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Accessibility, Poverty and Land Cover in Hambantota District, Sri Lanka.

Incorporating local knowledge into a GIS based accessibility model.

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A Minor Field Study

Anders Ahlström 2008
Master's Degree in Physical Geography and Ecosystem Analysis

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Abstract

Accessibility has been found closely linked to socio-economic indicators and to land use in many studies. The term has many definitions, basically the term describes the ability or the ease in which a location, opportunity or ware can be reached, obtained or be participated in by either spatially separated or socially separated people. This study has focused on the spatial separation. In this study accessibility have been modelled in a raster based approach in a GIS, the results are continuous estimated accessibility raster layers. The study is based on a qualitative and quantitative interview survey and geographical data attained in the country of the field work, Sri Lanka. It was crucial to estimate the travelling speed of different landscape entities, the frictions of the cost surface used in the accessibility model. Similar studies normally use one of two common approaches to attain the crucial frictions. The first is to use data from key informants, the second is to use the speed limits of the roads. The second approach is only feasible where the mean speed of the traffic is similar to the speed limits of the roads, and the first is vulnerable due to the uncertainties of the key informant data. In this study a successful method have been developed to integrate local knowledge and physical geographical data in a GIS-model. Data and methods commonly used in social sciences and humanities have been integrated with data and methods from natural sciences. This has been achieved by calculating the best fit door-to-door travelling speeds of three road classes from interview data. The results from these calculations have been used as frictions for the cost surface. The results of the modelling have then been compared to land cover and poverty indicator data. The comparative analysis showed strong relationships between land cover data and estimated accessibility and between poverty indicator data and estimated accessibility. The results suggest that people to a small amount are abandoning the traditional paddy farming close to towns. And it suggests that people with high estimated accessibility to markets are poorer than people with high accessibility to towns. However uncertain due to low resolution statistical data, the results suggest that high accessibility to markets can not pull the poor out of poverty. It also suggests that people living in close proximity to towns are better of than people living in close proximity to the large wholesale markets. The estimated, modelled accessibility measures also shows stronger relationships to land cover and poverty indicator data than the commonly used simple accessibility measure of Euclidian distance.

Key words: Physical geography, Geography, GIS, Sri Lanka, MFS, Accessibility, Local Knowledge, Land Cover, poverty.

Sammanfattning

Tillgänglighet har funnits starkt relaterat till socio-ekonomiska indikatorer och markanvändning i många studier. Termen tillgänglighet har många definitioner. I grunden beskriver termen möjligheterna eller med vilken lätthet man kan nå, förskaffa eller delta i en plats, vara eller en aktivitet beroende på spatial eller social separation. Denna studien har fokuserat på den spatiala separationen. I denna studien har kontinuerliga data av uppskattad tillgänglighet framställts genom GIS baserad modellering. Modellen är baserad på en kvalitativ och kvantitativ intervjustudie och geografiska data som erhölls i området för fältstudien, Sri Lanka. Det var avgörande att uppskatta reshastigheter av olika landskapsentiteter, friktionerna för kostnadsytan

som användes i tillgänglighets-modelleringen. I andra liknande studier används vanligtvis en av två vanliga metoder för att uppskatta de kritiska friktionerna. Den ena är att använda nyckelinformatörer, den andra är att utgå från hastighetsbegränsningar på vägar. Den andra går bara att använda där trafikflödets medelhastighet är lik hastighetsbegränsningen på vägarna i fråga, och den första är osäker på grund av osäkerheterna i svaren från nyckelinformatörerna. I denna studien har en fungerande metod utvecklats för att integrera lokal kunskap med fysikaliska geografiska data i ett GIS. Data och metoder som vanligtvis används inom sammhällsvetenskap och humaniora har integrerats med data och metoder som vanligtvis används inom naturvetenskap. Detta har uppnåtts genom att att beräkna de dörr till dörr hastigheter av tre vägklasser som bäst stämmer överäns med intervjudata. Resultatet av dessa beräkningar har använts som friktioner i kostnadsytorna, som använts i tillgänglighetsmodelleringen. Resultatet av modelleringen har sedan jämförts med marktäckning och fattigdomsindikatorer. Jämförelseanalysen visade på starka förhållanden mellan marktäckningsdata och uppskattad tillgänglighet, samt mellan fattigdomsindikatorer och uppskattad tillgänglighet. Resultaten tyder på att ett fåtal människor som bor nära städer överger den tradionella risodlingen. Och de tyder på att människor med stor uppskattad tillgänglighet till marknadsplatser är fattigare än människor med låg tillgänglighet till marknadsplatser eller stor tillgänglighet till städer. Trots osäkerheter på grund av lågupplöst statistisk data tyder resultaten på att stor tillgänglighet till marknader inte kan minska fattigdomen. De modellerade tillgänglighetsmåtten visar även starkare relationer till marktäckningdata och fattigdomsindikatorer än vad det vanliga, enkla, tillgänglighetsmåttet Euklidiskt avstånd gör.

Nyckelord: Naturgeografi, Geografi, GIS, Sri Lanka, MFS, Tillgänglighet, Lokal kunskap, Fattigdom, marktäcknig.

Preface

The field work of this study were funded by SIDA as a MFS scholarship and to a smaller extent by the SIDA/SAREC funded research project "Regional Development in an Open Economy – a comparative study of Hambantota and Gampaha districts, Sri Lanka". The aim of the MFS scholarships is to give students economical support to conduct fieldwork in developing countries. The MFS scholarship was supplied by the Department of Physical Geography & Ecosystem Analysis, Lund University. The study have been a part of the SIDA/SAREC research project, it is a study of Hambantota District.

Acknowledgements

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Contents

1. Introduction

1.1 Accessibility

Accessibility has many definitions. Basically the term describes the ability or the ease in which a location, opportunity or ware can be reached, obtained or be participated in by either spatially separated or socially separated people. Low accessibility can limit people, high accessibility can give people opportunities, such as the opportunity to sell their produce on a market, to be able to attend a job, or to be able to attend a good school: *"Accessibility is fundamentally about the life opportunities open to people"* (Farrington & Farrington 2005). This study focuses on the spatial, physical, accessibility.

Accessibility constitutes of two main parts, proximity, the spatial part, and mobility, the ability to move in space (Hanson S 1986). Proximity in this study is represented by the distance from departure to destination, road quality and terrain. Mobility is represented by the ownership of motor vehicles and the supply and reliability of public transportation systems. In this study the two parts are not separated. Accessibility is estimated as travel time in this study. It is dependent of the means of transport available, and it is dependent on both proximity and mobility.

Different measures of accessibility have been found closely related to a number of different physical and social indicators. The relationship between accessibility and land use is widely recognised both for urban and rural environments (Castella et al. 2005, Etter et al. 2006, Hanson 1986, Laurance et al. 2002, Nagendra et al. 2003, Verburg et al. 2004). Accessibility is also related to socio-economic factors, such as poverty, health and production patterns (Guagliardo 2004, Kam et al. 2005, Nanayakkara 2006, Olsson 2006, World Bank report 2007).

In some studies, accessibility is modelled by simple measures, such as distances from roads, towns and other destinations (Etter et al 2006, Nagendra et al 2003). In other studies, accessibility is studied by comparing villages in a more interview based approach (Olsson 2006). In this study a physically based model was developed for the Hambantota district. The model in this study is based on raster calculations[1]. One of the reasons for the raster based approach was incompleteness of the data. Substantial parts of the study area are served by small dirt tracks, foot paths, not always in the road network data that was available. The raster approach[1] allows for simultaneous on-road and off-road modelling, which can compensate for incompleteness in the data. This is not possible with available network analysis tools. A criterion when using network analysis in an accessibility study is that all roads are represented. Normally off-road travelling is calculated by the straight line distance to the closest road. This approach is not suitable when data quality/completeness is low or the travelling habits in the study area to a considerable part consists of off-road or foot-path travelling.

One simple, easy and quick measure of accessibility is Euclidian distance, often

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1. For explanations of raster theory, see for example Burrough & McDonnell (1998)

measured to roads (Etter et al. 2006, Nagendra et al. 2003). However, when measuring Euclidian distances to roads, the road becomes the destination. Destinations in the model in this study are chosen to represent where people are actually travelling to, or would want to travel to, like markets, hospitals, work, etc. Other studies have also recognised the need for more site specific and tailor made models (Verburg et al 2004). Euclidian distance studies do not take road quality, road length, absence of roads, physical obstacles or topography into account. All of which are incorporated in this model.

Traditionally social-sciences and natural sciences are separated. However, Pilesjö (2002) expresses a need to integrate these fields of science, within GIS, with each other. He also sees GIS as a tool where the join between the sciences can be facilitated. In this study a method is developed to integrate local knowledge into a physical GIS based model by using interview data as the base for assignment of frictions. Frictions are what define how fast the accessibility model can fictionally travel over a ground condition, a result of the estimated speed of travelling. The higher the friction of a ground condition, the slower the travelling speed is assumed to be. Generally there are two basic approaches to acquire frictions of roads for an accessibility model. The most common method is to use speed limits. However, to use speed limits is only feasible where the traffic flow has the same speed as the speed limits. A second approach is to use interviews of key informants or field estimations to estimate frictions. In this study a program is developed to estimate frictions on three road classes using interview data on travelling times, departure locations and destinations. This approach quantifies interview data and produces frictions based on local knowledge. It is a method that integrates local knowledge normally used in the field of social science with a GIS-model and geographical data normally used in natural science.

Accessibility modelling is important, e.g. because it can give insight in the relationship of socio-economic indicators and physical attributes to accessibility. A well confirmed model of accessibility entails that the results can be used to see which parts of the study area that are disadvantaged. A good model can also predict changes in accessibility in the planning process of new roads. It can act as a proof for marginalised areas with marginalised inhabitants. By comparing accessibility and socio-economic indicators or physical properties it is possible to better understand if accessibility is a driving factor for the different variables. If the understanding of a problem is good, it is easier to mitigate or solve the problem.

1.2 Objectives

The overall objective of this study is to estimate accessibility to major agricultural market spots and towns in Hambantota district, Sri Lanka, and to investigate possible relationships between accessibility, poverty and land cover.

To fulfil this overall objective a number of specific aims have been defined:

- Collect/capture physical geographical data (roads, topography, etc), and data on destinations (markets and towns).

- Collect data from interviews to better understand the accessibility problems in the study area. Furthermore, the interviews will act as foundation of the assignments of frictions.

- Develop and test a new method for assigning frictions of roads from local knowledge.

- Create a model for accessibility which takes off-road conditions as well as on-road conditions in to account, and to compare the result with that of the commonly used accessibility measure of Euclidian distance.

- Explore possible relations between the modelled accessibility, poverty and land cover.

1.3 Research questions

The research questions of this study are:

- How reliable in terms of precision as well as position is the obtained road network data, and how good are the data after geometric correction and reclassification?

- What are the appropriate weights for the different ground conditions, and how many different ground classes are appropriate to use while not limiting the detail of the result on the basis of the information available for assigning weights?

- Is it possible to join local knowledge and geographical data in a accessibility model?

- Is the modelled accessibility related to poverty?

- Is the modelled accessibility related to land cover?

- Is modelled accessibility closer related to poverty and land use than simple measures of accessibility such as Euclidian distance?

1.4 Research hypotheses

The research hypotheses of this study are:

- Local knowledge can be joined with geographical data in a physical model.

- Indicators of poverty are related to accessibility.

- Land cover patterns are related to accessibility measures

- Modelled accessibility is a better measure of actual accessibility than Euclidian distance.

1.5 Study area

Sri Lanka is one of the richer countries of South Asia, it is one of the *Lower-Middle* income countries of the world (Peiris 2006). The total population of Sri Lanka was estimated to 18.8 million in 2001 by the Department of Census & Statistics (DCS 2001). The growth rate of the population was 1.2 % the same year. The island has a proximate size of 65.610 km^2. It is located not far away from the southern tip of India, in the Indian Ocean. The study area of Hambantota district is located in the southern province of Sri Lanka, see Figure 1. Sri Lanka is divided in 4 administrative levels, provinces which are the largest, districts which are the second largest, divisions which is the third largest, and Grama Niladhari which are the smallest. Grama Niladhari is commonly called GN-divisions, and will be called GN-divisions throughout this thesis.

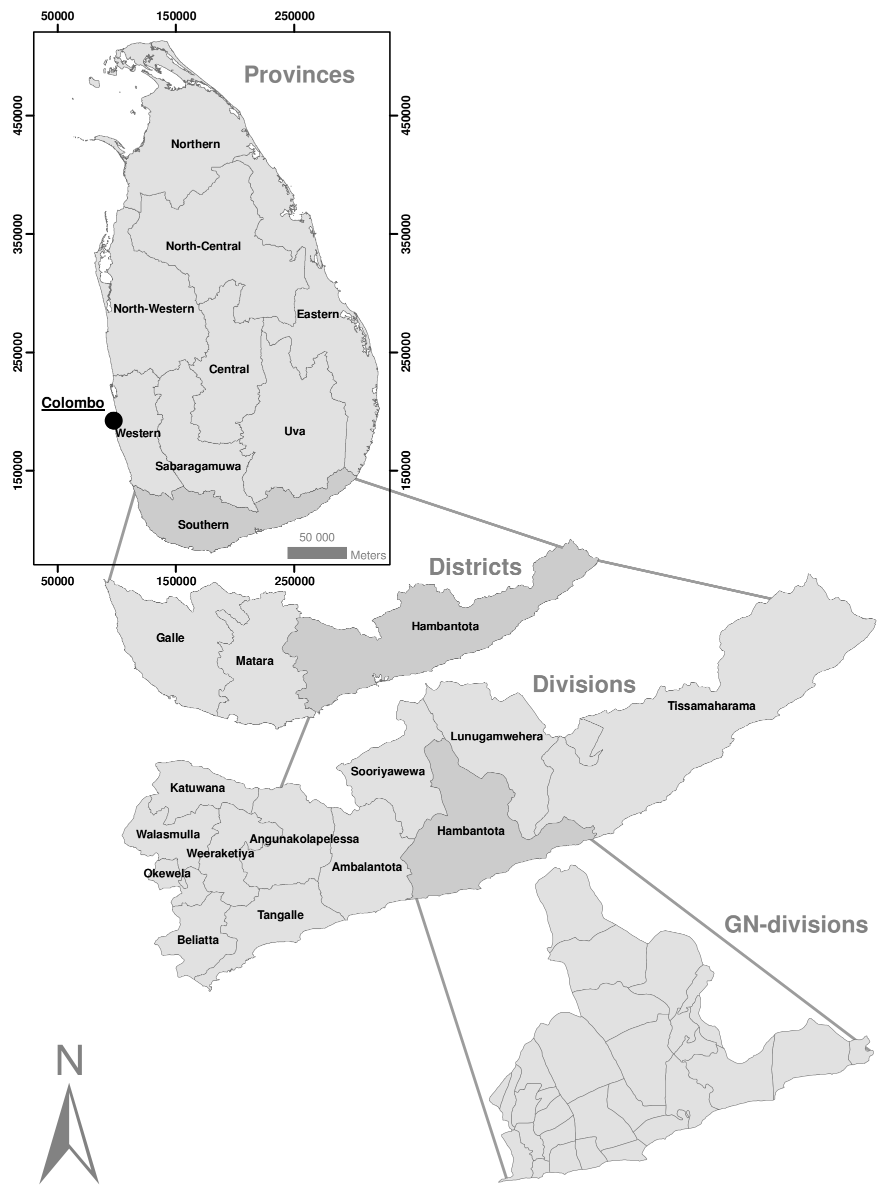

Figure 1. Map of Sri Lanka and the different administrative levels (Data and names comes from Survey Department and DCS 2006). Coordinates in SL1999.

Hambantota district constitutes of 12 divisions and 583 GN-divisions. Hambantota is one of the poorer districts of Sri Lanka (Peiris 2006). According to the department of census and statistics Hambantota district had the fifth highest rate of people below national poverty line in 2002 (DCS 2006). However the survey did not hold information on all districts of Sri Lanka, it did not hold information of the northern and eastern parts of Sri Lanka.

According to a source at the Chamber of Commerce in Hambantota, the poverty and neglect from the government have led to disturbances, uprisings and protests from the people of Hambantota district. The source points out the past lack of infrastructure development in the district as a crucial factor for the unrest in the district. Road quality both internally and connections to Colombo is bad.

1.5.1 Climate

Hambantota district is mainly located in the dry agro-ecological zone of Sri Lanka. Parts of the west is located in the intermediate zone, and a small part of the more mountainous north-west is located in the wet zone, see Figure 2 below.

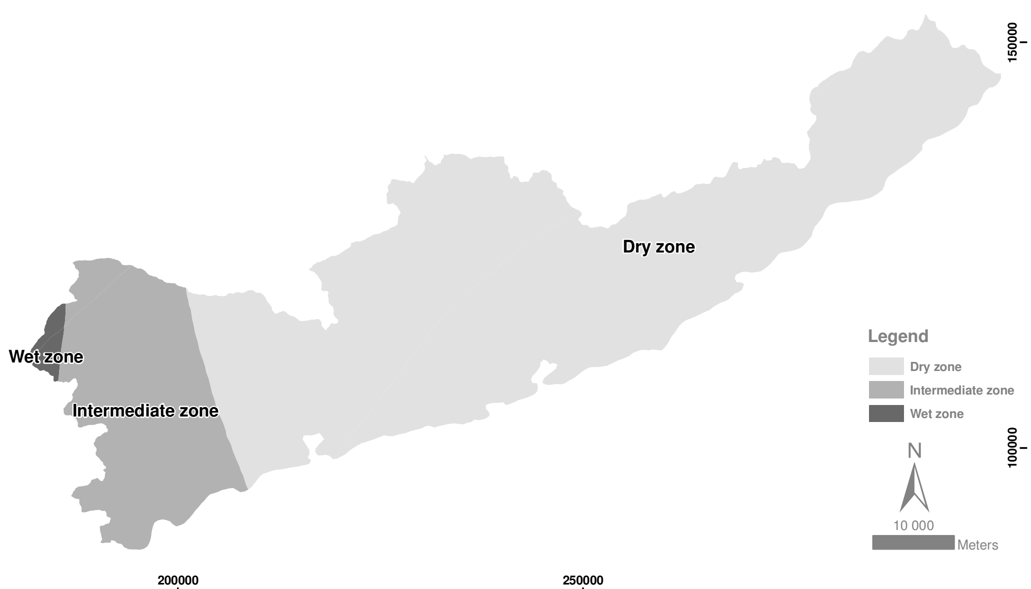

Figure 2. Map of the agro-ecological zones of Hambantota district. Based on data from IWMI (2007). Coordinates are given in Sri Lanka national coordinate system SL1999.

There are a number of wet seasons in the district. The inhabitants of Hambantota district expresses a wet season that stretches from October to January in interviews. This wet period is mainly part of the Second Inter-Monsoon season. However, parts of the rainy season that is perceived as one and the same season by the inhabitants of Hambantota district probably also constitutes of the Northeast Monsoon, with support from the definitions in Peiris (2006). The annual rainfall in the District is between 750 and 1000 mm in the dry areas, between 1000 and 1500 mm in the intermediate parts and between 1500 and 2000 mm in the wet parts (Peiris 2006).

1.5.2 Vegetation

The vegetation in the district is mostly dependent on the water availability. In the dry zone, the dominant none cultivated vegetation is bushes, see Figure 3. In the protected parts, Yala and Bundala national park (see Figure 11), the vegetation consists of bushes mixed with trees. The cultivated vegetation is dominated by paddy and banana cultivation. Banana has lately been on the rise as a popular crop, many paddy fields have been converted to banana cultivation. However, this seems to be a dynamic process, crops change depending on variations of prices and water availability over time. In the western wetter parts coconut, rubber and tea accompany paddy and banana as crops under cultivation. Generally it is greener and there are some forests, see Figure 4. The forests are mainly located in the least accessible areas, on small mountains and hilly areas.

Figure 3. Picture taken in the eastern parts of chena cultivation (slash and burn) and surrounding bush vegetation.

Figure 4. Picture taken in the western parts of paddy fields and surrounding forest.

1.5.3 Means of transport

The traffic of the roads in Sri Lanka and in Hambantota district is distinguished by the variations in means of transport. Many different vehicles, with different maximum speeds traffic the same roads. There are no rules for which kind of vehicles that are allowed to traffic even the largest roads. This induces a dangerous and slow traffic situation. Fast cars and buses travel in the same lanes as slow landmasters, old trucks and bicycles. Two vehicles that are handled in this study are illustrated below. A landmaster with a full cart of banana is illustrated in Figure 5, and a 3-wheeler can be seen in Figure 6.

Figure 5. A landmaster with a full cart of banana on the way to Sooriyawewa market.

Figure 6. A 3-weehler.

1.5.4 Roads

The overall road quality in Hambantota district is poor. But the most striking property of the road network is the internal differences. There is a west-eastern gradient in road quality, where roads are as best in the west and worst in the east. There are also more roads in the western part than in the eastern. This gradient is also visible in vegetation, land use and population density. The western area is wetter, greener, under farming and has high population density and good roads. The eastern part is dry, has bush vegetation, is more sparsely under farming except for the irrigated parts, and has low population density and bad roads.

Roads in this study are classified in three categories, primary, secondary and tracks. Primary roads are the best roads (Figure 10). They are paved and wide enough to allow easy overtaking and good enough to support mean speeds at about 50 km/h, as can be seen in Table 1. The mean speeds in Table 1 are measured with car at a pace in line with the main traffic.

Primary roads stretch from the west to the east and connect all the big towns to each other. Some Primary roads go from south to north in the western part and connect the highly producing agricultural areas with the big towns. Secondary roads are paved, they are wide enough to carry buses and lorries and they generally allow a mean speed of about 35 km/h (Figure 9). Secondary roads vary very much in quality, some have a lot of potholes while others have as good tarmac as the best primary roads. Secondary roads are most dense in the western part, where they connect smaller towns and villages with each other and with big towns and primary roads. In the eastern part, secondary roads replaces the primary roads, although they still have the official road class primary, they are not better in quality than secondary roads.

Figure 7. A foot path.

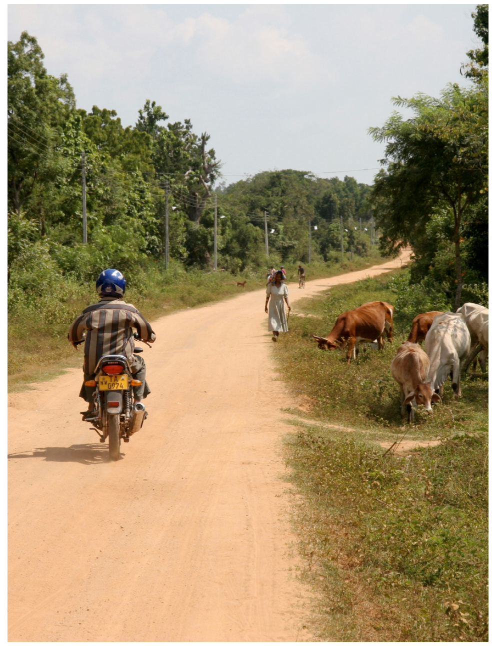

Figure 8. A track in medium condition.

Figure 9. A secondary road in bad shape.

Figure 10. A primary road in good condition.

Tracks, small dirt roads, connect small villages, farming plots, and other less populated areas with secondary or primary roads in the west (Figure 8). The tracks in the east, where primary and secondary roads are sparse or absent, are of a higher quality than in the west, they serve larger areas compared to the west. Because of the higher amounts of precipitation in the western parts, the tracks in the west are more badly affected by the wet season. Tracks can wary a lot in quality in the district, and between seasons, the mean speed that was measured is about 25km/h when travelling with car. Except primary roads, secondary roads and tracks, there are also foot paths in the study area (Figure 7). Although the foot paths were separated from tracks in the classification performed, they are common in the district. Foot paths are narrow dirt tracks. Although the name insinuates differently, they are in many cases fully passable with four wheeled motor vehicles.

Table 1. Mean travel speed calculated from measurements of distance and time. The measurements were performed by measuring the distance that was travelled in a car with the cars distance meter. On the same time the travel time was measured with a timer. With distance and time acquired, speed could be calculated. Only a small portion of the travelled distance in the study area could be measured.

	Road class		
	Primary	Secondary	Track
Mean travel speed (km/h)	50	36	25
Total distance used for speed calculations (km)	299	140	91

1.5.5 Accessibility, the situation in the study area

Hambantota district is an internally diverse area with regard on accessibility. The eastern area is very inaccessible, mostly due to the Yala National Park, which occupies a substantial part of the area, see Figure 11.

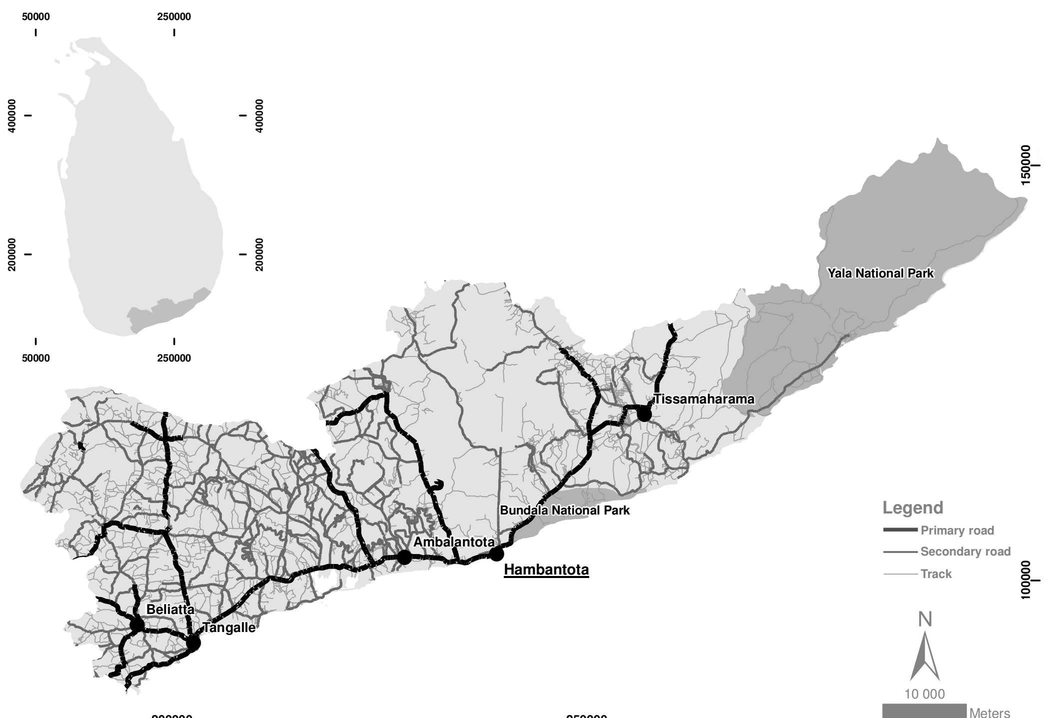

Figure 11. Map of the study area, Hambantota district. Coordinates are given in Sri Lanka national coordinate system SL1999.

The area to the west of Yala NP is also less accessible than the central and western parts. The western parts are the most populated and accessible area of the Hambantota district. The cost of travelling to markets and towns are high in the whole district, but especially in the central and eastern parts. The distances are longer, the road conditions are worse and the public transportation system runs with less frequency. Peiris (2006) expresses that the accessibility to markets in the whole southern region is of major influence for the inhabitants. The World Bank report (2007) shows a strong relationship between poverty and accessibility to Colombo for the whole of Sri Lanka on division level. The report also express that accessibility to market and towns is important on the local level: "*Poverty is concentrated in areas where connectivity to towns and markets, access to electricity and average educational attainment are relatively low, and agricultural labour is an important source of employment*" (World Bank report 2007: 13). Nanayakkara (2006) argues that roads and geographical isolation are highly correlated to poverty both on a district level and on a small scale level in Hambantota district. He also argues that improvement of access roads to remote villages in rural Sri Lanka is fundamental to reduce poverty and that road quality and accessibility is essential to attract investors to remote and under developed areas.

2. Data

This chapter focuses on the available road network data. To be able to perform good accessibility estimations, high quality road data are important. The existing data were of unknown precision and positional accuracy and needed to be evaluated and corrected. The evaluation and correction of road data set the rules for which data that were possible to use in the accessibility modelling.

2.1 List of data

The data that were used in the study is listed below.

Existing

The existing data used are as follows:

- Existing data have been obtained from Survey Department in Sri Lanka in the form of a road network in vector format. The data is digitized from 1:50 000 maps. The data have been subject to generalization and other mapmaking adjustments which explain some of its errors. The overall quality is poor.

- The road network data have been corrected and reclassified from field measurements and estimates. 232 positions, measured with GPS, on the road network have been used to evaluate and reclassify the road network data. 28 junctions measured with GPS have been used to rectify the road network data. The resulting data has high accuracy for primary and secondary roads.

- Topography data have been acquired from USGS as a 90m DEM from the Shuttle Radar Topography Mission (SRTM).

- Data on water bodies is obtained from Sandell (forthcoming), originating from a Landsat TM classification.

Captivated quantitative

Quantitative data have been collected as structured interviews in 154 households. A minimum of 9 households have been questioned in each village. The villages are spread out spatially in the district and according to distances from markets and cities. Census data have been bought on divisional level from the Census department of Sri Lanka. 260 GPS measurements and road classifications have been performed.

Captivated qualitative

Qualitative data have been captured as semi structured interviews with 4 officials in the Hambantota district and 40 village households. The household interviews have been used as a ground for creating a structured questionnaire for the quantitative data collection. Data on markets and towns has been obtained through interviews of officials as well as village level interviews

2.3 Method

2.3.1 Data quality

Road network data origins from digitalisations of 1:50,000 paper maps. The paper maps in its turn, origins from aerial photography. The data has low spatial quality, position, some as a consequence of generalisations in the map making process. However the map making generalisations do not explain all the positional errors. The data is also of low precision in the remark of road classification if compared to the real situation. The cause of this is according to a high official at the Survey Department, that the RDA, Road Development Authority classifies roads after an intended road quality. However in many cases, funds are insufficient either to maintain or to build the roads as to fit the intended quality of the road classes. The classes used by the RDA are primary roads, secondary roads, tracks and foot paths. He also argues that primary roads according to the Road Development Authority classification should have at least three lanes. This is not the case in reality, lanes are not used as marked and divided parts of the roads, and where they are, in larger cities in other parts of Sri Lanka, they are seldom used in the intended way, to divide the traffic into lanes. Instead, in the classification that is used in this study, the primary roads have the criteria to be wide enough to carry traffic in three fictional lanes. A slower vehicle should be easily overtaken, which increases the mean speed and flow of the traffic. A primary road should also be good in the remark of bumpiness and tarmac quality. The data comes classified in four main road classes as well as railways, which are not present within the districts boundary. Secondary roads are defined by that they are paved and narrower than primary roads. All roads that are paved and have less than three lanes should according to the RDA be classified as secondary roads. Tracks are dirt roads that are passable with at least four wheeled traffic. Foot pats are dirt tracks that are not passable with four wheel traffic. However in reality, many foot paths are passable with four wheel traffic, although the speed is often much lower than on tracks.

2.3.2 Transformation of collected data

Survey department data are attained in SL1999 projection. Collected and measured data in other projections and geodetic coordinate systems have been transformed and projected to SL1999 using parameters acquired from survey department, see Appendix 1 for parameters.

2.3.3 Geometric correction

In order to correct the position of the road network data as to better fit the real road network and thus be in line with other data used in the study and positions taken in the field, the road network acquired from survey department was geometrically rectified. The road network data were rectified using an affine[2] as well as a 2nd order polynomial[2] transformation method.

2. For information of transformation methods see for example Burrough & McDonnell (1998)

The transformations were based on 28 junctions spatially well distributed over the study area, see Figure 12. The junctions are mainly located on primary roads. The criteria for the junctions that were used was that they were to be able to be found in the road network data. A number of mapped junctions could not be used because of uncertainties of which junction in the road network data corresponds to the mapped junction.

2.3.4 Data precision and transformation method evaluation

To assess the precision with remark on road classification and the position of roads an evaluation were performed. A total of 232 GPS measurements collected in the field were used to evaluate which transformation method gives the best result, see Figure 12. A second objective of the evaluation was to see if the quality of data on tracks was good enough to allow the use of tracks in the future analysis. Quality of tracks was measured both as positional quality and as how many of the travelled tracks that were found in the road network data.

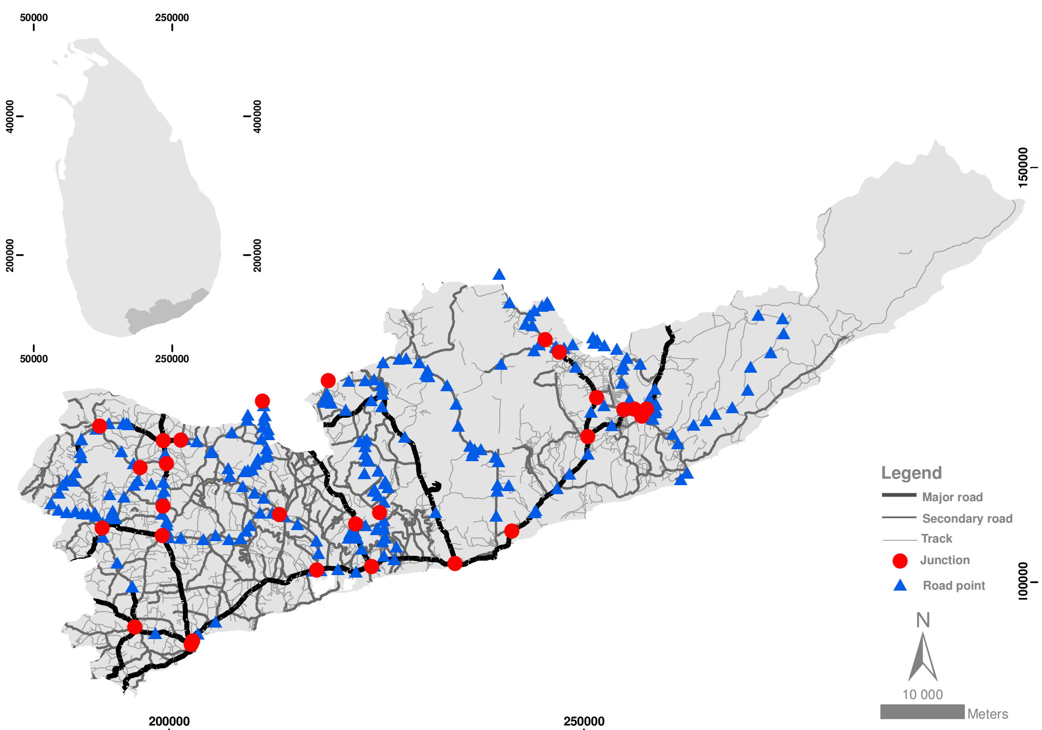

Figure 12. Map showing positions taken for data precision evaluation, reclassification and geometric correction. Coordinates are given in Sri Lanka national coordinate system SL1999.

All roads that were mapped with GPS were classified into three classes, primary roads, secondary roads and tracks. No roads were classified as foot paths because of the difficulties in distinguishing them in the field, a result of poor definition. Classification of the roads was performed after extensive travelling in the study area, which gave a good base for comparison of roads. The classification was based on a relative measure of road quality and width. The roads were also divided into three subclasses for every road class, good, medium and bad, based on their relative quality within the class

The evaluation of the spatial adjustment methods were performed by measuring the distances from points mapped with GPS and classified by its quality, to roads in the road network. The distance measurements were performed by measuring the distances in the GIS. Four different distances were measured for each mapped point. One distance was taken to the closest road of any class, a second distance was taken to the closest road of the correct class in the original road network, a third distance was taken to the closest road of correct class in the reclassified road network and a fourth distance was taken to the closest point on the road that the point was mapped on, the correct road, see Figure 13. The distance to the correct point on the correct road was not measured because it was not known in all cases.

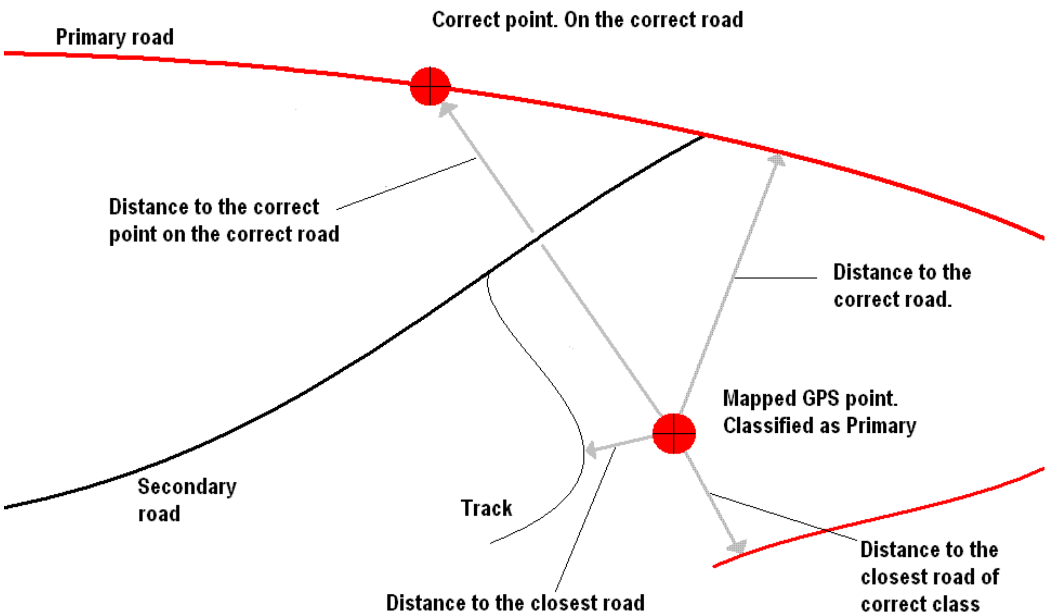

Figure 13. Figure showing the different distance measurements that was performed in the evaluation of position and precision of the road network data. The correct point is the actual location on the correct road where the point was mapped. However, the location visible in the GIS is the mapped GPS point's position. The aim of the geometric correction was to bring these two as close to each other as possible. However, only the distance to the correct road was used in the evaluation because the correct point on the correct road was not known other than for the junctions used in the geometric correction.

A total of 16 tests for each of the transformation methods were performed. Four tests for each road class and four tests for all classes together.

2.4 Results

2.4.1 Geometric correction

The 2nd order polynomial transformation gave the best result in 13 of 16 tests, and had the best mean distance from the correct road for all three road classes as can be seen in Table 2. Three out of 16 of the lowest mean values were found for the affine transformation. However none of these was the distance to the correct road. 2nd order polynomial transformation gave a mean distance of 93 metres from mapped GPS points and the correct road. Primary roads had the best fit, secondary had the second best fit, and tracks had the worst fit.

Table 2. Road network data evaluation, mean distances between mapped points and road network.

Type of transformation	Type of distance	Primary (m)	Secondary (m)	Track (m)	All (m)
	Closest road (no class)	116	131	161	139
No spatial	Correct class (not reclassified)	190	481	208	338
adjustment	Correct class (reclassified)	155	166	181	169
	Correct road	155	174	195	178
	Closest road (no class)	48	48	**146**	82
Affine	Correct class (not reclassified)	97	**390**	181	268
transformation	Correct class (reclassified)	54	59	**157**	92
	Correct road	54	61	167	96
2nd order	Closest road (no class)	**43**	**46**	147	**80**
polynomial	Correct class (not reclassified)	**92**	393	**178**	**268**
transformation	Correct class (reclassified)	**49**	**56**	159	**90**
	Correct road	**49**	**58**	**164**	**93**
Number of mapped points		40	113	79	232

2.4.2 Data precision evaluation

As can be seen in Table 2 above, primary roads had a mean distance of 92 metres between mapped road points and a road of the correct class after 2nd order polynomial transformation and before reclassification. The same measure was reduced to 49 metres to a road of correct class after reclassification. For secondary roads the mean distance between mapped road points and the correct class decreases from 393 metres before reclassification to 56 metres after reclassification. The mean distance from mapped road points to the correct road was 58 metres after 2nd order polynomial transformation. For tracks, the mean distance from mapped road points and the correct class went from 178 metres before 2nd order polynomial transformation to 159 metres after 2nd order polynomial transformation. The distance to the correct road was 164 metres after 2nd order polynomial transformation.

Table 3 illustrates the length of the roads of the three different classes that were reclassified. The reclassification changed the classes of road segments with a maximum of one step, primary was only changed to secondary, secondary only to track, and tracks only to secondary roads. No roads were upgraded to primary roads. A small distance of a track was digitised as can be seen in table 3.

The classification in the evaluation does not have the same classes as the road network. The road network has four classes, while the classification in the evaluation uses nine classes in total. For dirt roads, tracks and foot paths, three classes were used, bad, medium and good. The reason for this was that it was hard to distinguish the difference between footpath and tracks in field. According to the definition of the road classes from Survey Department, foot paths should not be passable with motor vehicles with more than 2 wheels. This is not true in reality, foot paths are in many cases passable with four wheeled vehicles. Foot paths and tracks can not be separated by the official definitions.

Table 3. Total and relative length of reclassified parts of the road network data.

Road class	Length (metre)	Part of class (before reclassification) (%)
Primary reclassified	60586	20.9
Secondary reclassified	49275	5.3
Track reclassified	13311	0.4
Digitised	749	-

Table 4 shows that there is a considerable difference in positional accuracy of the road network between roads classified as bad tracks and roads classified as medium and good tracks. Tracks mapped as bad tracks most often corresponds to roads classified as footpath in the road network data, while tracks mapped as medium or good tracks corresponds well to roads classified as tracks in the road network data with few exceptions.

Table 4. Mean distance to the correct road after 2nd order polynomial transformation for bad tracks and medium and good tracks.

Type of distance measured	Bad (metre)	Medium and good (metre)
Mean distance to the correct road (rubbersheet)	232	112

Of a total of 13 mapped points on dirt roads not found in the data, 11 were mapped as bad and 2 were mapped as medium or good. The good match between mapped bad tracks and foot paths in the road network data and the good match between mapped medium and good tracks and tracks in the road network data leads to the assumption that the spatial correctness and completeness of tracks are higher than that of foot paths. In other words are roads mapped as bad tracks in the field survey likely to correspond to foot paths in the road network data from Survey Department. Good and medium mapped tracks are likely to correspond to tracks in the road network data from Survey Department. This leads to the assumption that the missing roads would probably have been classified as foot paths and not tracks in the road network data. Separating mapped tracks by its classification as bad, medium and good, where medium and good corresponds to tracks and bad corresponds to foot paths, leads to that tracks have a completeness of 95%. Foot paths have a completeness of 57%. Primary and secondary both have 100% completeness. Completeness was measured by comparing the two data sets visually. For example, if five out of ten mapped points is considered not to correspond to a road in the road network data, the completeness of those points is 50%.

2.5 Discussion

The results in Table 2 indicate that the errors in evaluations of this sort are depending on which method that is used. The choice to use the data transformed with a 2nd order polynomial transformation in the future analysis was strengthened by its lower values for mean distances from mapped points to any location on the correct road. However if calculated in an automatic way, by using a built in function in a GIS such as distance from a point to the closest line the result could be another. When using a tool that calculates the distance from a point to the closest line in a GIS the choice is to either calculate the distance to the closest road or to the closest road of the correct class. Both of these measures indicate that a 2nd order polynomial transformation is best for only two out of three road classes. This leads to the assumption that these simplified measures are insufficient for evaluating the road network data in this study, and maybe in other evaluations performed in the same way as well. It indicates that measuring by hand, knowing which road that was actually travelled can give another answer than an automatic method, such as distance to closest line.

The measurement to the correct road gives the best approximation of how good fit the different transformations and the original data is to the evaluation points collected with GPS. However, the actual enhancement of the transformations is probable to be larger than what the results show. The fact that the measurements are based on the distance to the correct road, and not to the point on the road where it was actually measured, induces a smaller difference between the original network and the transformed networks in most cases. The difference in distance to the correct point and to any point on the correct road is probable to be smaller for the transformed networks compared to the original network given their higher spatial correctness. It is highly likely that the distance to the correct point have been reduced in more than one dimension.

A completeness of 95% for tracks, where 95% of all points mapped in field corresponds to a road in the road network data, strengthened the decision to use tracks in the future analysis. Primary, secondary and tracks were all considered to have acceptable positional accuracy and completeness. Most of the travelled roads not found in the road network likely correspond to foot paths. Another reason for using the tracks in the model was that they are very important in many less populated areas, mostly in the eastern side of the district. The tracks in this area are also of a higher quality than those of areas with more roads of primary and secondary class. Holding these roads outside of the analysis would likely affect the eastern side more than the western, and the effect would probably be substantial for the final result in the eastern part.

Foot paths have a completeness of 57%. These roads are very common in the district. Most areas are connected with a foot path. The travelling speed on a foot path in the road network data is therefore not much higher than the travelling speed of areas that are not classified as a road of any class. Table 4 shows mean distance to the correct road calculated for tracks classified as medium and good and for tracks classified as bad. The low completeness and the small difference in travelling speed to off road conditions implied that the foot paths was kept out of the future analysis.

To sum up, the following have been concluded in this section:

- 2nd order polynomial transformation is better than affine transformation when adjusting the road network data.

- Measurements between control points and the correct road is necessary for a good evaluation of position and precision of the road network data.

- Tracks can be divided into two classes, medium-good, and bad tracks, where roads mapped as bad tracks corresponds well to foot paths in the road network data.

- Medium and good tracks have acceptable completeness and acceptable positional accuracy.

- Bad tracks have low precision and low positional accuracy.

- Tracks in the road network data will, with support from the positional accuracy, precision and completeness of tracks mapped as good and medium tracks, be used in the accessibility modelling.

- Foot paths in the road network data will, with support from the low positional accuracy, bad precision and low completeness of roads mapped as bad tracks, not be used in the accessibility modelling.

3 Interviews

Interviews act as the foundation of the accessibility model. The results from this section were the ground for which accessibility problems that were later modelled, which means of transport that is important and which destinations that is important. Frictions, or travel speeds, for different vehicles and road conditions were later derived from interviews.

3.1 Method

3.1.1 Semi-structured interviews with key informants

The semi-structured interviews of officials were in three cases out of four conducted without an interpreter. A semi-structured questionnaire was used, but it happened that the discussion took other paths (see Appendix 2).

3.1.2 Semi-structured village interviews

The initial village interview survey had the main objective to give information on the transport and accessibility situation in Hambantota District. Transport and travel habits and perceptions of problems related to accessibility were addressed, and more general it functioned as a training and development of a suitable and well covering structured questionnaire. A semi-structured interview technique was used for these in total 40 village interviews, spread over 5 villages in the district (see Appendix 3). They were performed with the help of an interpreter. The survey also helped to develop a suitable language and mutual understanding with the interpreter, which helped chose the words and formulations suitable for the future cooperation with the interpreters.

3.1.3 Structured interviews

A total of 154 structured interviews were collected in 15 different villages spread out in the study area, see Figure 14. This study focuses on quantitative data. There are quantitative elements in the 40 semi-structured interviews performed as well. These results are also taken into account in the structured interview results below.

The interviews were collected by three interpreters. A structured questionnaire was used to collect the interviews. The interpreters were equipped with printed forms of the questionnaire, ready to be filled in with the respondents' answers. The interpreters were alone in the villages. The reason for the choice of this unsupervised method was that a large quantity of data was to be collected. With existing time limitations it would have been impossible to collect that amount of data in a supervised fashion. In total the structured questionnaire comprised of 40 questions, all related to accessibility, see Appendix 4. The expected answers were mostly either time, distance, numbers, destinations or choices. The interpreters did not have to do any extensive writing or questioning, the questions were mostly simple hands on question designed to minimize misunderstandings and misinterpretations. The first day, the first 15 interviews from two villages was treated as training interviews, not considered to be of high enough quality to be used in the analysis.

The villages selected needed to fulfil a criteria of compactness. All interviews in one village are represented spatially by the centre of the village. If the village is to spread out, the centre point of the village will not be a good estimate of the respondents' departure point. If the village centre point is not representative for the respondent departure points, later measurements of travel distances will not be representative for the respondents' answers. The reasons for not mapping every interviews position is the method of unsupervised interviews. The interpreters were alone in the villages, they had no GPS units, no training in taking GPS points and no facilities to move around in a spread out village. In a spread out village, they would not be able to collect as many interviews.

The interviews were distributed in the district according to estimated accessibility, to cover as large part of the district as possible and according to logistical limitations. No villages were selected in the most inaccessible areas. This is due to the low population density and the absence of compact villages. In the least accessible areas, mostly occupied by sparse chena cultivation (slash and burn cultivation) and bush vegetation, sized and compact villages are absent, and it can be hard to find houses at all. Interviewees in villages were selected through a technique where the interviewees were selected at a 90 degree angle from the main road and away at both sides. This implies selection over a trajectory, from the outskirts of the village on both sides and across the main road at a straight angle. Households were selected every 100 metres of the trajectory. Every other on the left side and every other on the right side of the trajectory path. About 10 interviews were collected in every village.

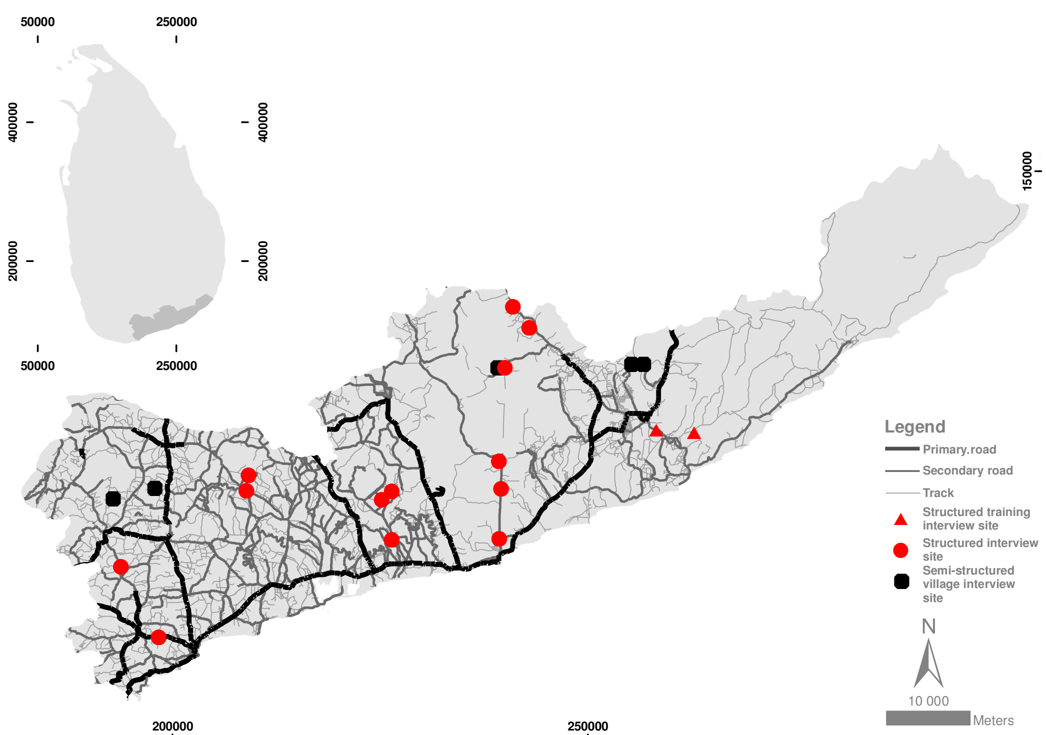

Figure 14. Distribution of interviews. Coordinates are given in SL1999 coordinate system.

3.1.4 Interview quality

The interviews with officials were of high quality. Answers could be discussed and misunderstandings minimized. However, there are uncertainties in the answers. Answers on questions about town and market sizes are estimations of the respondent.

Semi-structured interviews were supervised, this eliminates some misunderstandings. Illogical answers can be followed up, something that was not always possible for the structured unsupervised interviews. The semi-structured village interviews were of varying quality. Some questions, mainly about poverty and money, could not be performed because of unreliable answers.

The quality of the structured interviews varies widely, one respondent can give twice the travel time with the same means of transport and to the same destinations as another from the same village. But overall the structured interviews were successful, through first performing semi-structured more qualitative interviews together with an interpreter, the structured questionnaire could be adjusted for local perceptions, terms, problems, means of transport, etc. The overall perception is that the questionnaire were easy to understand, and easy to answer. The most important part was the dialogue with the three interpreters. By training and talking about the questions, misunderstandings were minimized and language barriers were overcome. Some of the more local adjustments of the questionnaire were done by the interpreters in the interview process. If the semi-structured interviews had not been performed, the structured questionnaire would have had a much lower quality. It is hard to know how much affect over the answers it had to be an outsider in the interview situation. The question of income was for example perceived as a question where the answer might have been affected by this. That was the major reason why the question of income was not asked. There is an apparent risk of the respondents trying to sound poorer and worse of than they are in reality. However, the questionnaire was designed to minimize these sources of error. The structured interviews were performed by local interpreters, without supervision. With mind on the negative effects on the quality of the answers a participating outsider might have, the fact that the interviews were unsupervised might also have positive effects on the quality of the data.

3.2 Results

The results below describe what have been found in the interviews. Part 3.2.1 below describes what the interviewees have said. It is not findings in the way of final conclusions.

3.2.1 Semi-structured interviews with key informants

The first semi-structured interview handled problems related to accessibility at a relatively small scale level. It addressed problems of farmer's accessibility to markets and villager's accessibility to work opportunities. The interviewee was a high official at REAP, Rural Economic Advancement Project in Hambantota District. The REAP was first initiated in 1997 by the Regional Development Division. It was according to Karunanayake and Abhayaratha (2002) initiated with the aim to focus on rural economic development. Karunanayake and Abhayaratha (2002) argue that the REAP puts focus on linkages between urban and rural areas, and recognises its significant role of the rural economic development. In the Southern region, which Hambantota is a part of, REAP has had a project to increase the quality of roads from villages to pollar markets according to the source at REAP. It has also improved the major markets in the southern province with respect of the quality and shape of the facilities

The interviewee at REAP expressed that the development of rural roads in Hambantota District is very important for the districts economic development. He argues that the accessibility to markets is low, with focus on farmers' possibilities to sell their produce. It limits the farmers' income and their connectivity to markets and large city areas: "*If roads are built, people will produce more and wholesale buyers will come"*. Most people in the district, more than 80% percent are involved in agriculture, making it the major occupation of the people in the district.

Market accessibility is the largest problem in Hambantota District: *"people centre around pollar markets, not around cities, schools or hospitals"*. A pollar market is a market where people come to sell and buy agricultural products. But they are also markets for other wares, they are both wholesale markets and fairs at the same time. Generally a market with trading in wholesale quantities is better for the seller than small village fairs. On wholesale markets the farmer can sell his whole produce to one buyer which saves time and it can also give better prices. On small fairs the buyers have less money and will bargain for lower prices.

Road quality is a critical factor for market accessibility. If the road quality is high, roads are easily passable with more simple vehicles, for example with bicycles. Even with a bicycle one can carry a large load if the road quality is high. The source also argues that investors and middlemen will provide transportation if the road quality is good.

The farmers normally do not have time to visit the markets themselves. However, paddy farmers have more time than others. Further, the passability during the rainy season is low, leading to that farmers can not arrive at markets in time which leads to that they are paid lower prices for their produce.

REAP has developed a total of 14 markets in Hambantota District. Some are more important than others and some are wholesale markets while others are not. The source also estimates the largest and most important towns and wholesale markets. The most important wholesale markets are as follows, with the most important first (major crops in the parenthesis):

1. Sooriyawewa (banana and vegetables)
2. Pannagamuwa (banana and vegetables)
3. Ranna (vegetables)
4. Barawakumbura (banana)
5. Ambalantota (banana and vegetables)
6. Weeraketiya (banana, vegetables and fruits)
7. Katuwana (banana and vegetables)

The most important towns in the district are as follows:

1. Beliatta
2. Tangalle
3. Ambalantota
4. Tissamaharama
5. Walasmulla
6. Weeraketiya

The markets and the towns can be seen in Figure 15 below. The four first towns in the list above are more important than the others. Walasmulla and Weeraketiya are smaller and less important than Beliatta, Tangalle, Ambalantota and Tissamaharama. Ambalantota, the third largest town, is expressed as the major commercial centre in the district. Ambalantota and Weeraketiya are both major towns and wholesale markets. Otherwise middlemen buy the agricultural produce on the wholesale markets and distribute them to the shops and fairs in the towns. Hambantota town is a relatively large town, but it is mostly an administrative centre. The source at REAP argues that it is not one of the major economical centres in Hambantota District, and that it therefore should not be regarded as an important destination.

The source argues that people in Hambantota District does not in any substantial extent visit markets outside of Hambantota District. Embilipitya is a large town and it has a wholesale market but it is far away.

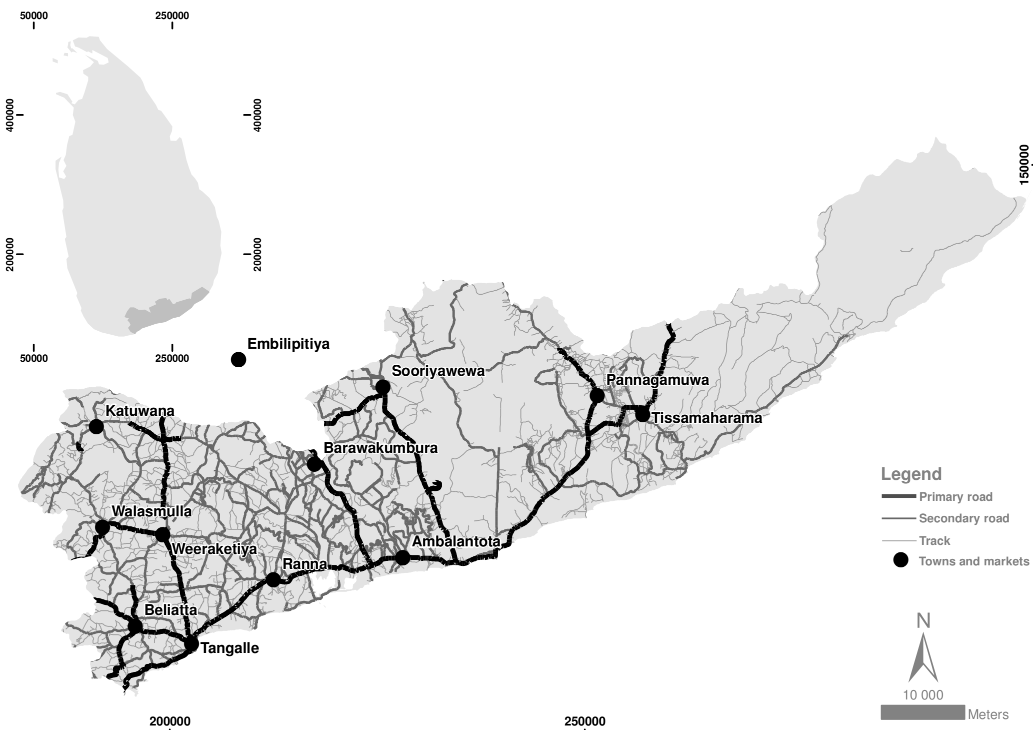

Figure 15. The largest and most important markets and towns for the people in Hambantota District according to REAP. Coordinates are given in Sri Lanka national coordinate system SL1999.

A second interview was about accessibility and regional economic development with a high official at the Chamber of Commerce in Hambantota town. The interviewee talks about transportation on a national and regional level, and explains that he have been lobbying for better roads between the rest of the country and Hambantota for a long time. The road travel times are too long on an inter provincial and inter district level. The travel time between Hambantota and Colombo, approximately 240 km away is 7-8 h, which means a mean speed of about 35 km/h. He argues that this travel time limits the development in the district. Other transportation facilities are lacking, there is no railway, airport or large harbour. However, all of these are in the planning or building process when writing.

The source at the Chamber of Commerce means that the physical part of accessibility, roads, is a larger problem than mobility in Hambantota, and that the road quality is influencing the mobility: *"if roads are there, other things will come. Infrastructure is the main bottleneck for the development of the southern area. Everything else will happen automatically, the private sector will kick in if infrastructure improves"*. The transport situation leads to bad business climate, and talented people moves away to larger cities to start their companies.

According to a high official at Lunugamwehera divisional secretariat there are about half as many owners of private motor vehicles in the rural areas compared to the urban areas.

3.2.2 Semi-structured village interviews

The semi-structured village interviews were about the villagers views of transportation and accessibility in general. One impression was that distances, giving the impression to be modest, are perceived as very long by the respondents. There were not many respondents who said that they often walked or cycled on moderate distances. Most use public or private transportation, which they describe as unreliable, time consuming or expensive. Petrol and diesel prices are very high relative the incomes of the villagers. Transportation is a relatively expensive, leading to isolation in rural areas and a large difference in development potential between urban and rural areas.

Some farmers are in debt to the local so called *mudhulale*. A mudhulale is a rich family, often with large holdings of property and means of transport. If the farmer is in debt to the mudhulale, he can be forced to sell his produce to the mudhulale instead of bringing it to the market or selling it to a better paying middleman. Others expresses difficulties to be allowed to sell at the markets, were families by tradition dominates the stands. These social factors influence the study in a way were one can not always be sure why the farmers for example do not take their produce to the market themselves. On the other hand, in an area with high accessibility and comparatively many opportunities, it is probably easier for the farmer to work his way out of dependency and into a *free* market. It is perceived as that these problems are more common the more rural and inaccessible the area is, where people do not have many options. This also implies that accessibility might influence for example a farmers selling habits in other ways than the simple measures of transportation costs and travelling time.

The difference in distance between a village and a good wholesale market and a small village market can be small. Still, because of transportation costs, farmers travel to a smaller markets were prices sometimes are lower although the distance to a larger market is only a little bit longer. This is probably an effect of the relative high transportation costs. A substantial part of the income from agricultural produce is taken by transportation costs according to the farmers in the survey. This implies that even a small distance, on the level of kilometres, can make it more profitable to visit the second best market within reach. One family in Colony no 4 expresses that the prices on the market in Tissamaharama is not reasonable, but the extra kilometres to Pannagamuwa market makes it more profitable to go to Tissamaharama, although the roads to Pannagamuwa are good. They also mean that no good middlemen come to their village. Another family say that they definitely would get a larger profit if they lived closer to Pannagamuwa and that they can not do anything else than farming because of the distance to large towns.

Many interviewees express a problem with large distances to good hospitals. Many visit small hospitals because of the cost to travel to a large, and good hospital. For many people it can also be very time consuming to visit a good hospital. They have to use a number of buses, all of whom probably is not on time. The same problem arises when sending their children to good schools, some children spend a very substantial part of their day travelling to and from schools. However, distances to school do not seem to be the determining factor of which children can visit a good school. Money and contacts appears to be the real limiting factor. Some highly educated or rich respondents say that the other villagers are not concerned by their children's schooling, and that it is the root of the problem. This is not at all strengthened by the interviews of the groups pointed out. The impression is that they are very concerned about their children's schooling, and see it as the family's way out of poverty. The fact that the access to schools of a large portions consists of the social part of accessibility, money, religion, status, contacts etc, implies that it can not be estimated by a physical accessibility model in a good way. Therefore schools are kept out of the analysis. This assumption is strengthened by Lindberg (2005). He argues that the access to schools is not a problem, it is the access to good schools that is a problem. Further he describes the accessibility to good schools as both a result of physical and social accessibility, were social accessibility is the strongest determinant.

Public transportation services are perceived as important for the respondents. Some have to walk long distances to catch a bus. One family in a remote eastern village expressed that they have to walk at least one way to the main road to catch the bus. This walk will take almost two hours one way. When at the bus stop at the main road, they will have to wait even more for the unreliable bus to come. The village is located by a secondary road of medium to bad quality. However, the village is at the very end of a road in a sparsely populated area. This implies that spatial separation, and not only road quality is determining for the transportation facilities available at a location.

Respondents in villages served by tracks expresses a decline in passability on tracks during the rainy season. One farmer in a western village which is served by tracks explains that he can take his rice produce to the market during the rainy season, but it takes a lot of time. He uses a landmaster and a wagon, and says he can not take as large loads as in the dry season and he have to have help to push the equipage on the muddy tracks. Not only is it difficult for farmers to take their produce to the market during the rainy season. Middlemen, normally coming and buying the produce at the village, do not come during the rainy season. This implies that farmers have to use, often rent, a motor vehicle, to take their produce to the market themselves. Some have to carry their produce per hand to the closest paved road or use a wheel barrow and wait for the middleman to show up.

In remote areas, were no large markets with reasonable price level are present, the rainy season have the implication that they either have to sell at lower prices to other poor people in the area, that they have to use an additional part of the profit of the production for transportation costs, or that they do not sell anything during the rainy season. However, the perception after extensive travelling in the study area is that most are served by or live in acceptable proximity to paved roads.

One landmaster driver in an eastern village of Hambantota District means that the speed one can travel on tracks in wet season is low, see table 5.

Table 5. Landmaster speed on different roads in dry and wet season and with full load. The information is given by a landmaster driver in an eastern village of Hambantota District.

	Primary and secondary in dry season (km/h)	**Primary and secondary in wet season** (km/h)	**Track dry season** (km/h)	**Track wet season** (km/h)	**Maximum speed on all roads with full load** (km/h)
Speed	12	12	8	2.5	5

3.2.3 Structured interviews

Ownership of motor vehicles

Table 6 below shows that the percentage, of the 183 households questioned in the matter, who has one or more motor vehicles is 38%. Most households have a motorcycle, second most have a landmaster, and the third most have a 3-wheeler. Three out of 183 have a lorry, 1 out of 183 has a car and 2 out of 183 have a tractor. 62% does not own a motor vehicle.

Table 6. Numbers and percent of respondents who own a motor vehicle (from all possible interviews).

	MC	**Land - master**	**3-Wheeler**	**Lorry**	**Car**	**Traktor**	**Total no of vehicles**	**No of households in possession of one or more motor vehicles**	**Total no of households**
Number	32	24	18	3	1	2	80	70	183
% of households	17	13	10	2	1	1	44	38	-

Perception of transportation problems

Most respondents, 45% of 168 respondents in total, answer that their main transportation problem is lack of transport facilities, either lack of an own motorised vehicle or bad public transportation as can be seen in Table 7. 39% answer that their main problem is bad road conditions.

Table 7. Perceptions of the main transportation problem (from all possible interviews).

	Lack of transport facilities	Bad road condidtions	Distances	Other	No problem / no answer	Total
Number	75	65	7	4	17	168
Percent	45	39	4	2	10	-

Many respondents connect the lack of public transport to bad road conditions. Where the supply of public transportation was viewed as the absolute most important part of the transport facilities. The respondents argue that one of the major reasons for bad public transport is the bad roads connecting their village with the numerous destinations. This were also confirmed by that the majority of the respondents giving the bad roads, and lack of transport facilities, as their major transportation problem were mostly served by bad roads. Villages with very good roads only had very few complaints about the bad roads and transportation facilities.

Travelling habits

The most common means of transport of the respondents is bus as can be seen in Table 8 below. 27% uses bus to travel to the market to sell their produce, 73% when travelling to the market to buy goods, 74% when travelling to a hospital and 76% when going to a town. Landmaster is the most common means of transport when travelling to the market to sell goods. Respondents use 3-wheelers second most when travelling to a hospital, probably because of the difficulties involved in transporting sick people.

Table 8. The travelling habits of the respondents.

	Means of transport								
	Bus	**3-Weehler**	**MC**	**LM**	**Bicycle**	**Lorrie**	**Traktor**	**Walking**	**Total**
Travelling to market to sell goods (No.)	12	0	1	27	2	2	1	0	45
(%)	27	0	2	**60**	4	4	2	0	100
Travelling to market to buy goods (No.)	109	11	14	2	12	0	0	1	149
(%)	**73**	7	9	1	8	0	1	1	100
Travelling to a hospital (No.)	133	32	9	0	4	0	0	1	179
(%)	**74**	18	5	0	2	0	0	1	100
Travelling to a town (No.)	107	6	16	0	10	0	0	2	141
(%)	**76**	4	11	0	7	0	0	1	100

Selling habits and their relationship to the ownership of motor vehicles

The selling habits of the 62 farmers in survey is not dependent on if they own a motor vehicle or not as can be seen in Table 9 below. Most farmers sell their produce to middlemen at home or at the field, 66% of the farmers not in possession of a motor vehicle and 69% of the farmers in possession of a motor vehicle sell to middlemen. Consequently, 34% of the farmers not in possession of a motor vehicle take their produce to the market themselves, and 31% of the farmers in possession of a motor vehicle take their produce to the market themselves. This indicates that the ownership of a motor vehicle is not determining of how the farmers sell their produce. There are more respondents without a motor vehicle that sell their produce themselves than respondents in possession of motor vehicles.

Table 9. Number and percent of farmers selling their produce on markets themselves (only from structured interviews).

	Selling 0% on markets themselves	Selling 100% on markets themselves	Part of farmers selling 0% on markets themselves	Part of farmers selling 100% on markets themselves	Total number
	(no)	(no)	(%)	(%)	
Farmers not in possession of a motor vehicle	41	21	66	34	62
Farmers in possession of a motor vehicle	18	8	69	31	26
All farmers	59	29	67	33	88

3.3 Discussion

Table 9 above indicates that the ownership of a vehicle is not a determining factor for if the farmers sell their produce to a middleman or if they sell their produce on markets themselves. The farmers who own a motor vehicle have a higher potential mobility than those that does not. However ownership of a vehicle does not seem to affect the cost of transporting agricultural produce to a market to a large extent, the actual mobility, the movement taking place. This result suggests that farmers with a motor vehicle (landmaster) do not have higher mobility with remark on selling their produce, where mobility is the actual transportation taking place, the actual mobility, than those without a motor vehicle (landmaster). Also, except for the journeys to markets to sell goods, about 75% of all journeys taking place are travelled by bus. 38% of the respondents own a motor vehicle, but only 15% of the journeys to town, 18% of the journeys to buy goods at markets and 23% when travelling to a hospital are taking place with the use of private motor vehicles (see Table 8). And some of these journeys are taking place with the use of rented vehicles, especially the journeys to hospitals because of the difficulties of transporting sick people. This reduces the percentage of journeys taking place with the use of a private motor vehicle. It should be noted though, that the questions were asked at a household level. If the household owns one motor vehicle and the members of the household splits up and travels to different locations, the logic of the reasoning above does not fully apply. However, it is unlikely that a large portion of the journeys given are due to different members travelling to different locations. According to field experience, it is common that the household stick together. A whole family can travel on a motor cycle.

Furthermore this might imply that distance and the supply of public transportation is the most important factors of actual mobility. In other words, road quality, distance and the potential mobility (supply of public transportation, the ownership of an own motor vehicle) are all inseparable for the measure of physical accessibility according to the results above. It seems as if mobility, one part of accessibility, is not a question about who owns a motor vehicle and who does not. Many factors are intervened.

Remote villages have the worst public transportation services, they are also the ones who have to pay the most for alternative transportation, and they are the ones who most need alternative transportation. On the same time, there are, according to an official of Lunugamwehera Division planning office, about twice as many people who own a motor vehicle in the urban areas compared to the rural areas of Lunugamwehera divison, Hambantota District. People with low accessibility have the worst supply of public transportation services, and they also have the lowest amount of personal transportation.

The interview of a high official at the chamber of commerce indicated that the road quality was the major problem for the economic development of the district. However the semi-structured interviews of villagers gave the information that distances to markets is the determining factor of which market to visit. The reason for this contradiction is probably the level of the accessibility assessed. The source at the chamber of commerce talked about a high level of accessibility. An inter-regional accessibility, while the village interviews addressed accessibility on a smaller scale, a lower level. It is possible that road quality is the most important factor for the large scale economic development of the region, while distances might be more determinant for the access to markets on a lower level, especially where the means of transport is a landmaster, as in this example (see 3.2.2). However, when addressing accessibility to towns, which might be more important than accessibility to markets, road quality might be the most important factor. Bad road quality affects the supply of public transportation negatively. The supply of public transportation services was expressed as very important by the respondents of the interview survey, and it is the dominant means of transport.

The major conclusions of this section are as follows:

- Road quality is important for the accessibility to markets and towns.
- Road quality is a major problem for the development in Hambantota District.
- Transportation is very expensive relative incomes of villagers.
- The wet season affects people who are served by tracks more than people who are served by tarmac roads.
- Most respondents answer that the lack of transportation facilities is their major transportation problem.

- Bad road quality is one of the most important reasons for bad public transportation.

- 62 % of the households in the survey do not own a motor vehicle. The most common means of personal transportation is motorcycles, 17% owns a motorcycle.

- Farmers who own a motor vehicle do not sell their produce on markets themselves in a greater extent than those who does not own a motor vehicle.

- Most farmers use landmaster when travelling to market to sell goods.

- Most households use bus when travelling to market to buy goods, when visiting a hospital and when visiting a town. Making bus the most used means of transport.

4. Estimation of speeds of door-to-door transportation

Estimation of frictions is important because frictions is the values which defines with which speed the accessibility model can model a transfer over a ground class. The ground classes can be roads, terrain or slope. The estimation of frictions of different ground conditions is traditionally based on speed limits, interviews of key informants or field estimations. However, in an area with bad road conditions and less good traffic order, it is not possible to use speed limits as a base for friction estimation. The speed of the traffic flow is depending on other factors than the speed limits. In this study, a program is written to estimate the door-to-door travelling speed on three road classes from household interview data. The results can be used as friction or cost for the road classes in the accessibility modelling.

4.1 Method

4.1.1 Data processing

Input data was collected as structured interviews. Travelling times to different locations and with different means of transport have been collected for a total of 139 households. The travelling time to up to three or four different destinations with the respondents most used means of transport and with landmaster has been recorded.

Every respondent have given the travelling time to three or four destinations and the means of transport. For every journey, a combination of departure, the village centres, and the various destinations, the distance of three road classes were measured. If there are four different destinations given by the respondents of one village. The distance needed to travel on primary, secondary and tracks to all four destinations was measured in a GIS program, for an example of the table of combinations see Table 10 below. The paths assumed to be taken from the departure to the destination were estimations of which roads the respondent would travel on. However, the length of the chosen paths was cross checked with given distances by the respondents. In most cases the choice of path was considered to be an easy choice.

Table 10. Example of some of the combinations of departure and destinations.

		Length of roads		
		Primary	**Secondary**	**Track**
Departure	**Destinantion**	(metres)	(metres)	(metres)
Village1	Sooriyawewa	0	26655	2037
Village2	Ridiyagama	0	10001	0
Village3	Sooriyawewa	3039	8584	3700
Village3	Hambantota	18196	569	4951
Village4	Angunakolapelassa	0	8299	0
Village4	Mideniya	2179	6719	2645
Village5	Thanamalvila	0	7772	772
Village5	Lunugamwehera	278	4876	772
Village6	Tangalle	4803	0	0

A total of 13 villages were used in the analysis spread out according to Figure 16 below. For the 13 villages 32 different combinations of departure and destinations were given. Positions for two of the 32 destinations were lacking. This resulted in that a total of 30 combinations of departure and destination were used. However, there were very few of the respondents given journeys that were affected by the lack of the two destinations positions.

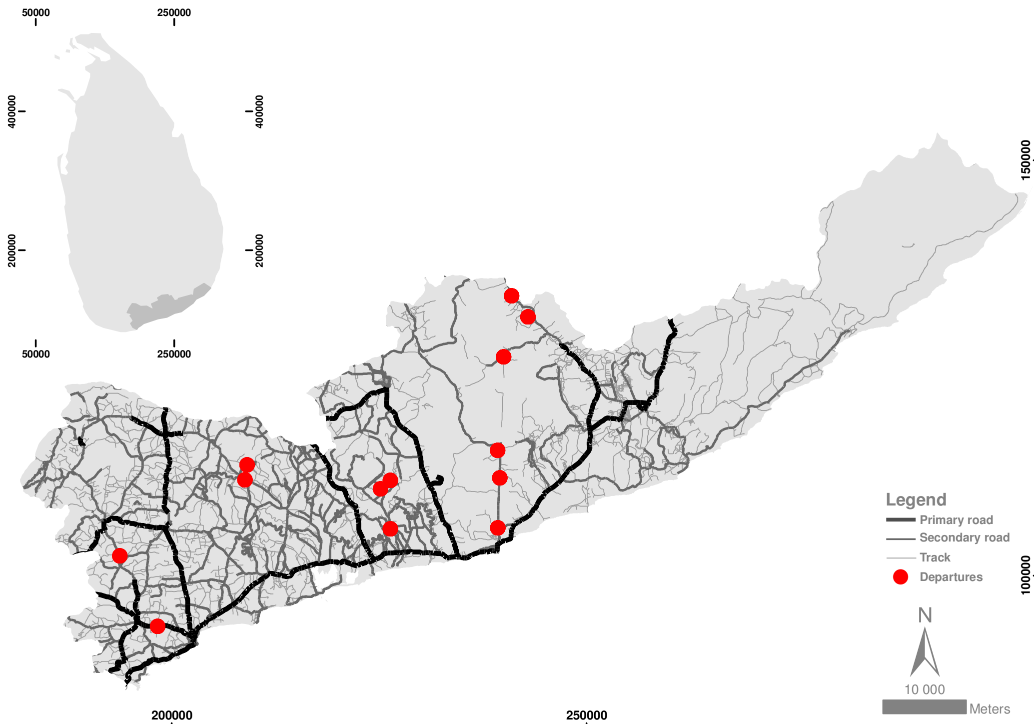

Figure 16. Map of departures used in friction estimations. Coordinates are given in SL1999 coordinate system.

The respondents gave information of which means of transport they were using for every specific journey. The different means of transport was the following:

- bus
- landmaster (LM)
- 3-weehler
- motorcycle (MC)
- bicycle

The next step was to connect the travelling distances to the departures. A matrix was produced for each and every means of transport. The matrixes hold information in four columns and a varying number of rows depending on the number of journeys given in the interviews. The first column holds information on travel time given by the respondent from the departure of the village to a destination. The three following columns hold information on the distances of primary roads, secondary roads and tracks from the village departure point to the destination that the travel time was given to. An example of a matrix is given below in Table 11.

As can be seen in Table 11 below, a given travel time from a departure to a destination was not always the same as another given travel time for the same departure and to the same destination. The respondents from one village did not always give the same answer to the travelling time to a specific destination. Every row in the different matrixes corresponds to one journey. Every journey has a destination, a departure, a travelling time and lengths of three road classes. However, the departure and the destination are irrelevant for the estimations of frictions. Only given travelling time and length of roads in the three classes were kept in the matrixes. Every row in the column represents one journey. In the following text, one row, one combination of travelling time and length of the roads will be referred to as a journey.

Table 11. Example of the travel matrix used in the friction estimations. The travel time of these journeys were given for bus.

	Estimated length of roads to the destinations		
Given travel time (minutes)	**Primary** (metres)	**Secondary** (metres)	**Track** (metres)
20	960	1882	267
30	960	1882	267
60	960	11550	0
60	960	11550	0
120	18196	569	4951
120	18196	569	4951
45	0	7772	772
40	0	7772	772
25	960	7898	0
30	960	7898	0

As a result of the respondents travelling habits, their professions and their knowledge of travelling with landmaster, the matrixes of different means of transport have different amounts of rows, or journeys, to base the estimations of friction on. The following amount of journeys is available for the different means of transport:

- Bus: 326 journeys
- Landmaster: 111 journeys
- 3-Weehler: 39 journeys
- Motorcycle: 25 journeys
- Bicycle: 20 journeys

4.1.2 Speed estimation program

The program that was used was written in MatLab, see Appendix 5 for the code. MatLab is a software that amongst others can be used to write calculation programs. My program searches for the speeds of the three road classes that give the smallest total error compared to the given travelling times. The program tests all possible and realistic combinations of travelling speeds on primary roads, secondary roads and tracks. Every journey, a combination of given travelling time and length of the three road classes is tested by every realistic combination of travelling speeds. From the combination of speeds and the distances of the road classes a travelling time is calculated. The calculated travelling time is then compared with the given travelling time. The absolute difference between given and calculated travelling time is calculated, the error. The square of the errors were not used because it gives great weight to very deviant given travelling times. For every iteration, every combination of speeds, the error of every journey in the matrix is summed up. This accumulative error is the total error of that specific combination of speeds. When a total error that is the smallest for the moment in the calculations is found, the value of the total error is saved, and the speeds of the road classes are recorded. If another combination of speeds gives a smaller total error, the smallest total error and the speeds are overwritten. When all possible combinations of speeds have been tested, the smallest total error and the best fit speeds have been found. The program operates with a predefined step. The step sets the increase in speed that is tested per iteration. A step of 0.5 km/h was used in all calculations. Because of the design of the program, with a nestled loop of three loops, a smaller step significantly increases the calculation time. Tests have been made to see if a smaller step gives a similar answer or not. The differences in the results when using a step of 0.1 km/h and when using a step of 0.5 km/h were less than the difference between the steps, less than 0.4 km/h. Hence it was concluded that a step of 0.5 km/h gives adequate detail, precision, of the results.

Two rules make sure that there is only one answer, see Equation 1 and Equation 2. The rules are as follows:

$$Speed_P \geq Speed_S \qquad \text{Equation 1}$$

$$Speed_S \geq Speed_T \qquad \text{Equation 2}$$

Where $Speed_P$ is the speed of primary roads, $Speed_S$ is the speed of secondary roads and $Speed_T$ is the speed of tracks.

For every journey the mean speed for the whole trip is also calculated. This gives a possibility to filter out unrealistic given travelling time values. Two values can be set, maximum allowed mean speed and minimum allowed mean speed. Only journeys with a mean speed within these values are used in the calculations. A measure of error is also calculated. The error is calculated as the sum of absolute differences between given travel time and the estimated travelling time divided by the sum of the given travelling time for all journeys, see Equation 3. Only the journeys within the limits are used in the measure of error. The filtering of journeys reduces the number of journeys used in the calculations.

$$Error = \frac{\sum \left| T_e - T_g \right|}{\sum T_g} \times 100 \qquad \text{Equation 3}$$

Where T_e is the estimated travelling time and T_g is the given travelling time in Equation 3.

If a road class have a high relative length. If it has a total length that is longer than the others, it will have a larger influence over the calculations. To visualise this, the percentage of the length of the road classes out of the total length of all three road classes have been calculated for every means of transport.

4.2 Results

The results of the calculations of best fit speeds and information about number of journeys used, total number journeys, the maximum mean speed allowed, the minimum mean speed allowed and percentage error of the calculations can be seen in Table 12.

Table 12. Table of calculated travel speeds.

	Road type								Length in estimations		
	Primary	Secondary	Track	No of journeys used	Total no of journeys	Max mean speed	Min mean speed	Error	Primary	Secondary	Track
Type of vehicle	(km/h)	(km/h)	(km/h)			(km/h)	(km/h	(%)	(%)	(%)	(%)
Bus	33.0	15.5	3.5	325	326	90	-	30	24	73	3
LM	7.0	6.5	6.5	74	111	11	-	18	16	82	2
3-weehler	22.0	22.0	7.0	38	39	90	-	32	31	66	3
MC	50.0	27.0	27.0	22	25	38	-	24	8	86	6
Bicycle	11.0	11.0	10.5	20	20	-	-	24	5	88	8

4.3 Discussion

The program incorporates all delays and travelling problems in the final estimated travelling speeds. The respondents have given the travelling time from door to door. This means that for example the walking time to the bus, the time it takes to change busses at a second bus stop, how often buses run or that tracks can be impassable in the wet season are all part of the final speeds.

The results of the program are by comparison to field estimations realistic. The estimation of speeds for bus is the calculation with most journeys. Buses travel fast on primary roads, sometimes faster than the mean speed of the rest of the traffic of the road. On secondary roads however, buses travel slower, they are also unreliable and late, and the service can be very sparse or absent. The low speed on tracks are justified by that the respondents often have to walk this distance to get to the bus. In the wet season buses either travel slowly or not at all on tracks. The estimated travelling times of the interviews are from door to door. If the respondent have to walk for half an hour and then wait for the not reliable bus for another half an hour it gives low speed on the road classes travelled. If many respondents that live by bad roads give long times due to long walks or long waiting times, and many respondents give relative short travelling times and live close to good roads, the bad roads gets lower speeds than the good roads in the estimations.

The calculations for motorcycle, landmaster, 3-wheeler and bicycle all have fewer journeys than for bus to base the calculations on. But the results of the program is strengthened by the fact that slower vehicles, not affected much by road quality, landmaster and bicycle, gets a similar travel speed for all road classes. Bicycles have a speed around 11 km/h on all road classes which is very realistic compared to field estimations.

The error of calculated travelling time compared to given travelling time might seem high with values around 30% for some modes of transport. There are two main reasons for these errors. The first is errors in the answers from the respondents in the interview survey. Some answers might be very inaccurate. Secondly there are considerable variations within every road class. Some respondents have to walk long distances along secondary roads, while others only need to wait for 10 minutes outside their door to catch a bus on another secondary road. The program calculates the best fit for all these variations within every class for the whole study area, resulting in big errors depending on data errors and variations within the classes.

It is probable that it is important to have large data set for the estimations of travel speeds. The data set for journeys with bus is relatively large. For the other modes of transport the data set is relatively smaller. To increase the quality of the estimations a filter has been used. For landmaster, the maximum mean speed of the journeys that is used was set to a relatively low value: 11 km/h. However this speed is in line with estimated maximum travelling speeds of interviews and field experience. The estimation of landmaster speeds is based on a mixture of trips in the purpose of buying, selling and visiting towns. Speeds vary much depending on how large of a load a landmaster is carrying. Interview results show that a landmaster can travel at about 5 km/h with a full load and around 12 km/h without a large load. On wet tracks a landmaster can travel at about 3 km/h (see table 5). The considerable variations in speed is a reason for the need of extensive filtering in the data, another reason is relatively high uncertainties in the answers. The question of travelling time with landmaster was partly forced. It was asked specifically, while the travelling times for the other means of transport were given as the travelling time with the most used means of transport. It was also perceived as a hard question, landmasters are seldom used, and the travelling time is therefore of less concern for the respondents than the travelling time of other more frequent journeys. It is possible to separate the trips with landmaster by their purpose, giving a separation by the load. However, the data quantity is relatively low, it would result in a small quantity of data used in the estimations. Furthermore, when a farmer visits a market to sell his produce, he only carries a large load one way. On the way back from the market, his cart is emptied and he can travel at a higher speed. The result of about 7 km/h travelling speed on primary and secondary roads is with these factors in mind, realistic.

One weakness in the estimations is the unbalanced relative distance of the classes. The distance used for secondary roads is the longest, the distance used for primary roads is the second longest, see Table 10. The distance used for tracks is relative secondary and primary very short. Consequently the class with the longest relative distance used in the calculations gets the heaviest weight. The same class affects the results the most. This problem could be solved by either using villages served with an even distribution of roads of the three classes.

One could argue that the error for the personal means of transport (all except bus) should be lower than the error for bus. The estimated speeds of the personal means of transport are not dependent on reliability and delays. They are not dependent on long walks or changes of busses. However, they are dependent on differences in road quality. The results do not show a clear pattern of differences in error, see Table 10. It was considered that the data set is too small for the personal means of transport to come to a conclusion why there is not a clear pattern.

A general source of doubt of the quality of the results is the quality of the input data. The times given by the respondents in the interview survey and the roads chosen to correspond to their journeys. It is hard to estimate the actual quality of the results. However, the results are realistic. To get the same information without using an interview survey would demand very extensive field work. The same journeys would need to be travelled many times during all seasons of the year. It would not be feasible to perform such a survey, and it would be very hard to estimate all the problems in a door-to-door travelling approach. This approach uses a set of data representing the inhabitants of Hambantota District perceptions of their everyday travelling. An empirical study can not collect the same data.

It would be interesting to apply the method on a study area with more varying ground conditions. Such a study could strengthen the method or show its weaknesses in a better way. The differences in travelling speed on different ground conditions would be clearer. The questionnaire and the choice of the location of the respondents could also be chosen to get a better relative distribution of road classes and other ground conditions. The questions could also be designed, and the locations could be chosen, to give a larger data set. In this study the questions on travelling times concerned the respondents most commonly travelled journeys. To ask for specific destinations the size of the data set and the relative distribution of classes could be enhanced. However, such questions are probable to get answers with lower quality. The respondents may not know the travelling times of these journeys as well as the journeys they often travel. This argument is also strengthened by the low actual mobility of the villagers in Hambantota District. Travelling is not an everyday activity. Why the travelling times of different destinations is not well known.

The program that was finally used is the second design. The first design did not have the design of nestled loops. It was more computational effective. It started at certain best guess starting values and searched its way to the final result by increasing or decreasing the speeds of the three road classes until all changes gave a larger error. However, it was shown that different starting values could give different answers. This is a result of the complex *error surface*. It was first assumed that the error surface was like a valley, the error would increase on both sides of the speeds that gave the lowest error. Leading to that the first time the program found such a valley, a minimum of error, where all speeds around the speeds found increased the errors, it would have found the best fit speeds. However, the error surface can have more than one valley. If the error surface has more than one valley, the first program does not find all the valleys, it can stop a local minimum. It is not certain that the first valley, the first minimum found, is the minimum with the smallest error. So a second edition was designed, a design that tests all possible realistic combinations of speeds before it stops. It is much slower, and it can not handle to small steps, but it guarantees that the best fit speeds with a certain step are found.

The results will be referred to as the speed of roads. It is rather the effective door-to-door travelling speed that is calculated, especially for bus. Anyhow, the effective travelling speeds with all delays and walking incorporated will be called the speed of the roads in the following text.

The major conclusions of this section are as follows:

- A method to estimate frictions, or travel speeds on roads have been developed and have been proven to be functional.

- The estimated speeds are realistic. But the quality of the result is uncertain. Implementation in another study area could give a better perception of the methods quality.

- All delays and actions that are needed to be taken to get from the home to the destination is incorporated in the final speeds.

- There is a weakness in the unbalanced relative distance of the three road classes used.

5. Accessibility modelling

The accessibility modelling is the purpose of all the previous sections of this thesis. The previous parts were meant to act as a foundation upon which the model is built. If the model is well founded, it gives credibility to the results. Good and credible results can then be used to see patterns of how accessibility is affecting or is being affected by other factors. The outcome of the accessibility modelling is mostly dependent on the frictions of the cost surface and the choice of the destinations.

5.1 Theory

The calculations of accessibility are based on raster calculations. All attributes of friction that is used in the accessibility calculations are represented by rasters. These rasters are combined to one main cost raster. Every cell in the cost raster has a value that represents its friction, or cost. The higher the friction, the longer time it takes to fictionally travel across the cell. The friction can represent many different measures. The most common is travelling time and monetary cost. The algorithm will avoid the most costly cells if they are not part of the least cost path. The least cost path, is the path from a certain departure to a certain destination that induces the least accumulative cost. The least cost path tries to avoid the cells with the highest cost, however it might cross a costly cell, if the passage over less costly cells brings an extra distance, or an extra number of cells that induces a larger accumulative cost than to travel the shorter distance over the more costly cell. The final least cost path is the path with the lowest accumulative cost with mind on both the cost of the cells that are passed and the number of cells that are passed.

The cost distance tool in the spatial analyst extension of ESRIs ArcGIS 9.2 was used in the calculations. Two sources of information were used and were required by the tool. The first was the cost raster, defining the frictions of the surface that was to be travelled. The second was the destination or the destinations that were to be reached in the calculations. The cost distance tool calculates the least cost path of every cell in the cost raster that is not defined as NoData, to the destination. When multiple destinations is used, the least cost path to the destination which can be reached with the leas cost is calculated. A new raster is created in the calculations. This raster will represent the cost of every cell in the cost surface to reach the destination, or the least costly destination. When the frictions of the cost surface represents travelling time, the new raster represents the total travelling time of every cell to the destination, or to the least costly destination.

A raster based least cost path algorithm generally works similar to well known network algorithms such as Dijkstras Algorithm[2]. Common shortest path algorithms searches their way step wise, from the start to the destination. The search of a shortest path algorithm can be divided into the following steps to find the least cost path and the total accumulative cost of the cost surface raster in Figure 17 below:

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2. For information on network algorithms, see Worboys and Duckham (2004).

1. Calculate the cost from the green starting cells middle point in Figure 17 to its neighbour's middle points. A straight line transfer, to cells situated directly to the sides of the starting cell is calculated as (Equation 4):

$$Cost = \frac{Cost_{Cell1} + Cost_{Cell2}}{2} \qquad \text{Equation 4}$$

Where *Cost* is the cost of the transfer, $Cost_{Cell1}$ is the cost of the departure cell and $Cost_{Cell2}$ is the cost of the destination cell. The cost to a diagonal cell is higher, it induces a longer distance and it is calculated as (Equation 5):

$$Cost = \sqrt{1^2 + 1^2} \times \frac{Cost_{Cell1} + Cost_{Cell2}}{2} \qquad \text{Equation 5}$$

Where *Cost* is the cost of the transfer, $Cost_{Cell1}$ is the cost of the departure cell and $Cost_{Cell2}$ is the cost of the destination cell.

The Cost of travelling from the starting point, the active cell, to its neighbours will be 55 to the right, 78 diagonally below the starting point and 10 straight below the starting point. These values are saved in a matrix, often called the state matrix. The calculations in step 1 are illustrated in Figure 18.

2. The next step is to locate the cell in the state matrix that has the lowest value and that has not yet been visited by the algorithm. In this case, the only cell with a value in the state matrix is the starting point, and its neighbours. The starting point was visited in step one, resulting in that the cell directly below the starting point, with the value of 10 in the state matrix is the cell with the lowest value that is not visited. The cell is set to active and all costs to the active cells neighbours are calculated according to equation 2 and equation 3 above. In this case the costs will be 78 to the right side above the active cell, 55 straight to the right, 78 to the right side below the active cell and 15 to the cell straight below the active cell. The accumulative cost to reach these cells is then calculated. The accumulative cost is the cost of the active cell, 10, added with the cost to its neighbours, 78, 55, 78 and 15. Resulting in the accumulative costs of 88, 65, 88 and 25.

3. Next the new accumulative cost to the neighbours of the active cell is compared with their previous calculated accumulative costs. If the cells accumulative cost have not been calculated or if the new value is lower than the previous, the state matrix is updated. The value diagonally above the cell and to the right will not be updated. The previous value of 55 is lower than the new value of 88. The cell to the right will be updated. It had the value of 78 but the new value of 65 is lower. The cell below the active cell and to the right will be assigned with the value of 88. It did not have a value before and is therefore not tested against an old value. The cell below the active cell is set to 25 in the state matrix. The new state matrix is illustrated in Figure 19.

4. Once again the cell in the state matrix with lowest value that has not been visited is located. In this case it is the third cell from the top, to the left in the matrix. It has a value of 25 which is lower than the other cells that have a calculated accumulative cost. The cell is set to active and step 2 and 3 is repeated. This procedure repeats until the destination is found. When the destination is found, the least costly path and the

smallest accumulative cost from the starting point to the destination are found. The least cost path is represented by the arrows in the state matrix in Figure 20 below. However, the actual path needs to be stored separately. Note that all cells that have a value in the final state matrix (Figure 20) would not be visited in a real execution of the algorithm. Numbers in Figure 17 – 20 below are borrowed from Eklundh (2001).

10	100	40	10
10	100	40	10
20	100	40	10
20	20	10	10

Figure 17. The cost surface used in the example above. Green indicates the starting point, the departure. Red indicates the end point, the destination.

0	55		
10	78		

Figure 18. The state matrix produced in step 1. The blue colour indicates the active cell.

0	55		
10	65		
25	88		

Figure 19. The state matrix produced in step 3. Gray indicates the visited cell. Blue indicates the active cell.

0	55	125	102
10	65	117	92
25	85	93	82
45	53	68	78

Figure 20. The final state matrix of the example above. The arrows indicate the final least costly path

5.2 Method

5.2.1 Input data

Road network data has its origin from Survey Department. It has been subject to geometric correction and reclassification. The Road network has been divided into three new layers, one each for the road classes: primary, secondary and tracks. Next the three layers were converted to raster. The rasters have a resolution of 90 metres.

Slope is calculated from a 90 metres DEM acquired from USGS. The slope raster is reclassified in four classes, 0-5% slope 5-10% slope, 10-20% slope and above 20% slope.

Water bodies were acquired from Sandell (forthcoming). The data origins from a satellite image classification, and it was acquired as a raster. It was resampled from 30 metres resolution to 90 metres resolution. A nearest neighbour resampling technique was used. According to Sandell (forthcoming) small water bodies are not well represented in the data.

Destinations have their positional origin in field measurements and free hand digitalisation. For the free hand digitalisation the rectified road network were used as a background as well as data on towns and villages from Survey Department. Destinations were buffered with 250 metres to insure that the destination cells in the analysis are connected to the road network. The decision of which destinations to use is based on interview data, but many of the destinations are confirmed by field visits. The destinations used can be seen in Figure 21 and are as follows:

Markets:

- Sooriyawewa
- Pannagamuwa
- Ranna
- Barawakumbura
- Ambalantota
- Weeraketiya
- Katuwana
- Embilipitiya

Towns:

- Beliatta
- Tangalle
- Ambalantota
- Tissamaharama
- Walasmulla
- Weeraketiya
- Embilipitiya

The extent of all data layers is larger than Hambantota District. This is to assure that the modelled travelling routes take the shortest route although it might not always be within the Hambantota District boundary.

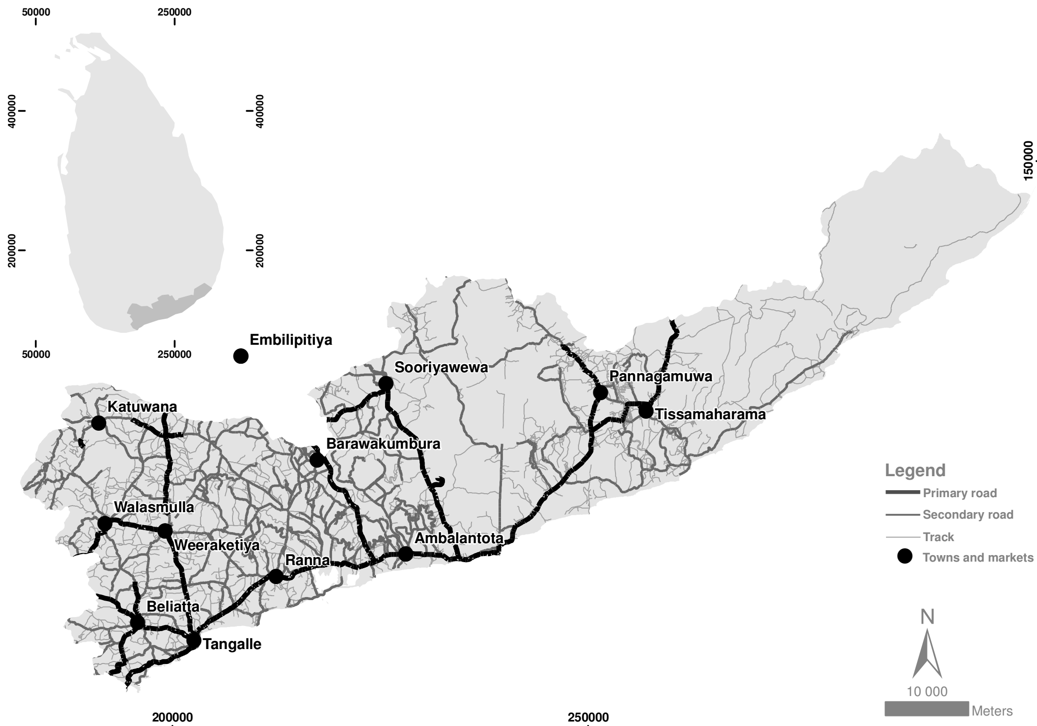

Figure 21. Map of selected markets and towns used as destinations. Coordinates are given in Sri Lanka national coordinate system SL1999.

5.2.2 Cost surface

The cost surface constitutes of roads in three classes, slope in 4 classes and water bodies as can be seen in Figure 22. The cost, or friction of the classes are dependent on which means of transport that is modelled. For every cell in the raster, the pixel with the lowest friction of five different raster layers was calculated. The layers are primary roads, secondary roads, tracks, slope and water bodies. The three road layers only hold information of the roads. The rest of the raster cells are comprised of NoData. Water bodies were later set to NoData because the model does not take travel over water in to account. To set water to NoData means that the modelled path can not cross the water bodies in the cost surface.

The origins of frictions of roads were the program for speed estimation, and interview data. The interview based and the program based frictions can be seen in Table 13 below. Speeds given in Table 5 in the interviews section acts as the base for landmaster speeds from key informants. The speeds were calculated with the assumptions that a cart is pulled by the landmaster, that the cart is full one way of the journey, and that the wet season lasts for 3 months. The friction of slopes was defined according to field estimations and it is in line with other studies (Verburg et al 2004).

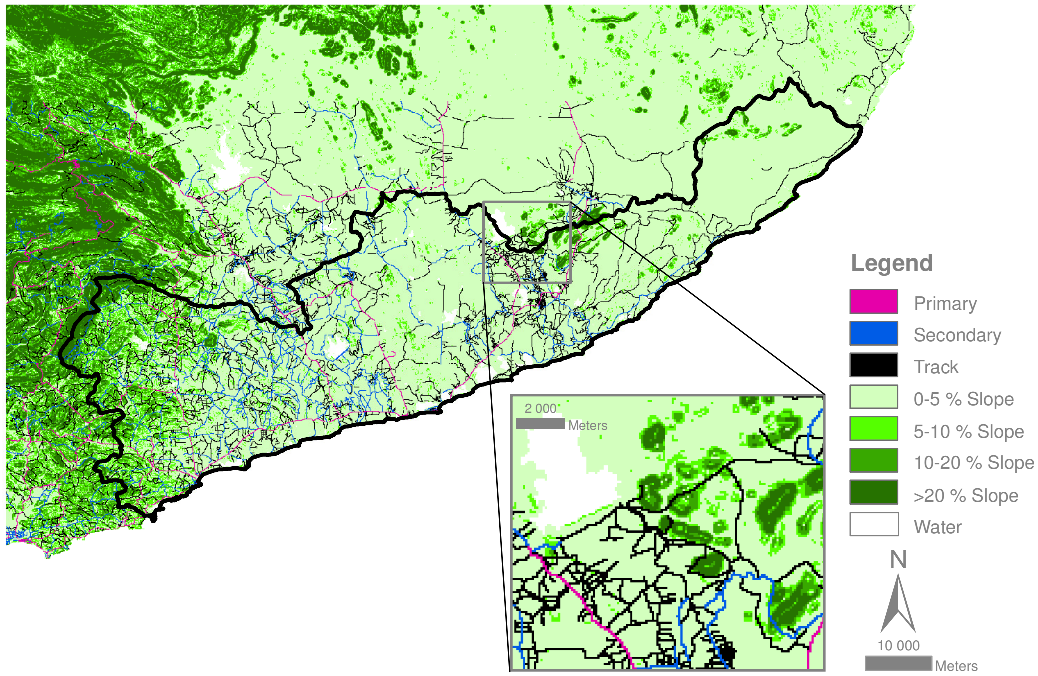

Figure 22. Figure illustrating the different classes of the cost surface used in the accessibility modelling.

Terrain such as forest, swamps and paddy fields were not incorporated in the cost surface. The main reason for this was that there are many foot paths in the district. Most areas are connected with a foot path. The main factor of friction in the district is slopes and water bodies. A transfer from a point in the cost surface to another point were no roads are apparent is according to a straight line where there are no slopes or no water bodies. In reality, this transfer is taken place on a foot path, if no foot paths are present at the departure point, the transfer to the closest foot path is taken in the terrain. However, were no slopes and no water bodies are apparent the transfer to the closest foot path is likely to be short relative the whole of the off-road distance. The off-road frictions were set to represent transportation along winding foot paths and to a small extent, in the terrain. The terrain is not assumed to have a substantial influence on accessibility to most areas in Hambantota District. Were terrain do have a substantial influence, in forests, the terrain is represent by slope. This simplification has its origin in the location of forests in the study area. Forests are mostly located on hills and mountains, were the slope or the soils are unsuitable for other use of the land. The second reason for not incorporating terrain in the cost surface was an insufficient basis for the decision of frictions for the different terrain classes.

The cost surface does not increase in friction over the national parks, Bundala and Yala. The access to the parks is restricted, however, there are villages in the national parks, and some roads connecting other areas pass thru the national parks. And those roads are not restricted.

Travelling speeds were recalculated to frictions. A low travelling speed will give a higher friction than a high travelling speed. Frictions are defined as the time it takes to cross a cell of 90*90m of a specific ground condition.

Table 13. Travelling speeds used to calculate frictions for the cost surfaces.

Type of friction	Bus (SPEED) (km/h)	LM (SPEED) (km/h)	LM (key informant) (km/h)
Primary	33.0	7.0	8.5
Secondary	15.5	7.0	8.5
Track	3.5	6.5	5.7
0-5% Slope	2.0	2.0	2.0
5-10% Slope	1.5	1.5	1.5
10-20%Slope	1.0	1.0	1.0
>20% Slope	0.25	0.25	0.25
Water	∞	∞	∞

5.2.3 Accessibility estimations

The accessibility estimations have been performed in ArcGIS 9.2. The spatial analyst extension tool, cost distance is used to calculate the accessibility measures. Input for the tool was the cost surface and a single destination or a set of destinations. The cost distance tool only accepts integer frictions. To make sure that the precision of the frictions is kept intact, they were multiplied with a large value before the calculations, and the result was then divided with the same value after the calculations. Euclidian distances were calculated from selected towns and markets.

5.3 Results

Below the results of the accessibility modelling can be found. It should be noted that in this section (5) and the next (6) most of the maps that are presented do not hold any information on coordinate system, nor do they have any grids. A grid was considered to interrupt the message of the figures. For maps of the same extent that have coordinate systems and grids presented, see Figures 2, 11, 12, 14, 15, 16 and 21.

Figure 23 below illustrates the accessibility to selected markets when travelling by bus. There is a clear gradient with better accessibility to markets in the western parts than in the eastern parts. This is due to better roads and more markets.

Figure 24 below illustrates the accessibility to selected markets when travelling with landmaster. The results show that accessibility when using landmaster is not as dependent on road quality as accessibility with bus. The basis for the frictions used in the maps below are in all cases except for Figure 25 and the figures of Euclidian distance (Figures 26 and 29) the speed estimation program. The accessibility estimation visualised in Figure 25 was calculated using frictions from key informants. A striking characteristic of the comparison of the estimated accessibility figures of landmaster accessibility to markets and bus accessibility to towns is that the bus accessibility to a larger extent follows the good roads, while the landmaster accessibility is more evenly distributed around the destinations. The Euclidian distance, also called straight line distance, from selected markets is illustrated in Figure 26 below. The correlation between accessibility to markets when using landmaster and the Euclidian distance from markets is illustrated in Figure 27. The correlation (0.8657) results in a R^2 value of 0.7495.

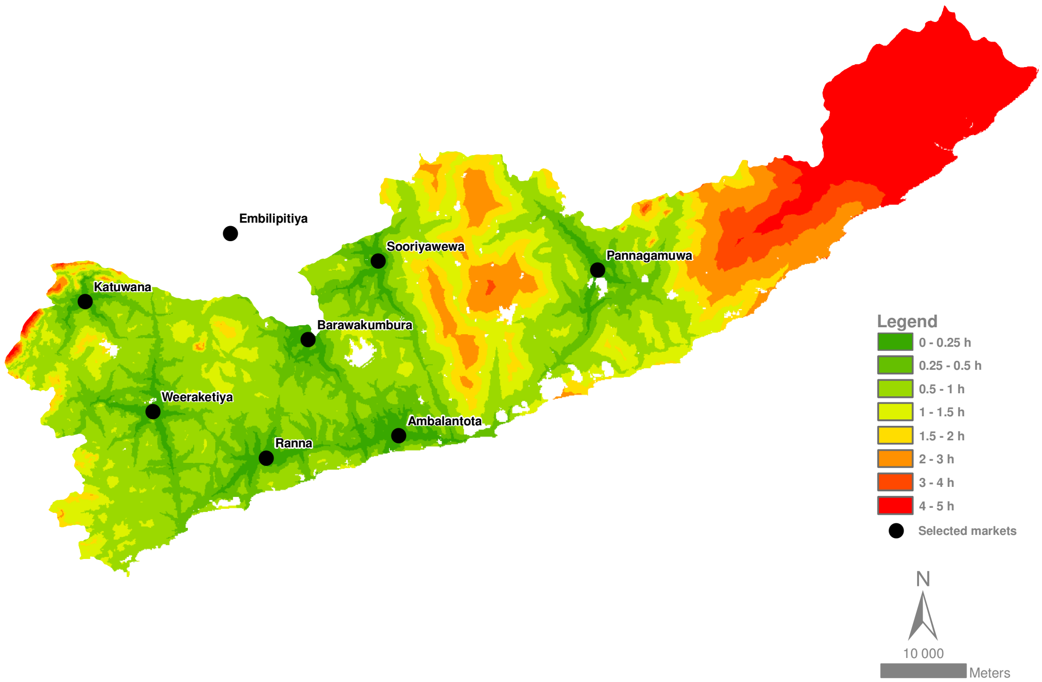

Figure 23. Figure showing estimated accessibility expressed as hours to selected markets travelling with bus.

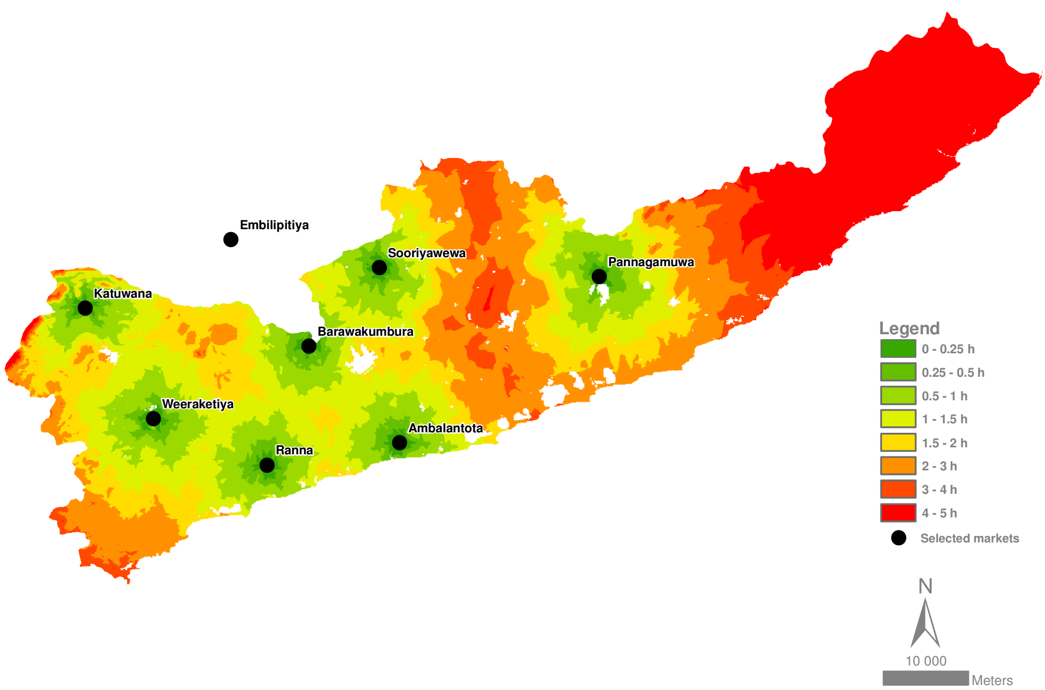

Figure 24. Figure showing estimated accessibility expressed as hours to selected markets travelling with landmaster.

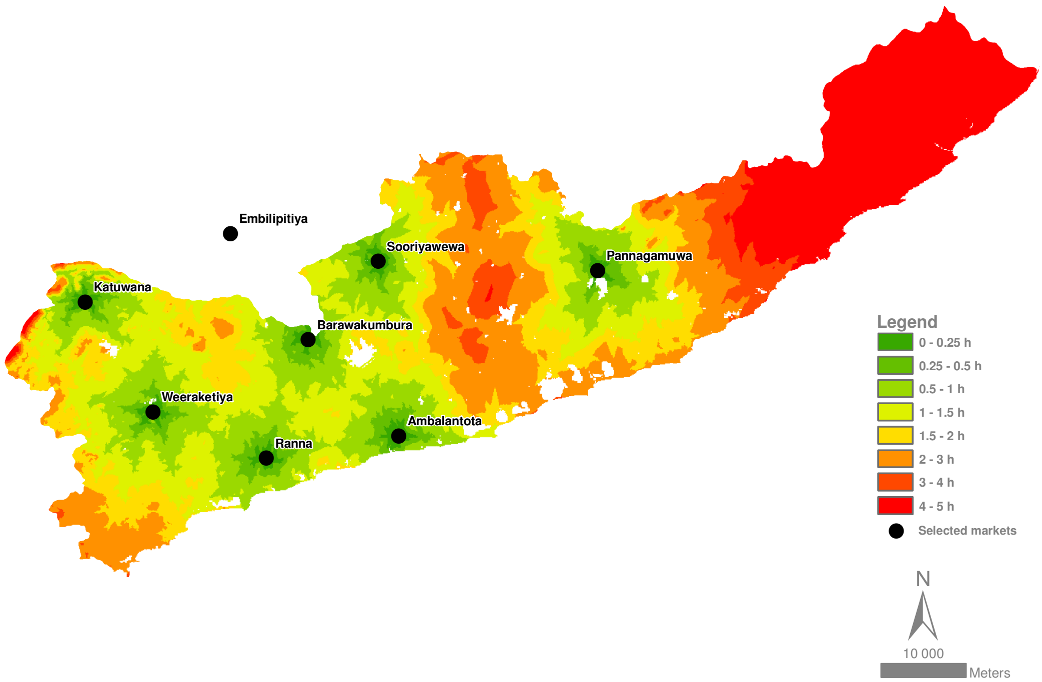

Figure 25. Figure showing estimated accessibility expressed as hours to selected markets with landmaster. The origin of the frictions is a key informant.

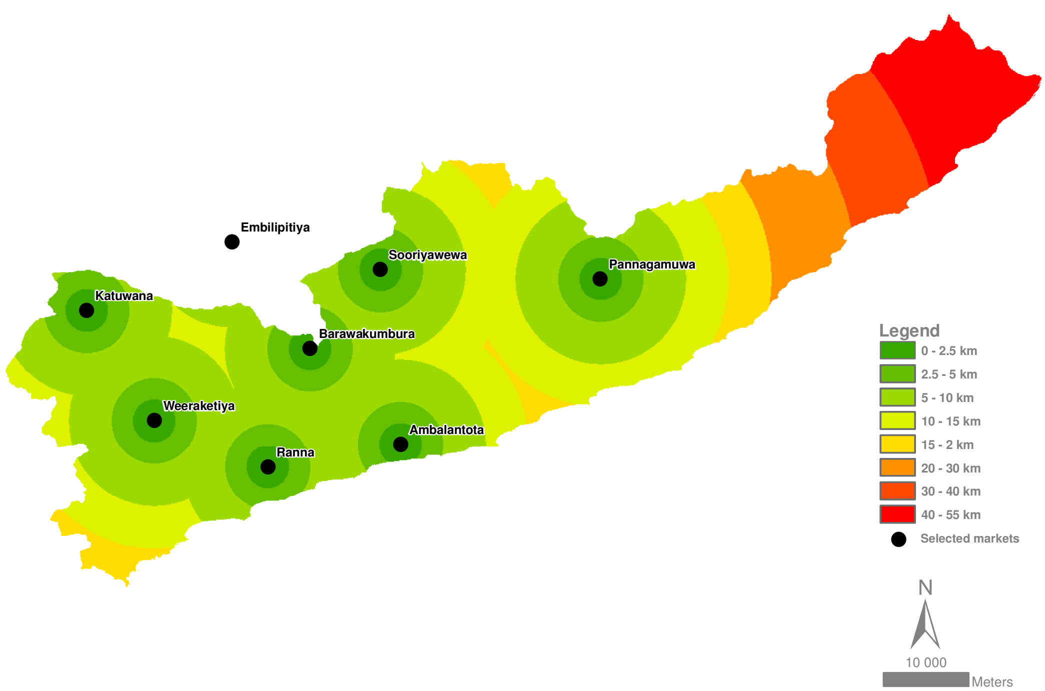

Figure 26. Figure showing Euclidian, or straight line, distance from selected markets.

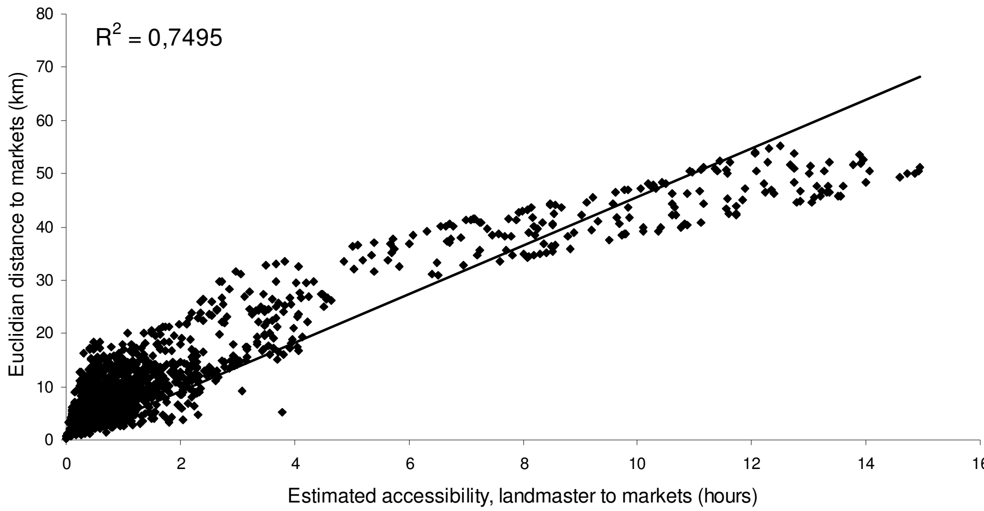

Figure 27. Graph showing a scatter plot of 1465 randomly sampled values of Euclidian distance and estimated accessibility to market.

The central and the eastern areas of Hambantota District have a lower estimated accessibility to selected towns when travelling with bus than the western areas, as can be seen in Figure 28. There are more towns in the western parts and the roads are better and the road network is denser. The Euclidian distance from towns is illustrated in Figure 29.

The correlation between estimated accessibility when travelling to towns with bus and the Euclidian distance from towns (0.7284) results in a R^2 value of 0.5306, as can be seen in Figure 30. The correlation of estimated accessibility and Euclidian distance is lower for bus travelling to towns than for landmaster travelling to markets. This is mostly due to the frictions of roads in the different cost surfaces used for landmaster modelling and bus modelling. It is not a result of the location or number of destinations. The friction of roads for landmaster is similar for all road classes. This means that a landmaster is considered to travel with similar speed on all road classes. Busses on the other hand, are considered to travel considerably faster on primary roads than on secondary roads and tracks. This induces an estimated accessibility less similar to the Euclidian distance.

The number of towns reachable within one hour with bus is illustrated in Figure 31. There is a difference with more reachable towns within one hour in the west than in the eastern and central parts. The results show that the number of towns reachable within one hour is very dependent on road quality.

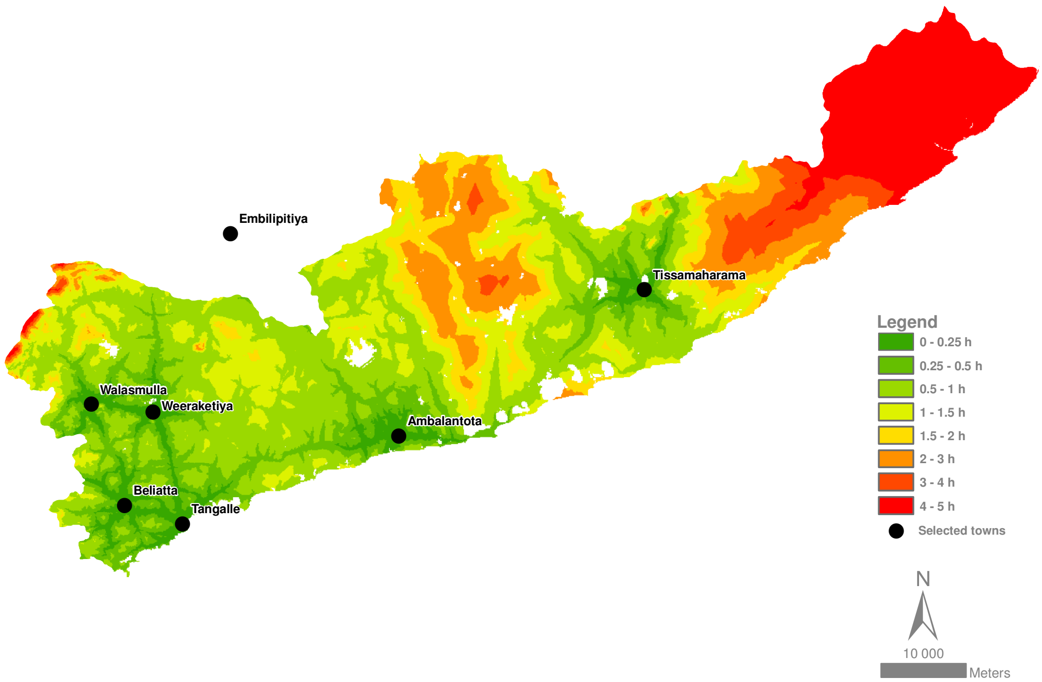

Figure 28. Figure showing estimated accessibility expressed as hours to selected towns travelling with bus.

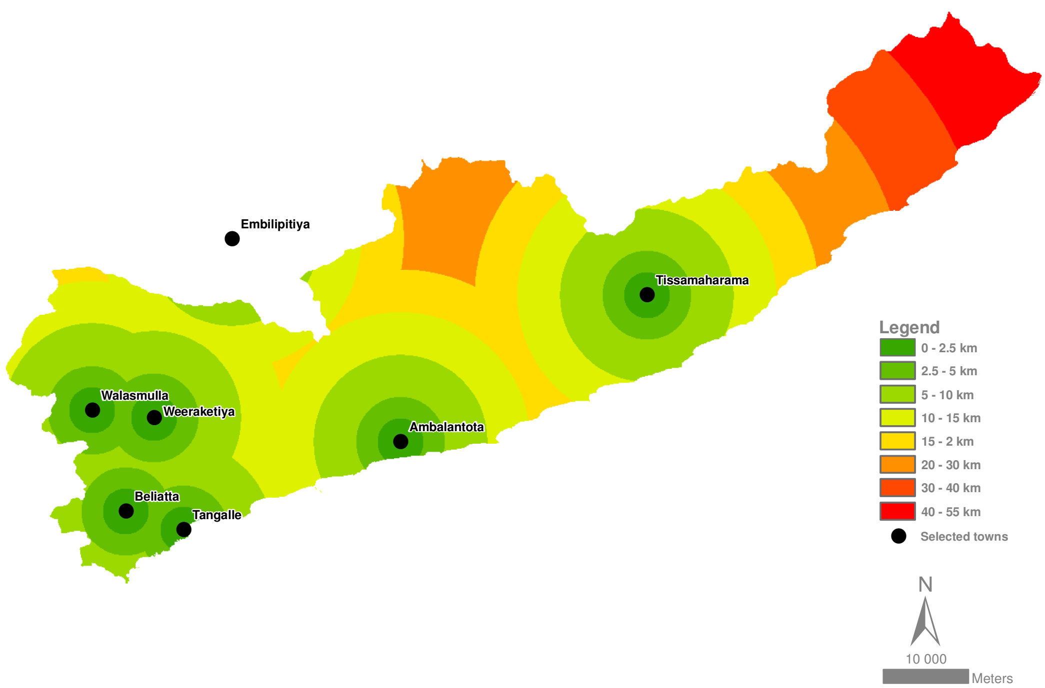

Figure 29. Figure showing Euclidian, or straight line, distance from selected towns.

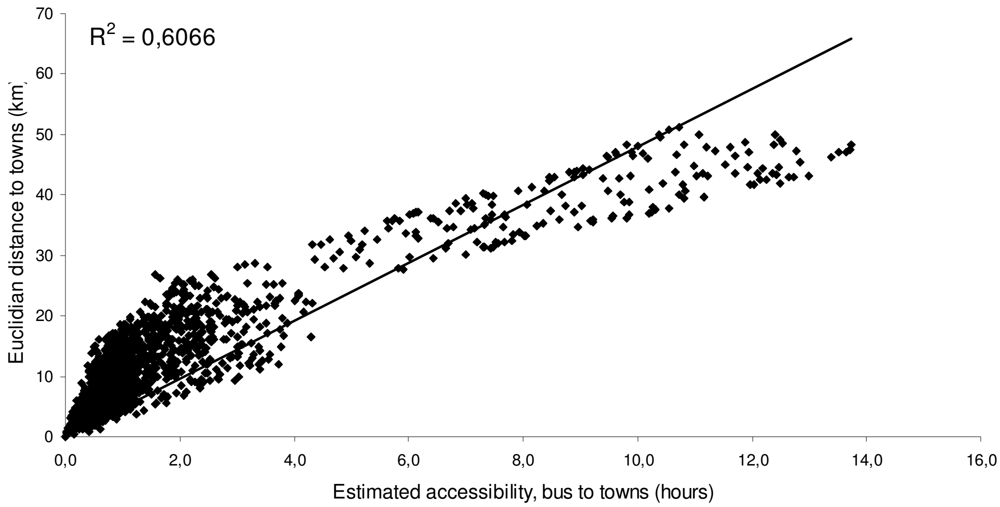

Figure 30. Graph showing a scatter plot of 1465 randomly sampled values of Euclidian distance and estimated accessibility to towns when travelling with bus.

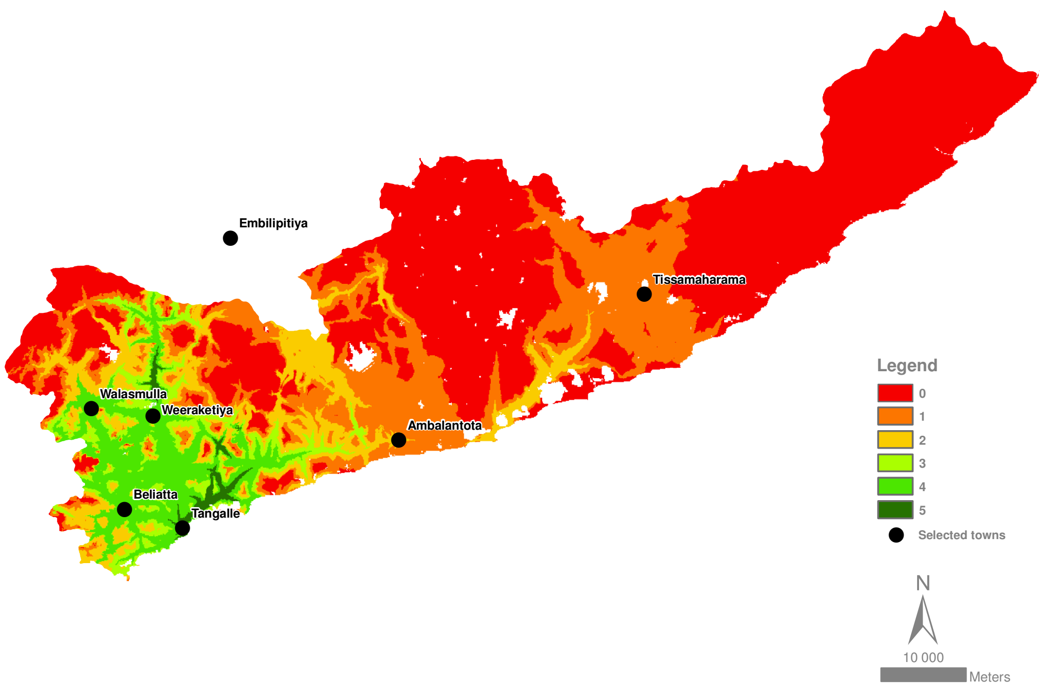

Figure 31. Figure showing the potential number of selected towns reachable within one hour with bus.

5.4 Discussion

The modelling of bus travel time to the seven largest markets and towns in Hambantota is not only dependent on the speed a bus can travel. The weights or frictions of the cost surface, the basis for the accessibility calculations, have their origin in the program for estimation of speed. It is important to remember that these speeds, which will later be frictions, are also dependent on other variables than the speed a bus can maintain on a road class. The frictions are also dependent on availability and reliability of the public transportation services. On a bad road, bus services are sparse or abundant. On a bad road the bus service is unreliable, the passengers often need to wait for long time at the buss stop because they do not know when the bus will come. This is a larger problem at bad roads partly because there are simply less busses running. The accessibility to markets and towns when using bus is low at places away from primary and secondary roads, where the supply of public transportation services is low.

The results of market accessibility for landmaster are close to the measures of Euclidian distance to markets (see Figure 24 and 26). This is because of the relatively low difference of friction between the different road classes. When travelling with bus the similarity to Euclidian distance is less because of wider spread of the friction values. When travelling slowly on all roads, as with landmaster, distances are comparatively more important than road quality. However, the interview survey showed that there are relatively few farmers who take their produce to the markets themselves. Hence there are other factors influencing how easy it is for a farmer to sell his produce. For example, if a farmer lives close to a good road, he is probably better served by middlemen than a farmer that lives at bad roads. A farmer with many selling options is likely to get a better price and profit from his produce than a farmer that has few selling options. So although the estimated accessibility for landmaster to markets does not put a weight on road quality, it might still be important for those not taking their produce to the markets themselves.

The results of how many towns that are reachable within one hour when using bus shows a clear pattern with more reachable towns in the west than in the east (see Figure 31). The results show that a place relatively far away from a town can have more reachable towns within one hour than a location in one of the towns. This does not mean that one is worse of at a location in a remote town, such as Tissemaharama. The results need to be compared both by the number of towns reachable within one hour and the distance to the closest town.

The choice of destinations is a critical part of the study. More resources could have been spent to find the most important destinations. Even though the model can estimate the accessibility to different locations with high accuracy, the results are useless if the destinations are not relevant to the data the results are to be compared to. Therefore in a study of accessibility, a lot of effort should be put on selecting the important destinations. In this study all destinations are given the same importance. But in reality this is not the case. An idea could be to weight the different destinations by their importance. However, to acquire reliable data on a destinations importance is very difficult and resource consuming. Studies conducted in Sri Lanka to collect data on centrality of towns, a measure that describes its size and economic importance, such as the JICA report 1997, are unreliable, and have little foundation in the present situation, See Appendix 6 (JICA 1997). There is a substantial difference between the centrality index from JICA and the centrality estimations, the towns, used in this study. The low resemblance of the JICA centrality index to the present situation and the destinations used in this study could also be a result of the time difference since the centrality was estimated and the time of this study. However it is unlikely that there has been a large enough change in ten years to induce such large differences.

The choices of which markets and which towns to use as destinations in the modelling are based on interviews and on field experience. Many respondents give other towns and markets as an answer to the questions of where they go most often. However, for acquiring the weights, the destinations did not need to be the ones later used in the accessibility estimations. As mentioned in section 4, the location of the departures and the destinations are irrelevant once the length of the roads and the time of the given journey have been linked. In other words, the respondents sometimes answered that they go to other markets and towns than those considered to be the most important. The markets and towns given that are kept out from the modelling are often small and do not have any or very little, wholesale trading. They are sometimes markets were poor people buy products from other poor. To sell at these markets will likely give a smaller profit than to sell at a larger market. Somewhere the limitation of which markets to use as destinations has to be set. It is in other words assumed that a large market or town is better to go to than a small, although many respondents can not afford to go to the large markets and towns. In this case all markets with wholesale trading were used, and none that does not have any regular wholesale trading were used. For towns a certain size or economic activity was wanted. Hambantota town is an example of a medium sized town which in a first look would be given as a destination as the districts administrative centre. However, Hambantota town is not used as a destination due to low economic activity. It is mostly an administrative centre, and no extensive production or trading is occurring according to the interviewee at REAP. Many towns given as answers to the question of where respondents go to visit towns do not give as many working opportunities or trading opportunities as the largest towns, used in the model.

However, people sometimes do go to a smaller town if that is closer than one of the destinations in the model. People also sometimes do sell their produce on a smaller market with lower prices and less customers if it is closer than one of the wholesale markets used in the model. This means that the model does not reflect people's actual habits with concern on journeys to markets and towns. It is not a modelled of what people do, it is model of what opportunities people have to do things. The model result represents the potential accessibility, or the opportunities to visit good markets and larger towns. People with low accessibility to large towns have smaller opportunities to work in other sectors than the agricultural sector. People with low accessibility to good markets are likely to produce less, and to have a smaller income from agriculture. For example, farmers with low market accessibility have small possibilities to invest in large quantities of agricultural supplies. These farmers have to visit markets often to buy supplies. Accordingly, farmers with low market accessibility have to pay more and spend more time on transport to markets to buy supplies. The worse the accessibility, the smaller the net income and the smaller the means available to invest are. If the farmers buy supplies in a small local market, they have to pay higher prices to compensate for the sellers transportation costs.

The raster approach used in this study has some weaknesses compared to a vector based approach. The raster approach is somewhat coarse. It does normally not have the spatial resolution of the vector approach. The spatial resolution is limited by the cell size which is the highest resolution an object or a part of an object can have in the raster model. A road will never have the same potential positional accuracy in the raster model as in the vector model, resulting in for example errors in estimations of road length. However, this weakness was considered to have little influence on this study, because 90 metres resolution is considered to be enough or even more than enough. There are also substantial factors that favour the raster approach. For example, with the raster approach the model is not tied to travel on roads. It can take off-road short cuts to, from and between roads. This is very important because of the incompleteness of the data. As argued, there are many foot paths that are not in the road network data.

If defining off-road conditions as the areas outside roads in a cost surface, then the amount of off-road travelling is highly dependent on the completeness of the road data. In the national road database in Sweden, the completeness of the road network is very high if not almost perfect for the roads that are trafficked by motor vehicles. In Sri Lanka the completeness of the road network that is trafficked by motor vehicles is relatively low. Although the low completeness of the road network data in Sri Lanka is partly due to that the traffic traffics small roads. Road types that are barely used in for example Sweden are trafficked a lot in Sri Lanka. The traffic on these roads is very important to consider to get a good picture of the traffic patterns in Sri Lanka, while they are not very important in Sweden. The point is that different approaches, raster or vector, are best for different conditions, and in rural Sri Lanka the raster approach is due to the arguments above likely the most suitable.

Another more general factor influencing this study is that the speed of transportation is not directly linked to the speed limits of roads. The speed of the traffic is slower, and more dependent on road quality and intensity. This is the main reason why substantial effort was needed to estimate the real speed of roads, or the effective travelling time of a journey.

In this study three classes of roads, slope and water have been used to construct a cost surface. The number of classes used is dependent on the availability of data. The results might have been better if more classes had been used. First of all the quality of the results might have been higher with more classes, more road classes and more terrain classes. Secondly the quality of the results might also have been higher if the resolution of the data (water bodies and topography) and the precision and completeness of the data were higher. On the other hand, to use many classes requires that the classes used have high accuracy, both regarding precision and position, and it requires that there is a solid base for the assigning of weights. It is thus not known if more classes would enhance the results of this study. It is considered that it is better to leave classes out of the analysis if their quality is low, such as foot paths. And there is also a question if it is good to use land cover (terrain) in a model that is later to be compared to land cover even if land cover data are available.

6. Accessibility, socio-economic indicators and land cover

In this chapter the results of the accessibility modelling is compared with socio-economic indicators and land cover. As described in the introduction, previous studies have found different measures of accessibility closely related to a number of socio-economic indicators and land cover. However, the absence of high resolution data has called for the development of a method to generalise the accessibility measures to be able to compare it with the available statistical data.

6.1 Method

6.1.1 Accessibility and indicators of poverty

The results of the accessibility modelling in section five have a cell size of 90 metres. The highest level of data on socio-economic indicators available is division level. The divisions of Hambantota District have a mean size of 219 km^2. Socio-economic data was acquired from the department of census and statistics in Colombo. The acquired report holds a number of indicators and statistics for 119 selected divisions (DCS 2006). The report holds information on all divisions of Hambantota District. Two indicators and three estimated accessibility results were chosen for the comparison between of the statistical data and the estimated accessibility. The statistical data chosen were the percentage of households without electrical lights and the percentage of inhabitants below national poverty line. The national poverty line is a measure of income, all having an income that is below the national poverty line falls in the category of poor. The first two chosen estimated accessibility measures consisted of estimated accessibility to market with landmaster and estimated accessibility to town with bus, they were considered to be the most important according to the interview survey. Bus is the main mean of transport overall and when travelling to town, landmaster is the most common private mean of transport when travelling to a market to sell goods, as was found in the interview survey. The third accessibility measure was Euclidian distance to towns. It was chosen as a comparison to the two estimated accessibility measures.

To be able to compare the accessibility models results with the data of socio-economic indicators a method to generalise the accessibility data was developed. The aim of the generalisation was to get a value for each accessibility measure at divisional level. But a simple mean value within each division does not take the population patterns into account. And a mean value does not compensate for extreme values, people does not live on mountains. A mean value weights all cells in the accessibility rasters equally. A high mountain in an otherwise relatively accessible division would greatly affect the mean value. The mean value would thus not represent the mean accessibility of the inhabitants of the region. Instead, the accessibility was first generalised to GN-divisional level and then weighted by the relative number (per division) of inhabitants in each GN-division (Figure 1). The method developed gives a generalised accessibility value depending on an approximation of where people live and it takes the extreme values of accessibility in the GN-divisions into account. The method is described in the following steps below:

1. First three chosen results of the accessibility modelling were resampled. The rasters were resampled from 90 metres cell size to 270 metres cell size. The cells is in step two converted to points, why a resampling was needed to get a manageable size of the data set. The resampling method used was bilinear resampling. The method of bilinear resampling was chosen because it better reflects a point (which the cells was later converted to, see step 2) in the middle of the filter window than a mean value of all cells in the filter window. The data loss of the resampling was considered to be insignificant.

2. Secondly, the resampled rasters was converted to points. About 35000 points were created from each raster, one point for each cell. After the conversion the points hold the same values as the originating raster. The points were located in the cell centres.

3. The third step was to overlay the point data of estimated accessibility with a polygon layer of the GN-divisions of Hambantota District. The aim of this step was to link point data of accessibility to the GN-divisions of the district.

4. Data on GN-divisional identification codes and the accessibility values of the points were extracted and imported to a program written in MatLab, see Appendix 7.

5. In the program written, the lowest value of each GN-division was found. All 35000 accessibility values were tested for each chosen accessibility measure. The lowest value of each GN-division was recorded together with the identification number of the specific GN-division.

6. The result of the program was then exported back and joined with the polygon layer of GN-divisions in the GIS.

At this stage, the lowest value of the resampled accessibility rasters was found and linked to the correct GN-division. To use the lowest accessibility value of a GN-division (the value of the best accessibility) was an approximation that was assumed to best represent the accessibility of the inhabitants of each GN-division. And it is an approximation that can easily be calculated. It is likely that most people of a GN-division lives by, or close by the low accessibility areas of each GN-division. Field experience tells that most people have an access road to the main roads of the GN-divisions. These access roads are not always in the data used in the modelling. The travelling time to the lowest value of the GN-divisions is probable to be relatively low compared to the lowest accessibility value of the GN-division. In other words, most, if not all, houses in a GN-division have a road connection or a short off-road distance to the point in the GN-division with the lowest accessibility value. Although this point will be somewhere at the outskirt of the GN-division, the travelling time to this point from the houses in the GN-division is probably, for most GN-divisions (those not close to a destination), low relative the estimated travelling time from the lowest accessibility value point to one of the destinations. To let the lowest value of each GN-division represent the whole GN-division takes both the extreme values of low accessibility (high accessibility values) and the lack of data in the model in to account. It is also probable that most people in each GN-division lives at a place in the GN-division with high accessibility. The points used to represent the GN-divisions are the points with the highest accessibility in each GN-division, why they are also an approximation of where people live. On the other hand the point will represent a location close to, or at the border of the GN-division. That is not a realistic scenario, but it was considered to be the best approximation.

The next step in the generalisation was to weight the accessibility values with the relative amount of population of the GN-divisions and produce weighted values of the 12 divisions. The weighting was based on a GN-divisions fraction of its division's total population. If for example a GN-divisions has 5% of the total population of its division, the accessibility value of that GN-division will have 5% weight. The result of the weighting was three accessibility values per division, one per accessibility measure. The weighted values were values that represent the whole division. Because the new generalised, division level, accessibility measures was weighted by where people live, it is important that the statistical data it was later compared to was collected at locations and in numbers in line with population patterns. But how the data have been collected is not known. The population data on GN-level was attained from the district secretary in Hambantota town.

6.1.2 Accessibility and land cover

Accessibility was also compared to land cover. Data on land cover were acquired from Sandell (forthcoming). The land cover data is a result of a Landsat TM image classification. For a more detailed explanation of the land cover classification see Sandell (forthcoming). The same estimated accessibility measures as in 6.1.1 were chosen for this analysis.

The two estimated accessibility measures and Euclidian distance were compared to the land cover to see if there are any relationships between the distribution of different land cover classes and the accessibility/distance measures. Both the estimated accessibility, the Euclidian distance and the land cover data were in raster format. To be able to compare the raster's they had to have the same cell size. To get the same cell size the accessibility rasters and the Euclidian distance raster were resampled from 90 metres to 30 metres cell size using a nearest neighbour resampling technique. This means that there will be no data loss, not in the resampling and not in the comparison to the land cover. The accessibility and the Euclidian distance rasters will have cells with the same value in a 3*3 cell window. However, there might be different land cover cells within this window why the smaller cell size of the accessibility and Euclidian distance rasters were preferred.

The next step in the analysis was to reclassify the accessibility and Euclidian distance rasters into intervals. This means that all cells within a minimum and a maximum estimated accessibility value or distance were assigned the same value. To be able to compare estimated accessibility and Euclidian distance to land cover data, some kind of fractions needed to be calculated. To allow this the land cover was also divided into intervals, where the amount of a land cover class within the intervals could be compared to the area of the interval and the mean estimated accessibility/distance value of the interval. Resulting in a set of percentage values of the land cover classes and corresponding values of estimated accessibility/distance. If for example forest covers one fourth of the first interval's area, and half of the second interval's area, and the first interval have an mean estimated accessibility value of 1h travelling time to town and the second have a mean estimated travelling time of 2h to town, the analysis would tell us that the amount of forest increases with distance to towns. The rasters were divided into 12 intervals using quantiles. This means that the intervals were of equal area.

To get a representative value of estimated accessibility and Euclidian distance within each interval it is not enough to take the mean value of the minimum and the maximum values of the intervals. A mean value of all the cell values in the intervals was instead calculated. The next step was to reclassify the land cover data. The land cover data were reclassified by multiplying the number of the classes by 100. For example class 2, paddy, was multiplied by 100, resulting in a class value of 200. This reclassification allowed for a simple addition of the land cover data and the accessibility and Euclidian distance rasters. The results can be acquired as a list where each unique value corresponds to a land cover class and an accessibility or Euclidian distance interval (1-12). For example, if we add a cell from an accessibility raster within the interval 4 and a cell from the land cover raster of the class 200, the cell in the resulting raster would get the value of 204. By comparing the number of cells of a specific number, an interval and a land cover class, with the total number of cells in that range, a percentage of the land cover within that class could easily be calculated.

Finally the relationship between the land cover classes and the mean estimated accessibility/Euclidian distance values of the different intervals was investigated in a correlation analysis.

6.2 Results

The result of the generalisation of bus travel time to towns from 90 metres raster to GN-divisional level is illustrated in Figure 32 below. Figure 33 below illustrates the population weighted generalisation of the GN-division accessibility values of bus travel time to town to divisional level.

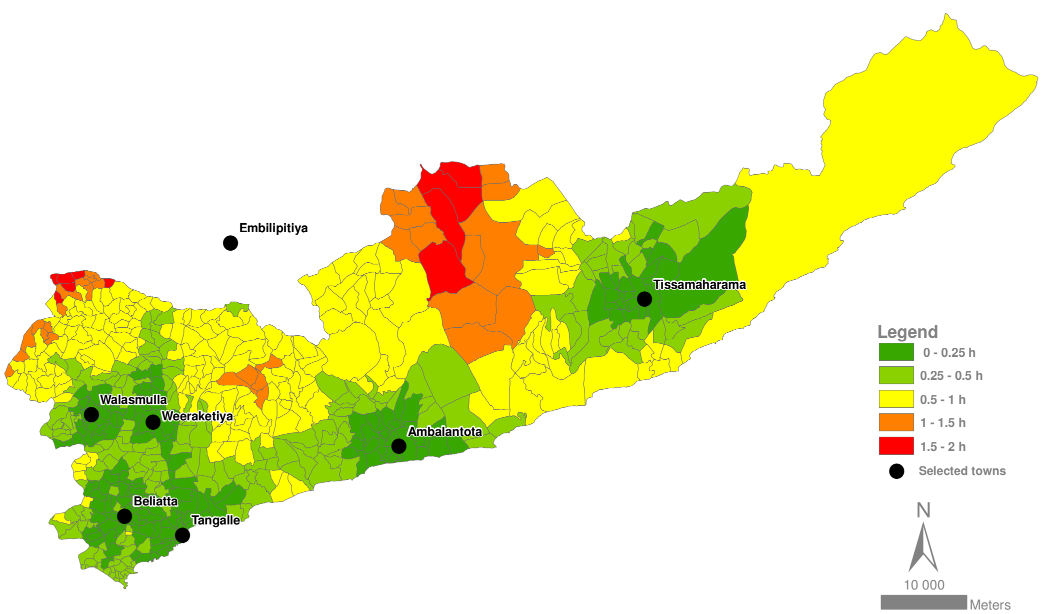

Figure 32. Figure showing generalised estimated accessibility to towns as travelling time when using bus for GN-divisions.

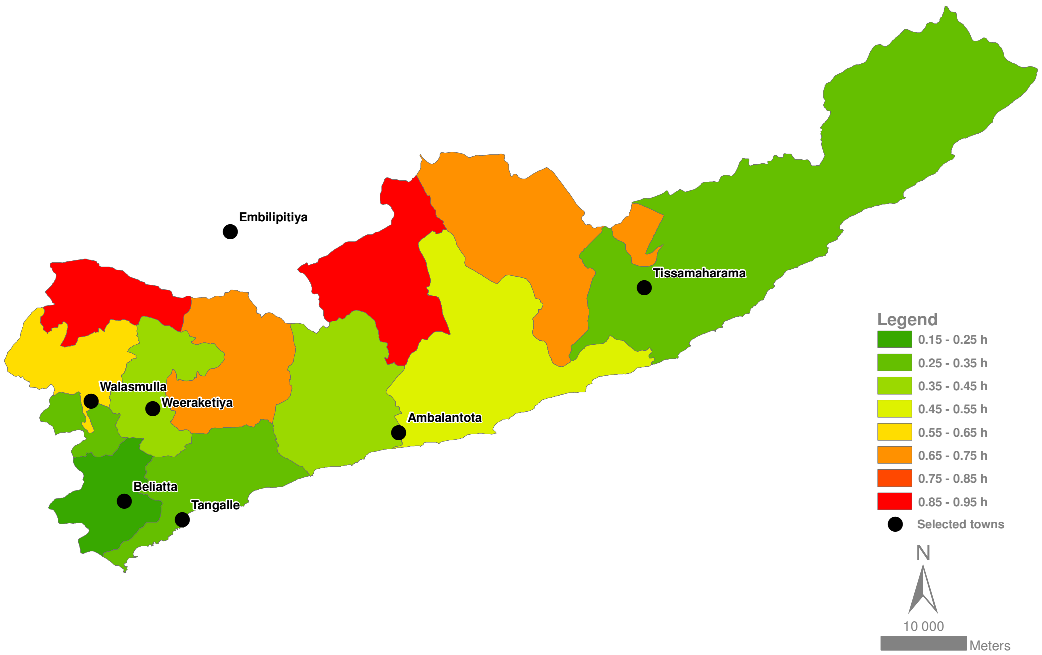

Figure 33. Figure showing generalised estimated accessibility to towns as travelling time when using bus for divisions.

In Figure 34, 35 and 36 three scatter plots of the percentage of the population below the national poverty line and the different estimated accessibility measures and Euclidian distance are presented. The accessibility measures are generalised according to the method described earlier to divisional level. In Figure 37, 38 and 39 the same accessibility measures are compared to the percentage of the households in each division that does not have electric lights in their homes.

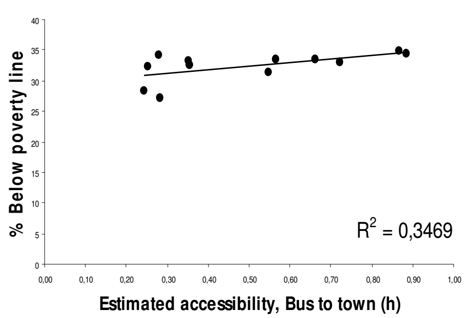

Figure 34. Scatter plot of estimated accessibility to towns with bus and the percentage of the population below national poverty line.

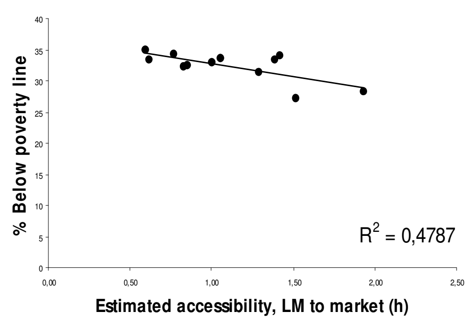

Figure 35. Scatter plot of estimated accessibility to markets with landmaster and the percentage of the population below national poverty line.

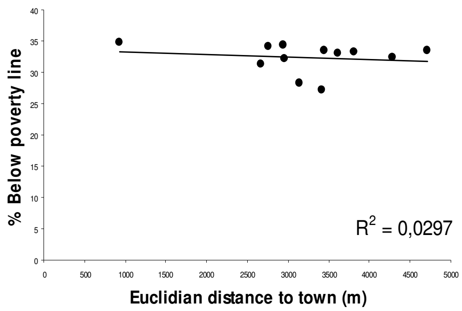

Figure 36. Scatter plot of Euclidian distance to towns and the percentage of the population below national poverty line.

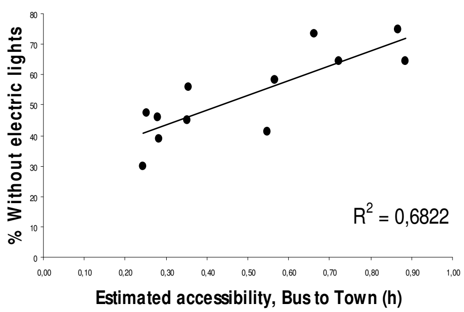

Figure 37. Scatter plot of estimated accessibility to towns with bus and the percentage of the households without electrical lights.

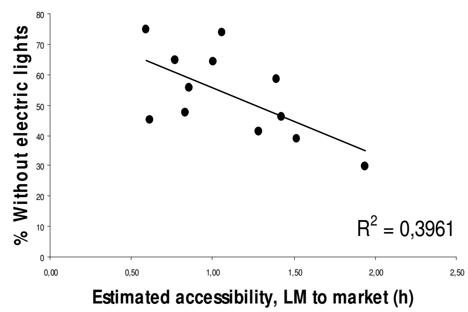

Figure 38. Scatter plot of estimated accessibility to markets with landmaster and the percentage of the households without electrical lights.

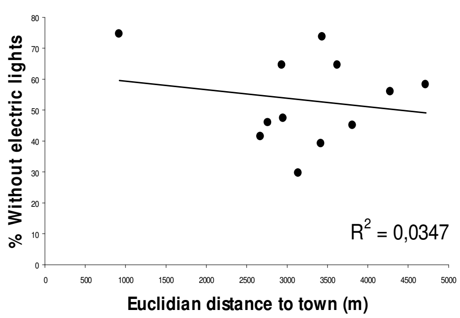

Figure 39. Scatter plot of Euclidian distance to towns and the percentage of the households without electrical lights.

The results illustrated in Figure 35 indicate that poverty increases with estimated landmaster accessibility to markets while it decreases with estimated bus accessibility to towns (Figure 34). Figure 36 show that Euclidian distance does not explain poverty as the percentage of the population below the national poverty line at all. The same relationships are found for estimated accessibility and the percentage of the population without electric lights. The percentage of households without electric lights decreases with estimated bus accessibility to town (Figure 37) and increases with estimated landmaster accessibility to markets (Figure 38). The measure of Euclidian distance to towns shown in Figure 39 does not show any relationship to the percentage of households without electric lights either.

The results of the correlation analysis of the relationships between different land cover classes and two accessibility measures and Euclidian distance is found below. The highest correlations found were those of shrub land and estimated accessibility to markets with landmaster and to towns with bus. Both resulted in an R value 0.98 giving a R^2-value of 0.95. However, three other land cover classes that were considered as interesting for this study and their relationships to estimated accessibility/distance are presented below. In Figure 40, 41 and 42 the relationships between the percentage of paddy land and the chosen accessibility measures and Euclidian distance are illustrated.

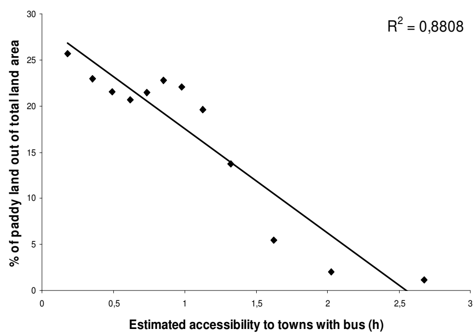

Figure 40. Scatter plot of estimated accessibility to towns with bus and the percentage of paddy land out of total land area.

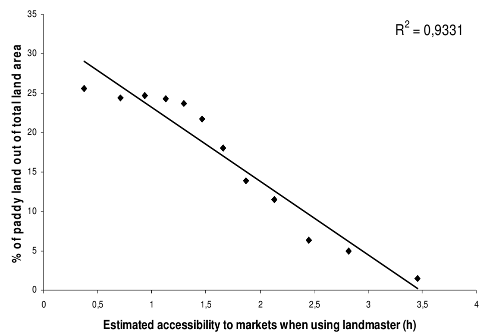

Figure 41. Scatter plot of estimated accessibility to markets with landmaster and the percentage of paddy land out of total paddy land area.

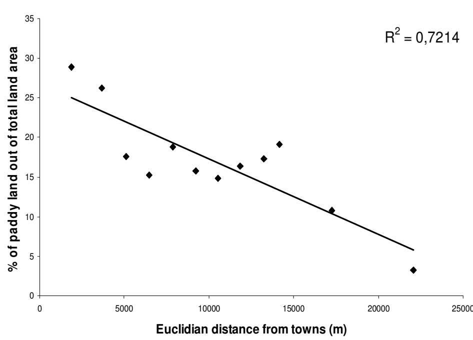

Figure 42. Scatter plot of Euclidian distance to towns and the percentage of paddy land out of total land area.

In Figure 43, 44 and 45 the relationship between the percentage of forest and the chosen accessibility measures and Euclidian distance are illustrated. In Figure 46 and 47, the relationship between the chosen accessibility measures and the percentage of abandoned paddy land out of paddy land is illustrated.

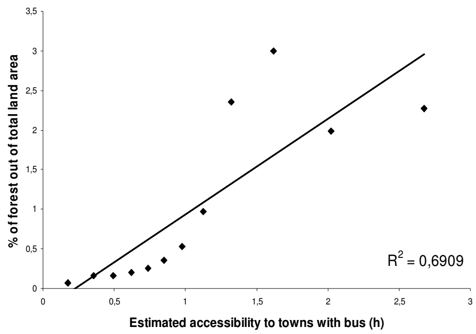

Figure 43. Scatter plot of estimated accessibility to towns with bus and the percentage of forest out of total land area.

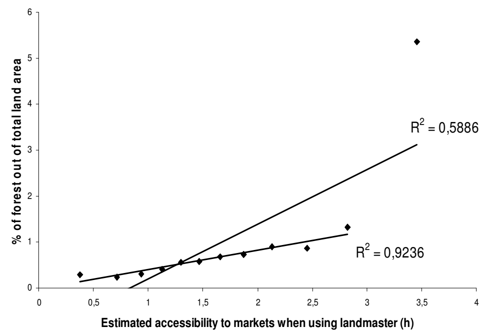

Figure 44. Scatter plot of estimated accessibility to markets with landmaster and the percentage of forest out of total paddy land area.

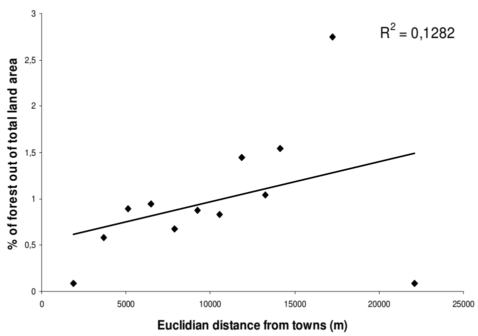

Figure 45. Scatter plot of Euclidian distance to towns and the percentage of forest out of total land area.

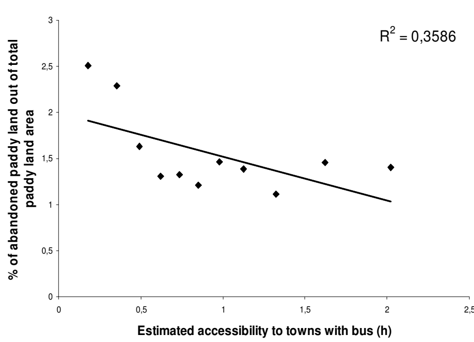

Figure 46. Scatter plot of estimated accessibility to towns with bus and the percentage of abandoned paddy land out of paddy land.

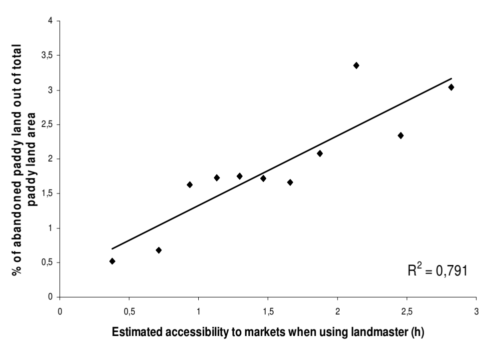

Figure 47. Scatter plot of estimated accessibility to markets with landmaster and the percentage of abandoned paddy out of paddy land.

6.3 Discussion

Not to have access to statistics on e.g. poverty at GN-division level was a big set back for the study. The idea of creating a continuous high resolution accessibility measure was partly to compare the accessibility to detailed data on socio-economic indicators. The lack of such data induced the effort to perform a weighted generalisation of the accessibility data. The aim was to have accessibility data on divisional level that represented the accessibility of the inhabitants of the division.

The results indicate that accessibility to large wholesale markets do not make people less poor. It makes them poorer. Accessibility to towns on the other hand seems to induce a small decrease in poverty. Furthermore, it is important to note that some of the towns and the wholesale markets used as destination are the same, they have the same localisation. This means that the result of the relationship of the poverty indicators can not be totally contradictory. To still see a difference in the relationship strengthens the results credibility. However, the results in Figure 34, 35, 36, 37, 38 and 39 are uncertain due to the generalisation of the accessibility data.

Although the comparison of generalised accessibility estimations and poverty indicators showed a relationship, a lot of the accessibility variation was lost in the process. To weight the accessibility by the inhabitants in a GN-division builds on the assumption that the collection of the poverty indicator data was performed in a way were the amount of the data was collected according to the amount of people that lives in each GN-division. However, this is not known, it is also not known if data was even collected within each GN-division. So except from speculations, the analysis really only shows that the market centred divisions are poorer than the town centred divisions.

According to the interview of a high official at REAP, market accessibility is the most important accessibility in Hambantota District. The better the market accessibility, the better of the inhabitants are. Peiris (2006) also expresses the market accessibility as an important factor influencing poverty. Although the correlation analysis of the poverty indicators in this study has its weaknesses, it indicates the opposite. But the correlation analysis might just show that divisions with a market as a major centre of economy is poorer than a division with a town as a major economic centre. However, if the statistical data was collected at GN-level, and according to population patterns, there is more variation hidden in the results. Then variations within the division are also seen in the correlation analysis, and the conclusion that poverty increases with accessibility to markets and decreases with accessibility to towns is strengthened. If, however, the data was mostly collected at the central, larger towns or market towns of the divisions, all the correlation analysis shows is that the market towns is poorer than the towns that have other economic activities as their main economic activities. It is unlikely though, that the statistical data was collected with such bad distribution, and it is likely that the correlation analysis show an indication of the real situation.

The source at REAP also expressed that people centre around markets. If assumed that the largest factor of land cover alteration, and its distribution today is anthropogenic, then the land cover distribution should be closer related to accessibility to markets than to towns. From the results it is hard to draw any real conclusion on the subject. Both estimated accessibility measures are strongly related to land cover. There is no clear pattern where land cover is closer related to market accessibility than to town accessibility or the other way around. Note also that some of the destinations in the accessibility estimations are both markets and towns.

Land cover and estimated accessibility show a strong relationship. Paddy is most strongly related to the estimated accessibility to markets with landmaster (see Figure 41). The relationship to accessibility to towns with bus does also show a strong relationship (see Figure 40). Euclidian distance from towns shows a lower but although quite strong relationship to the percentage of paddy land as can be seen in Figure 42.

The correlations between estimated accessibility and the percentage of forest show weaker relationships than for paddy land. The relationships between estimated accessibility and forest are strong until they reach the most inaccessible areas, the mountains. The relationship between percentage forest and estimated accessibility to markets with landmaster is stronger than the relationship to estimated accessibility to towns with bus although the correlation analysis shows a lower R^2 value (see Figure 43 and Figure 44). The relationship between percentage forest and estimated accessibility to markets shows a strong relationship for all intervals except for the last interval, the one with the lowest accessibility. This is because almost all the forest in the study area is growing on steep slopes and mountains, areas that are modelled as relatively inaccessible in the accessibility estimations. The correlation analysis of estimated market accessibility with landmaster and forest shows a straight relationship, with increasing forest until the hills are reached, where almost all the forest is located. This relationship is close to how the location of forest was perceived in the field visits.

In Figure 43 the relationship between estimated accessibility to towns and forest cover is illustrated. The plot shows that there is a trend with increasing residuals, which indicates that more effort needs to be put on the subject. The Euclidian distance, in Figure 45, on the other hand shows no strong relationship to the percentage of forest. This is because there can be a hill or a mountain close to a town. These areas will get a low Euclidian distance (high accessibility), while the accessibility model will give them a relatively low accessibility value. So the Euclidian distance measure can give a high accessibility value to a mountain top that is close to a town, but a low accessibility on the level ground in the valley on the other side of the mountain or hill. This is compensated for in the accessibility modelling, why it gives a better prediction for land cover patterns with these characteristics.

It is obvious from the results that the study has focused on assigning weights on roads, on where people travel often, and not on more extreme off-road terrain, such as mountains and hills. If looking at the relationships between forest and the two estimated accessibility measures in Figures 43 and 44, it can be seen that the forests are reached earlier with bus than with landmaster. At the mountains, the model does not handle the slopes correctly. The accessibility of mountains is probably too high, the friction is too low. For bus, the model can cross the mountains and reach the other side of the mountain. That is not in most cases supposed to be a trip with smaller cost than the trip of going around the mountain. The model for bus travelling reaches the hill slope relatively fast, and the low friction of mountains makes it possible for the model to find a least cost path over the mountain and to the other side. This is probably the reason for the increasing residuals. The landmaster model seems to reach the mountains late, almost all forest fall within the same interval, the last. But it seems like if the intervals mean accessibility value is too high, the model climbs the slopes too quickly. These shortcomings does not necessary need to be a result of the assignment of frictions, it could be a result of the data used for calculating slopes. The quality and the resolution of the topographical data might induce a loss of steep sections of hills, or a loss of peaks.

Abandoned paddy and accessibility measures is interesting because it can give a picture of how much people are abandoning the traditional paddy farming for other sources of income. This is a very complex process, but the analysis can show if there is a relationship between accessibility and the abandonment of paddy. The analysis do not show a clear relationship between measures of accessibility to towns with bus and the percentage of abandoned paddy out of paddy land (see Figure 46). However it is evident that there is more abandoned paddy close to towns (high estimated accessibility) than far away (low estimated accessibility) although the amount of abandoned paddy does not decrease in a straight relationship to the accessibility measure. The relationship of abandoned paddy and the accessibility to markets with landmaster show a stronger relationship ($R= 0.89$, $R^2 = 0.79$). There is less abandoned paddy at locations with high estimated accessibility to markets than there are at locations with low estimated accessibility to markets.

The results indicate that more people close to towns surrender their paddy than people do close to markets. A possible reason for the relationships could be that more people close to town give up agriculture for other businesses. However the results of the analysis are uncertain. The amount of abandoned paddy is low compared to not abandoned paddy. There are many other reasons for abandoning paddy. The most common reason is according to field experience shortage of water supply. It should also be noted that the accuracy of the classification for abandoned paddy is low according to Sandell(forthcoming). But the results is in line with what was expected, people do not find agriculture profitable and searches for other sources of income, as a supplement or as a substitute. There is no obvious reason why there should be errors in the classification leading to the relationships shown. There is neither any obvious reason why there should be a shortage of water close to towns and not close to markets, or far away from towns. So the results might, however uncertain, indicate that people are in fact abandoning paddy farming for other non-agricultural sources of income. It should be noted in the context of the arguments that there are not any other crops growing on the abandoned paddy fields. No crops that might need less water.

The study area is with regard on land cover a large, inhomogeneous and diverse area. There are three agro-ecological zones in the area. In the dry zone, the cultivation is strongly dependent on irrigation schemes. There are also different soils in the area. All together the physical prerequisites and the irrigation schemes affect the distribution of cultivation, and therefore also affect the land cover in Hambantota District (see Schubert 2004). Although the relationship between land cover and estimated accessibility is strong, this is a large source of error. It can not be expected to get perfect relationships between accessibility and land cover in an area where the land cover is strongly dependent on irrigation schemes and there are pronounced differences in physical conditions apparent.

Another source of error is the classification accuracy. The classification is not perfect why the correlation analysis can not be expected to show perfect relationships. Taking the sources of error into account, the results from the correlation analysis indicates that there is a strong relationship between land cover and the modelled accessibility measures.

One interesting question is of what comes first. Is the land cover of an area influenced by the accessibility, or is the accessibility to an area affecting the land cover? It is a difficult question to answer. However, it is possible that when a relationship has been set, for example bad accessibility to a forested area, it will probably preserve the relationship. If for example, the accessibility to a poor village is low, the reason for the relationship, of low accessibility to a poor village, could be either that the accessibility is in fact low, or that the accessibility is low because the village is poor. A reason for not building good roads to a poor area might be the lower demand because of smaller economic activity. However, when the relationship is set, it is probable that it is more or less preserved. Hence, the question of what comes first does not really matter for an existing situation. But it is interesting for the understanding of the development of the relationship.

7. Conclusions and final remarks

The study has found that it is possible to join the local knowledge of the transportation situation with geographical data to construct an accessibility model. It has been found that estimated accessibility seems to be related to poverty and land cover. It has been found, although uncertain, that people with high estimated accessibility to markets seems to be poorer than people with high estimated accessibility to towns. The study has also found that modeled estimations of accessibility are closer related to poverty indicators and land cover patterns than the simple accessibility measure of Euclidian distance.

Overall this study has shown that it is possible to successfully integrate interview data into a quantitative GIS-based accessibility model. The successful results call for a study that better tests the speed estimation method. Such a study could increase the understanding of the method's strengths and weaknesses. It could also test if the method is better than the traditional method is to estimate frictions, by subjective field estimations. One way to do such a study would be to collect a large data set in an area of diverse road quality. The data could then be divided into two groups, one for estimating the speed of roads in the program, and one for evaluating the results. Another interesting part of such a study would be to also incorporate slope and rainfall in the speed program. This would result in more classes, and therefore would require a much larger data set.

As a last word, Hambantota District is an interesting area when it comes to development and accessibility. It is a traditionally poor, inaccessible and farming oriented area when looking at it at a regional level. However, as mentioned earlier, at the time of the field study there was much happening. A large harbour was in the planning face, an international airport was being built, a highway from Colombo was in the building stage, however temporarily haltered, and a railway extension, connecting Hambantota District to the capital were being planned. A traditionally inaccessible area, without any good connections to the national and international markets is maybe about to become a major hub for international trading and business, and the amount of tourism might also increase. Normally these kinds of investments are allocated close to the already existing economical centres, but in this case they are located in one of the poorer, undeveloped areas of the country. At a second visit in the study area in February 2008, 3 months after the end of the field survey, the building of the harbour was already in full progress. In very short time, the regional accessibility of the area will radically change. The question is how this will affect the inhabitants of the area. Will the benefits be distributed? Will overall accessibility increase? And what will happen to poverty and livelihood strategies?

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Appendix 1.

Transformation parameters attained from Survey Department

SL Datum 1999

Coordinates of Piduruthalagala - 200 000 N,200 000 E (As on Topographic Maps)

Transformation Parameters - WGS 84 to Everest Ellipsoid

Shifts X= 0.2933
Y= -766.9499
Z= -87.7131

Rotation X= 0.1957040 seconds
Y= 1.6950677
Z= 3.4730161

Scale Factor 1.0000000393

Projection Parameters - Everest Ellipsoid to Transverse Mercator Projecton

Everest India 1830
False Easting 200000
False Northing 200000

Central Meridian	80 46 18.16000 E
Central Parallel	7 00 1.7290 N

Scale Factor 0.9999238418

Appendix 2.

District Questionnaire

1. How is the accessibility to commercial centers in Hambantota district?
2. How is the accessibility to good markets in Hambantota district?
3. How is the accessibility to good schools in Hambantota district?
4. How is the accessibility to hospitals in Hambantota district?
5. How is the mobility in Hambantota district?
6. Where are the main commercial centres in Hambantota district?
7. Where are the main markets in Hambantota district?
8. How does the accessibility to markets affect the people in Hambantota district?
9. How does the accessibility to commercial centres affect the people in Hambantota district?
10. How does the accessibility to good schools affect the people in Hambantota district?
11. How does the accessibility to hospitals affect the people in Hambantota district?
12. How does the remoteness from Colombo affect Hambantota district?
13. What is the mean travel speed on tracks in Hambantota district?
14. What is the mean travel speed on secondary roads in Hambantota district?
15. What is the mean travel speed on primary roads in Hambantota district?

Appendix 3.

Village Questionnaire

1. What is your profession?

   IF Farmer

   1.1 What do you produce?

   1.2 How much land do you use, owned and rented?

2. Do you own a motor vehicle (what, which)?

   2.1 Can you lend or hire a motor vehicle (what, which)?

3. How big part of your produce do you sell on markets yourself?

   IF not 0

   3.1 Which market do you visit the most to sell your produce?

   3.2 Why do you visit that market to sell your produce?

   3.3 How do you travel to the market to sell your produce?

   3.4 How long time does it take to travel to the market and back to sell your produce?

      3.4.1 How long time does it take to travel to the market during the rainy season?

   3.5 Is it expensive to travel to the market and back to sell your produce?

   3.6 What is the distance to the market (one way)?

   3.7 Do you know of any better market for selling your produce, which?

      IF Yes

      3.7.1 Why don't you visit the better market the most to sell your produce?

      3.7.2 How long time does it take to travel to the better market and back to sell your produce?

      3.7.3 Is it more expensive to travel to the better market and back to sell your produce, instead of travelling to the most used market?

      3.7.4 What is the distance to the better market (one way)?

4. How big part of your produce do you sell to a middleman?

4.1 Why do/don't you sell to a middleman?

4.2 *IF not accounted for;* What do you do with the rest of your produce?

5. Where do you go to visit a hospital?

5.1 How do you travel to the hospital?

5.2 How long time does it take to travel to the hospital and back (travel time only)?

5.3 Is it expensive to travel to the hospital and back?

5.4 What is the distance to the hospital (one way)?

6. Do you feel that you have access to good schools (distance, time and travel cost)?

7. Do you want to move from this village?

7.1 Why do/don't you want to move from this village?

IF Yes

7.2 What would you value the most if you could move your house and your land to a new area?

8. How often do you visit an urban area per week?

9. How many manufacturing companies are there in your village?

IF 0

Why do you think there aren't any manufacturing companies in your village?

10. What do you think about the public transportation system, is it:
More than enough, enough, not enough or far from enough?

11. When is the main wet season?

12. How does the wet season affect the roads?

13. Which roads does the wet season affect?

14. Does the wet season affect all roads of the same type the same?

15. What is the biggest transportation problem for you, is it:
Distances, lack of facilities or bad road conditions?

Appendix 4.

Questionnaire

Village name ……………………………………………………………………………. Household number…..

Number of households in village…………….. Village main occupation……………………..............................

Name of person conducting the survey *(your name)*…………………………………………………………….

In all questions, YOU refer to the whole household, not just the person being interviewed

1. What is your households main profession or source of income?________________________
(e.g. Paddy farmers)

2. Do you, or someone in your household, own a motor vehicle, what/which?_____________
(LM – Land master, 3W – 3 wheeler)

2.1 Can you, or someone in your household, rent or hire a motor vehicle *(yes/no)*?________

3. *IF FARMER OR PRODUCER:* How big part of your produce that you sell, do you sell on markets yourself *(also to middlemen at the market)* (%)?_______________________________

3.1 Which market do you most often visit to <u>sell your produce</u>?_______________________

3.1.1 Do you mostly sell as wholesale (yes/no)?_________________________________
(If yes: double check that 3.1 is a wholesale market)

3.1.2 What is the ONE WAY distance to market (3.1) *(state unit!)*?________________

3.2 How do you mainly travel to the market to <u>sell your produce</u>?_____________________
(e.g. Buss, LM)

3.3 How long time does it take to travel to the market in (3.1) ONE WAY with the mean mentioned in (3.2) in DRY season to <u>sell your produce</u> *(state unit!)*?__________________

3.3.1 Same as (3.3) but in WET season?_______________________________________

3.4 How long time does it take to travel to the market (3.1) ONE WAY with a LM to <u>sell your produce</u> in DRY season *(state unit!)*?____

3.4.1 Same as (3.4) but in WET season?_______________________________________

3.5 From which position do you specify travelling time and distance to the market in (3.1) *(e.g. from home, field, main road)*?____

3.5.1 How long time does it take to travel to the position mentioned in (3.5) from the village in DRY season when selling your produce *(state unit!)*?___________________

3.5.1.1 Same as (3.5.1) but in WET season?_______________________________

3.5.2 What is the distance from the village to the position mentioned in (3.5) *(state unit!)*____

3.6 How often do you visit market (3.1) to sell your produce *(state unit!)*?______________

4. *IF FARMER OR PRODUCER:* How big part of your produce that you sell, do you sell to a middleman (%)?____

4.1 Where do you sell to the middle man?____
(e.g. home, main road, field)

5. Where do you most often go to visit a market to <u>buy goods</u>?_________________________
(even if not farmer or producer)

5.1 What is the ONE WAY distance to the market in (5) <u>from the village</u> *(state unit!)*?____

5.2 How do you mainly travel to market in (5) to <u>buy goods</u>?________________________
(e.g. LM, buss, 3W)

5.2.1 What is the cost of travelling to the market in (5) ONE WAY with the mean in (5.2) to <u>buy goods, from the village</u> *(rupees)*?________________________________

5.2.2 How long time does it take to travel to market in (5) ONE WAY with the mean in (5.2) in DRY season, <u>from the village</u> *(state unit!)*?_________________________

5.2.2.1 Same as (5.2.2) but in WET season?_____________________________

5.3 How long time does it take to travel to market (5) ONE WAY with a LM in DRY season, <u>from the village</u> *(state unit!)*?____

5.3.1 Same as (5.2) but in WET season?_____________________________________

6. Where do you, or someone in your household, most often go to visit a hospital?____

6.1 How do you mainly travel to the hospital in (6)?________________________________

6.2 What is the distance ONE WAY to the hospital in (6), from the village *(state unit!)*?____

6.3 How long time does it take to travel ONE WAY with the mean in (6.1) to the hospital in (6) in DRY season, from the village *(state unit!)*?________________________________

6.3.1 Same as (6.3) but in WET season?_______________________________________

6.4 What is the cost of travelling to the hospital in (6) ONE WAY, from the village *(Rupees)*?____

7. Where do you, or someone in your household, most often go to visit a town?____________

____

7.1 How often do you, or someone in your household, normally visit an town per week?____

7.2 How do you, or someone in your household, mainly travel to the town in (7)?________

____

(e.g. buss, LM, foot cycle)

7.3 How long time does it take to travel to the town in (7) ONE WAY with the mean in (7.2) in DRY season, from the village *(state unit!)*?_________________________________

7.3.1 Same as (7.3) but in WET season?_______________________________________

7.4 What is the ONE WAY distance to the town in (7) from the village *(state unit!)*?______

____

8. What is the biggest transportation problem for your household? *(encircle the answer)*

Distances

Lack of transport facilities

Bad road conditions

Other_______________

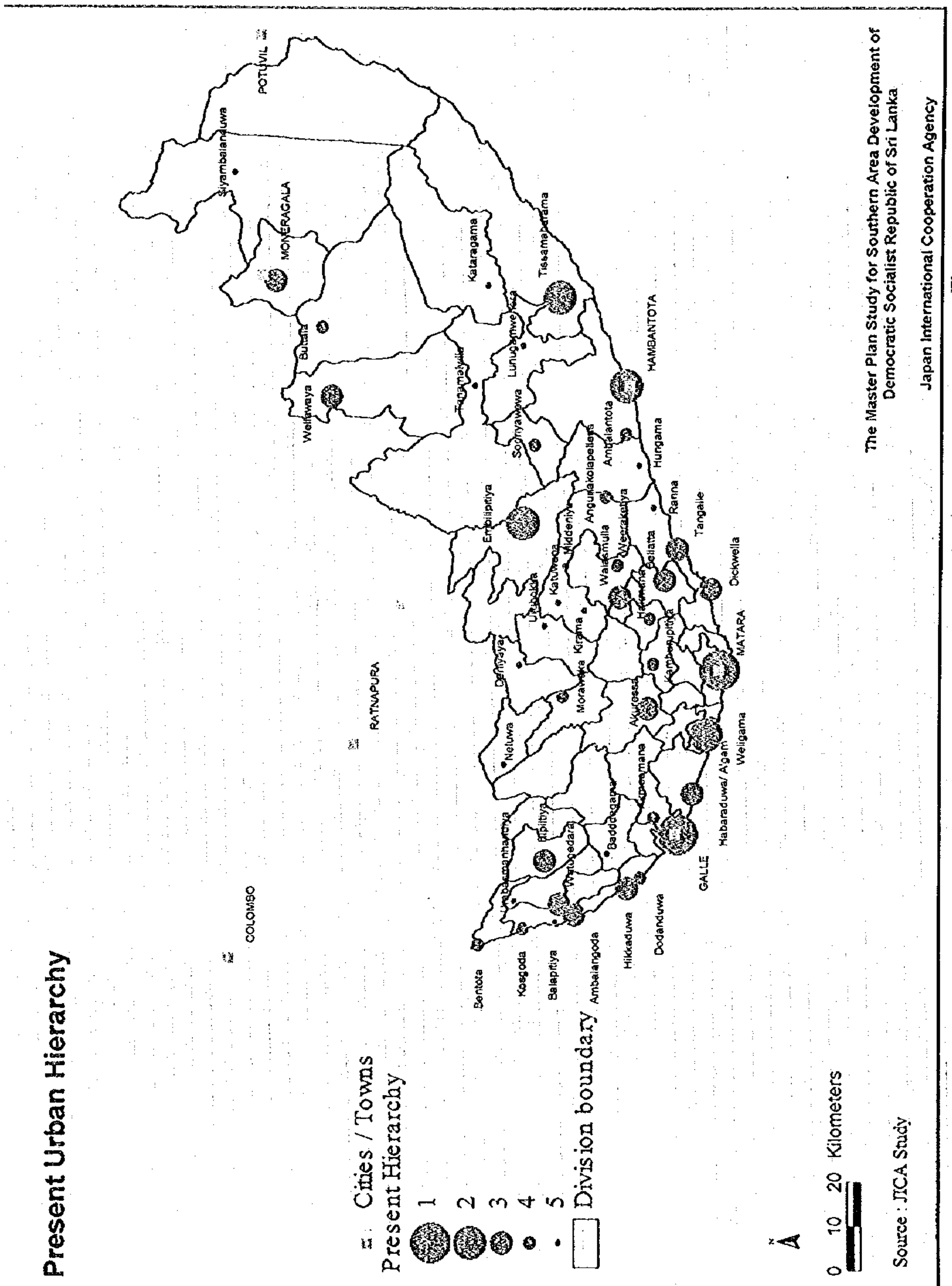
9. Remarks:

Appendix 5.

```
% SPEED

% Written by Anders Ahlström. 2007-11-15

clear all

% The travel time matrix constitutes of respondents travelling time and
% measured distances for three road classes
% Matrix=[minutes primaryKM secondaryKM TrackKM; minutes primaryKM... ...]

Matrix=[ ];

%Gives the total number of lines in the Matrix
no=size(Matrix);
no=no(1);


%Keeps track of how many lines are used in the calculations
noUsed=0;

limit=100; %Max mean speed
lowerlimit=0; %Min mean speed

error=0;
MinError=Inf;
prim=inf;
sec=inf;
tra=inf;
step=0.5;
noUsed=0;

for track=1:step:100

    for secondary=track:step:100

        for primary=secondary:step:100

            error=0;
            for i=1:no

                %Tests if the mean speed of the journey is within the given
                %boundaries. If it is, the journey will be used in the speed
                %estimations. Otherwise, the journey will not be used.

               if ((Matrix(i,2) + Matrix(i,3) + Matrix(i,4))/1000)/...
                  ((Matrix(i,1)/60)) < limit & ((Matrix(i,2) + Matrix(i,3)...
                  + Matrix(i,4))/1000)/((Matrix(i,1)/60)) > lowerlimit

                   %This part calculates the accumulative error. It is
                   %important to calculate the absolute values for each
                   %journey. If total numbers were used for all journeys,
                   %the calculated travel times errors over the given and
                   %the calculated travel times errors below the given
                   %travel time will to some extent when summarizing them
                   %remove some of the total error.

                   error=error+ abs( ( (Matrix(i,1)) ) - ( ( ((Matrix(i,2)/...
                   (1000*primary))*60) + ((Matrix(i,3)/(1000*secondary))*60)...
                   + ((Matrix(i,4)/(1000*track))*60) ) ) );

               end

            end

           %Tests if the error is smaller than the smallest so far
           %registered error. if the error is the smallest so far, the road
           %speeds are updated with the so far best fit value. When all
           %road speed combinations have been tested, the best fit values
           %have been found

           if error < MinError % There is not two solutions with the same error
```

```
                MinError=error;
                prim=primary;
                sec=secondary;
                tra=track;
            end

        end

    end

end


% Calculates the percentual error of the calculations
totmin=0;
for i=1:no
    if ((Matrix(i,2) + Matrix(i,3) + Matrix(i,4))/1000)/...
       ((Matrix(i,1)/60)) < limit & ((Matrix(i,2) + Matrix(i,3)...
       + Matrix(i,4))/1000)/((Matrix(i,1)/60)) > lowerlimit

            totmin=totmin+Matrix(i,1);

            noUsed=noUsed+1;

    end
end

percentualError=(MinError/totmin)*100;

% Calculates the total length for every road class
primLength=0;
secLength=0;
trackLength=0;

for i=1:no
    if ((Matrix(i,2) + Matrix(i,3) + Matrix(i,4))/1000)/...
       ((Matrix(i,1)/60)) < limit & ((Matrix(i,2) + Matrix(i,3)...
       + Matrix(i,4))/1000)/((Matrix(i,1)/60)) > lowerlimit

           primLength = primLength + Matrix(i,2);
           secLength = secLength + Matrix(i,3);
           trackLength = trackLength + Matrix(i,4);

    end
end

totLength=primLength+secLength+trackLength;
prim_percent=(primLength/totLength)*100;
sec_percent=(secLength/totLength)*100;
track_percent=(trackLength/totLength)*100;


% Prints the values
no
noUsed
MinError
percentualError
prim
sec
tra
prim_percent
sec_percent
track_percent
```

Appendix 6.



Present Urban Hierarchy
Cities / Towns
Present Hierarchy
1
2
3
4
5
Division boundary
0 10 20 Kilometers
Source : JICA Study
COLOMBO
RATNAPURA
MONERAGALA
HAMBANTOTA
MATARA
GALLE
POTUVIL
Siyambalanduwa
Kataragama
Tissamaharama
Buttala
Wellawaya
Sooriyawewa
Ambalantota
Hungama
Ranna
Tangalle
Dickwella
Weligama
Habaraduwa/ A'gama
Embilipitiya
Neluwa
Akuressa
Morawaka
Kirama
Deniyaya
Urubokka
Beliatta
Walasmulla
Weeraketiya
Middeniya
Angunakolapelessa
Kamburupitiya
Hikkaduwa
Dodanduwa
Ambalangoda
Balapitiya
Kosgoda
Bentota
Elpitiya
Baddegama
Imaduwa
The Master Plan Study for Southern Area Development of Democratic Socialist Republic of Sri Lanka
Japan International Cooperation Agency
Figure :

Appendix 7.

MatLab program for finding and saving the lowest estimated accessibility value for each GN-division. The example below is written for estimated accessibility to towns with bus.

```
town_bus_matrix=(INPUT_TABLE);

for i = 1:583
    lagstaAccess = 10000;
    for j=1:length(town_bus_matrix)
        if town_bus_matrix(j,1) == i && town_bus_matrix(j,2) < lagstaAccess
           TOWN_BUS_GN_result(i,2)=town_bus_matrix(j,2);
           TOWN_BUS_GN_result(i,1)=town_bus_matrix(j,1);
           lagstaAccess=town_bus_matrix(j,2);
        end
    end
end


TOWN_BUS_GN_result
```

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