure 9, highlight areas of high accessibility around the major cities of Nairobi, Kisumu and Mombasa, and in Nyanza and Western provinces; people in these areas enjoy access to a range of different types of market.

Figure 9: Composite Market Accessibility.



5. CONCLUSIONS

The objectives of this analysis were: 1) to a produce a generalised, regional map of market access; and 2) to review and investigate different approaches to accessibility mapping that may have relevance to pro-poor livestock policy development.

A requirement of a regional accessibility model is that the data contributing to it must be consistent across the region of interest. To include more detailed road data for Somalia compared to the rest of the region, for example, or a more detailed market dataset for Kenya, would completely invalidate a regional map. This restriction may enforce the use of proxy variables or poorly detailed datasets in order to preserve consistency across countries. In the IGAD region, fairly standard road and land cover databases are available, as described in Section 3. Efforts are underway to develop a more detailed and globally consistent road database[4]. Standardised market information is much more problematic, so reasonably standardised population data provide the most consistent estimate of markets for regional analysis. Using populated areas as a proxy for markets has been shown to be useful in determining development domains (You and Chamberlin, 1994; Omamo *et al.*, 2006) and in poverty mapping (Rogers *et al.*, 2006; Robinson *et al*., 2007). Treating all populated areas (e.g. those above 5,000 people) as equal, however, may limit the usefulness of these estimates; surely a town with 500,000 mouths to feed and pockets to dip into will present more opportunities than one of 5,000? The challenge is to determine whether the generalisations made in such models are reasonable, or whether they limit the usefulness of the results.

In relation to the second objective, we suggest that choice of mode of transport and type of market are highly dependent upon a multitude of factors that are likely to interact in quite complex ways. These include, for example: not only the distribution of but also the quality of the road network; the type of goods to be transported, or services to be procured; the value or cost of those goods or services; the wealth and assets of the person wishing to transport goods or services; the availability and costs of different types of transportation service; the use of multiple modes of transportation along a marketing chain; logistical (e.g. road blocks), legislative (e.g. taxation) and security (e.g. cattle theft) issues related to particular routes or modes of transport; seasonal factors such as ephemeral rivers and poor road conditions; and, in the case of live animals, the availability of feed and water *en route*, and possibly the risk of contracting particular diseases (trypanosomiasis, for example, from tsetse-infested areas). Because of factors such as these, and the generally poor and highly variable quality of data, it is likely to be difficult 1) to model accessibility accurately, and 2) to make sensible generalisations. Furthermore, it is likely that the detailed input data relevant to such applications, such as markets and transportation networks, are available only at national or even sub-national levels, at a consistent level of detail.

The examples described in Section 4 highlight that market access is likely to be highly commodity-specific and so for commodity-specific applications accessibility maps should be constructed using appropriate data and parameters. In this case it is useful to have the relevant datasets in place and the methodology automated so that accessibility surfaces can be produced and adjusted quickly in response to particular questions. By providing a documented procedure to estimate market accessibility, and some baseline datasets, this paper facilitates users to produce accessibility maps as the need arises.

The emphasis in this paper is on how increased market access could be beneficial for livestock keepers and thus be a contributing factor to their welfare and livelihoods.

[4] see http://www.ciesin.org/confluence/display/roads

However, for the reasons mentioned above and the fact that the role of livestock varies among rural households, highly specific, livestock-oriented accessibility estimates are likely to be more misleading than enlightening in poverty analysis unless the analysis is stratified appropriately – according to the role of livestock. Travel time to milk collection centres, for example, may be a highly relevant and significant welfare predictor variable for households for which dairy production is an important source of income, but not for the rural population as a whole.

Access to markets may be an important variable in analyzing the potential for buying or selling livestock or livestock products, but in terms of targetting resource allocation (e.g. for delivery of veterinary services), a number of other variables needs to be taken into account. In the example of veterinary services, the revenue required for a commercial service provider to be economically sustainable and the willingness of livestock keepers to pay for services are particularly relevant. Unfortunately such data are not systematically collected, but a questionnaire-based approach, called the contingent valuation method (Mitchell and Carson, 1989), has been used in the field of animal health to measure demand for non-market goods and services and to assess willingness to pay in a number of countries (e.g. Swallow and Woudyalew, 1994; Echessah *et al.*, 1997; Kamuanga *et al.*, 2001; Ahuja and McConnell, 2000; Hooton *et al.*, 2003).

In the case of access to animal health service provision these variables must be accounted for in addition to the time or cost taken to reach a service-provider. The marginal areas, where the highest proportion of poor livestock-keepers reside, are characterised by poor infrastructure, few vehicles and low population densities, all of which result in considerable costs both to service providers and to livestock owners (Ly, 2003). Indeed, studies in Zimbabwe suggest that transaction costs are the major constraint in determining the expressed demand for animal health services (Woods, 2000).

Peeling and Holden (2004) discuss the effectiveness of community animal health services – drawing from surveys and case studies in a number of countries. By comparing similar livestock keepers, both with without access to the services of Community Animal Health Workers (CAHWs), they showed how such services could have a dramatic impact on their livelihoods – especially in remote areas where access to professional veterinary services is limited. Since CAHWs are local and affordable, they are more accessible to the poor and contribute to improvements in the health of their livestock (resulting in lower levels of mortality). These improvements are reflected in the welfare of the livestock keepers themselves.

A useful application of the accessibility model might be to estimate access to villages where community animal health services are available, and to combine such information with livestock distribution data to determine areas where access to animal health facilities and services may constrain livestock production and marketing. By including information on willingness among livestock keepers to pay for services, and on income expectations among service providers, these accessibility estimates could be used to help prioritize interventions aimed at provision of appropriate livestock services in the Horn of Africa.

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ANNEX A. COMMANDS TO GENERATE THE ACCESS SURFACES

Step-by-step methodology to generate the generic market accessibility for the IGAD region. These commands were written for ArcInfo, but are also available in ArcGIS and ArcView.

1. Prepare the roads grid: first recode the shapefile by creating a new field (for example call it rd_tt), floating, and reclassify the primary roads as follows:

Table A1: Roads Classification.

Road type	Average speed	Cell crossing time (min/m)
Primary roads	60 km/hr	0.001
Secondary roads	30 km/hr	0.002
Unknown	30 km/hr	0.002

Then convert it to grid:

igad_rd = shapegrid (igad_roads, rd_tt, 0.008333)

2. Similarly, prepare the land cover and slope grids: first reclassify the grids according to travel speed reported in the tables below:

Table A2: Land Cover Classification.

Land cover type	Average speed	Cell crossing time (min m^{-1})
Open or sparse grasslands, croplands (> 50%, or with open woody vegetation, or irrigated), mosaic of forest/croplands or forest/savannah, urban areas	3 km hr^{-1}	0.02
Deciduous shrubland or woodland, closed grasslands, tree crops, desert (sandy or stony) and dunes, bare rock	1.5 km hr^{-1}	0.04
Lowland forest (deciduous or degraded evergreen), swamp bushland and grassland, salt hardpans	1 km hr^{-1}	0.06
Submontane and montane forest	0.6 km hr^{-1}	0.09
Closed evergreen lowland forest, swamp forest, mangrove	0.3 km hr^{-1}	0.18
Waterbodies*	-	-

Note*: It was assumed that water bodies represent a barrier, rather than a means of transportation to markets so a water mask was created and the calculations were performed considering only the 'land' types

Table A3: Slope Classification.

Slope	% (slope_reclass)
0 - 2	100
2 - 5	80
5 - 8	60
8 - 12	50
12 - 16	40
16 - 32	20
> 32	10

then clip the reclassified grids (called afglc_rc and igglobeslp_rc respectively) to the IGAD (or country) boundary (one way to do it is with a selectmask command):

setwindow igad_bnd

igad_sloperc = selectmask (igglobeslp_rc, igad_bnd)

igad_glcrc = selectmask (afglc_rc, igad_bnd)

3. Prepare the markets grid: convert the shapefile, by taking the population as value for the grid:

   igad_mkt = shapegrid (igad_settlements, es00pop, 0.008333)

4. In the case of the regional accessibility surface, include a grid of the country boundaries to account for delays at international borders (for this analysis we have estimated a delay of 1 hour, thus assigning a value of 60 min to traverse a 1 km-cell).

5. Convert the grids to Lambert Azimuthal Equal Area projection, using the following commands and then entering 0 as the radius, 40 as the longitude and 10 as latitude, when asked for the parameters:

   Commands

6. Calculate the travel cost surfaces, by first calculating the friction surface (trcost1) and then weighting it by the slope factor (trcost2):

   setwindow igad_rd_la

   trcost1 = merge (igad_bnd_la, igad_glcrc_la, igad_rd_la)

   NOTE: The <merge> command works on precedence, which means that, cell-by-cell, the value for border takes precedence over that of roads, which in turn takes precedence over land cover.

   trcost2 = (trcost1 / (float(igd_slprc_la) / 100))

7. Calculate the accessibility surface (masking out water bodies first)

   Setmask igad_mask (where igad_mask is the mask of waterbodies)

   Access_mkt5k = (costdistance (con(igad_mkt_la > 5000, 1), trcost2) / 60)

   NOTE: if the markets are available only as locations (lat/long coordinates, but have no other attributes) use the following expression:

   Access_mkt = (costdistance (con(mkt_la > 0, 1), trcost2) / 60)

   so that all points are included.

8. Project the access grids back to geographic

   Accmkt5k_geo = project (access_mkt5k, project_igad_utm_geo.txt, #, 0.008333)