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Promoting Sustainable Rural Access and Developing a Risk Based Vulnerability Assessment for Rural Communities in the Changing Climate of Sub Saharan Africa

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Literature Review (final)

Report No HGL 02

March 2014

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Promoting Sustainable Rural Access and Developing a Risk Based Vulnerability Assessment for Rural Communities in the Changing Climate of Sub Saharan Africa

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This project was funded by the Africa Community Access Programme (AFCAP) which promotes safe and sustainable access to markets, healthcare, education, employment and social and political networks for rural communities in Africa.

Launched in June 2008 and managed by Crown Agents, the five year-long, UK government (DFID) funded project, supports research and knowledge sharing between participating countries to enhance the uptake of low cost, proven solutions for rural access that maximise the use of local resources.

The programme is currently active in Ethiopia, Kenya, Ghana, Malawi, Mozambique, Tanzania, Zambia, South Africa, Democratic Republic of Congo and South Sudan and is developing relationships with a number of other countries and regional organisations across Africa.

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1. INTRODUCTION

This literature review has been undertaken during the initial phase of a short research study to investigate the relationships between climate variability and projected climate change and the performance of rural roads in the region of Sub-Saharan Africa (SSA). The purpose of the study is to assess what effects these relationships might have on rural community livelihood and is based on the premise that an increase in the intensity of geo-hazards[1] brought about by climate change and an increase in climate extremes will adversely affect rural access (Project Inception Report Jan 2014).

The following extracts summarise the situation with regard to the intensity of geo-hazards globally and in the context of climate variability and climate change effects on rural access in the SSA region.

''Human activities, especially in the last two centuries, have had a huge impact on the environment and landscape through industrialisation and land-use change, leading to climate change, deforestation, desertification, land degradation, and air and water pollution. These impacts are strongly linked to the occurrence of geomorphological hazards, such as floods, landslides, snow avalanches, soil erosion, and others'' (Alcantara-Ayala and Goudie 2010).

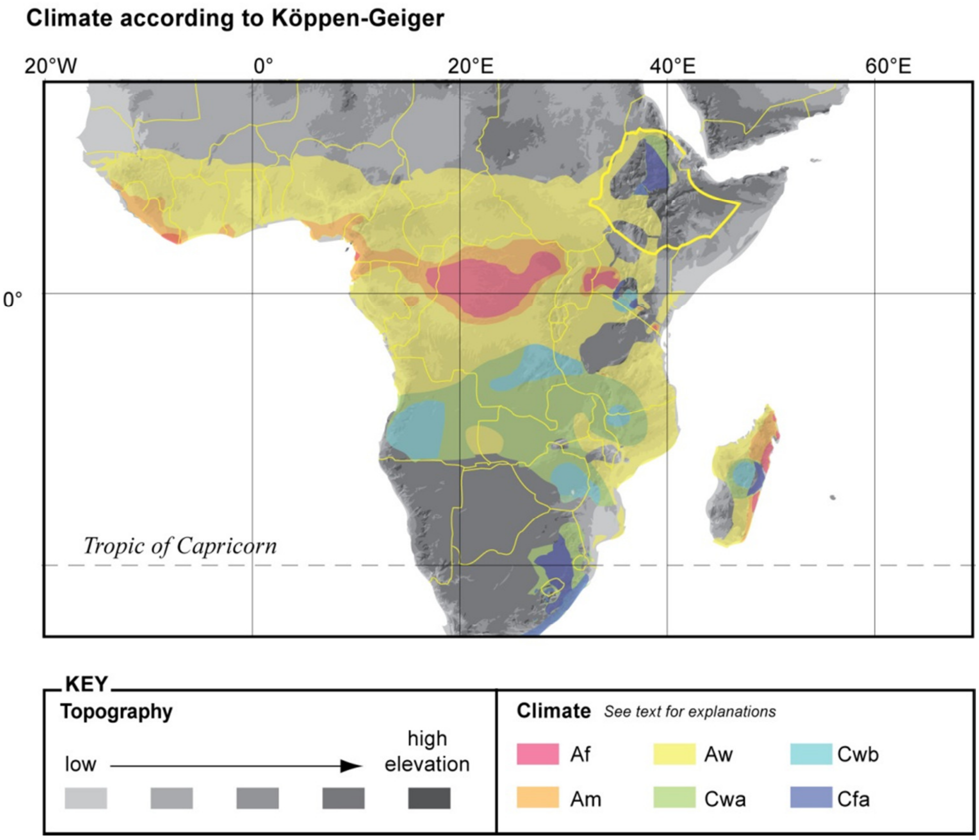
''The frequency and intensity of extreme weather in Africa is predicted to increase as a result of climate change. The impacts on a continent in which 333 million people already live in extreme poverty threaten to be devastating…If no action is taken to help developing countries adapt and plan for the future, climate change threatens to undermine development gains made over the past few decades… Substantial new investments are required, for example to build infrastructure that is better able to withstand flooding or to improve irrigation to make agriculture less vulnerable to drought'' (DFID 2010).

''(With respect to climate change) Africa is especially vulnerable, as evidenced by the impacts of current climate variability and weather extremes such as floods, droughts, and storms, which severely affect economic performance, food security, livelihoods of the poor, and key assets including natural resources as well as transport infrastructure (roads, bridges, airports, ports), energy infrastructure (including hydropower and thermal plants and transmission and distribution systems), water and sanitation systems, and coastal defenses'' (AfDB 2008).

Sub-Saharan Africa lies to the south of the Sahara Desert. Geographically, it therefore includes the Sahel which occupies a west-east belt, up to 1,000km wide, from Senegal in the west to Eritrea in the east between the latitudes of approximately 10^{o}N and 15^{o}N. According to the Koppen classification the Sahel has a semi-arid B(S) climate, and is therefore part of the same dry climate classification that includes the Sahara Desert B(W). The horn of Africa (Djibouti, Somalia and eastern Ethiopia) and southwest Africa (southern Angola, most of Botswana and South Africa and all of Namibia) also fall into the B(W) and B(S) climatic zone. The remainder of the region experiences either C or A climates corresponding to Temperate Warm Humid or Tropical Humid conditions. It is these humid climate zones that are the main focus of this study, as shown on Figure 1, and they include those countries that form the core of the DFID-sponsored African Community Access Programme, namely Ethiopia, Kenya, Malawi, Mozambique, Tanzania, South Sudan and DR Congo.

[1] Geo-hazards here are taken to include, *inter alia*, landslides, erosion, flooding, sedimentation, wind-blown sand, changes to sub-soil water regime and soil stability

Figure 1: Distribution of climate zones in SSA (from Hearn 2011)



Af – equatorial, fully humid

Am – equatorial, monsoonal

Aw – equatorial, winter dry season

Cwa – warm temperate, winter dry, hot, wet summer

Cwb – warm temperate, winter dry, warm, wet summer.

Despite the focus of this study on countries within the humid zone of SSA, the region remains too large to cover in any detail during the programme of this study. Consequently, it was decided to concentrate on the countries of Ethiopia and Uganda in order to illustrate the relevant issues. Ethiopia has a varied climate and topography, a rapidly expanding road network and a rural population of in excess of 80% of the nation's total (compared to that of 70% for SSA as a whole (World Bank)). Uganda also has a high rural population and a high incidence of climate-related geo-hazards.

This review is divided into five sections:

i) climate variability and climate change in SSA, and Ethiopia and Uganda in particular

ii) the effects of climate variability and climate change on geo-hazards

iii) the ability of rural roads and other forms of rural access to accommodate these geo-hazards

iv) the impacts that a potential reduction in rural access serviceability might have on rural community livelihood and gender issues.

2. CLIMATE CHANGE AND CLIMATE VARIABILITY

Climate comprises the averages of weather elements (such as rainfall and temperature) over a given area during a given period of time, usually the period of record. Climate change has been the rule rather than the exception over geological time, and especially during the Quaternary period (last 2.6 million years) when glacial and interglacial episodes in the higher latitudes and pluvial and interpluvial episodes in the lower latitudes (including Africa) had a marked influence on landscapes, land cover and geo-hazards (Goudie 2010, McGuire 2013). There have been important climate variations that have occurred during the last 10,000 years with recognisable sequences of cool-wet and warm-dry periods. Even shorter periods of climate change, lasting 100 years or more, have also taken place and have been manifested in the higher latitudes through increased debris flow and avalanche activity. These events are likely to be associated with sunspot cycles, transient patterns in atmospheric oscillations and possibly volcanic eruptions (see discussion in Lee and Fookes (2005). Fluctuations over even shorter periods, for example in the form of annual or decadal sequences of heavy rain or droughts, may be associated more with variability within longer climate cycles rather than the result of climate change *per se*. Consequently, difficulty usually occurs in differentiating between fluctuations and extremes that occur within the existing climate and those that indicate a trend towards a changing climate regime. Meteorological records in many parts of the world, including Africa, are often too short and/or too unreliable to allow apparent extreme events to be attributed confidently to either climate variability or climate change.

This review summarises the observed climate change and variability in SSA and the anticipated direction of climate change in the future. Ethiopia and Uganda are used as illustrations. It does not examine the reasons for climate change or the interventions required to avert the process.

2.1 Recent Trends in Climate Change and Climate Variability in SSA

There has been a gradual warming of the African continent since the 1960s, though this warming has not been uniform (Christensen et al 2007). Rates of between 0.1 and 0.3^{o}C per decade are reported by these authors while Stockler et al (2013) (see below) report approximate temperature rises of 1^{o}C between 1900 and 2005 for both west and east Africa. With regard to annual rainfall a review of published information by Christensen et al (2007) indicates a general decline in West Africa since the 1960s, including decreases of between 20 and 40% between 1931 and 1960 and between 1968 and 1990. Ojo et al (2003) report significant temporal and spatial variations in rainfall in West Africa, though there has been an overall downward trend resulting in water deficits and droughts. By contrast a 10% increase in rainfall has been recorded during the last 30 years along the Guinean coast, according to the same authors. In East Africa, southern areas have experienced a reduction in rainfall, while northern areas have experienced an increase (Christensen et al 2007). Increased annual variability in rainfall has been recorded since the 1970s with higher rainfall anomalies and greater periods of widespread and intense drought. Changes to the seasonality of rainfall have also been observed, and in Angola, Malawi, Namibia, Zambia and Mozambique a significant increase in heavy rainfall events have been recorded (Christensen et al 2007).

Table 1 summarises the trends in temperature and annual rainfall between 1960 and 2006 for a number of countries in SSA. The table has been developed from summary data contained in the various UNDP Climate Change Country Profiles produced by McSweeney et al (2010). These key data are derived from a subset of 15 of the 22 models used by the IPCC for its Fourth Assessment Report (2007). The table confirms the range of recorded temperature rise across the region and indicates an overall decrease in annual rainfall in most countries. There is generally a lack of data to indicate whether annual rainfall has changed in its intensity, though some seasonal changes have occurred, and higher seasonality may have resulted in higher intensity rains of shorter duration. The highest recorded reductions in annual rainfall have occurred in Gabon, Equatorial Guinea and Nigeria, occupying the tropical zone of West Africa, as reported by Christensen et al (2007). There is no evidence of increasing annual rainfall over the assessment period, though seasonal, decadal and geographical variations occur within individual country records, and these may contain rainfall increases not reflected in the annual average for each country.

2.2 Future Climate Change Predictions in SSA

2.2.1 Temperature

The prediction of global trends in climate change is subject to significant debate and uncertainty, and the prognoses for regional change are even more varied and uncertain (Liggins et al 2010, Levine et al 2011). Average annual and seasonal temperatures in Africa are considered likely to increase at a higher rate this century than the global average (Ringler et al 2011). However, as with recent past climate variations, there are likely to be significant regional variations. Christensen et al (2007), for example, note that the drier sub-tropical regions of Africa are likely to warm more than the moister tropics. Table 1 shows the predicted average annual temperature change for countries in SSA by 2060 and 2090, corresponding to a maximum rate of increase of approximately 0.5^{o}C per decade.

The Working Group 1 Contribution to the Fifth Assessment Report of the IPCC (Stocker et al 2013) provides an Atlas of Global and Regional Climate Predictions in its Annex 1. For the middle of the range greenhouse gas concentration scenario (RCP 4.5) and the median percentile range of model predictions there is a predicted 2-4^{o}C increase in both winter and summer temperatures over the period between 2005 and 2100 for both west and east Africa when compared to the reference period of 1985 to 2005.

2.2.2 Rainfall

Climate change predictions for rainfall in Sub-Saharan Africa are very variable. Conway et al (2009) note that there are low to medium levels of confidence in rainfall predictions due to the scarcity of studies and observational data. Christensen et al (2007) suggest that the subtropics of Africa will become drier while the tropics will become wetter. The intensity of extreme weather is also predicted to increase, with the result that an increased rainfall intensity seems likely. Table 1 shows that the extent of annual rainfall falling as heavy rain is anticipated to increase by between 10 and 20% by 2090. The table also illustrates the wide range in predicted annual rainfall change across the region between the various models used. These predictions range by 50%, though the overall consensus is for increased annual rainfall. For some countries a median or mean prediction range is quoted and, with the exception of Angola (with a desert or semi-arid climate), these increases range from +1% to +14%.

Table 2 gives a very broad indication as to how future climate change is anticipated to affect the various countries in the SSA. Countries in the Sahel (Senegal, Burkino Faso, Mali, Niger, Chad, Mauritania, parts of Sudan and the Gambia) are excluded from the table due to forecasting uncertainties. The table indicates that those countries in southwest and central southern Africa, that already experience dry climates (see below), will experience an overall reduction in rainfall while the countries that form the Horn of Africa and the neighbouring region will experience some of the greatest increases in rainfall.

Table 1: Past and predicted climate changes in SSA (data from McSweeney et al 2010, excludes Sahel)

Country	**1960-2006 Climate Change**		**Predicted Future Climate Change**			
	Temperature change (^{o}C/decade)	Rainfall change (mm/decade)	Average annual temperature change (^{o}C)		Mean annual rainfall change by 2090 (%)	
			By 2060	By 2090	Average	Proportion of annual rainfall falling as heavy[1] rain
Angola	+0.33	-24	+1.2-3.2	+1.7-5.1	(-)27-(+)20 Median -1-(-)6	Predicted to increase, no figures
Benin	+0.24	No long term trend	+1.0-3.0	+1.5-5.1	Too wide a range of predictions for annual trend. Overall decrease in JFM[2] and AMJ[2] and increase in JAS[2] and OND[2]	No data available
Equatorial Guinea	+0.14	-44	+0.9-2.5	+1.3-4.1	(-)6-(+)20 Mean (+)1-4	Up to +12
Ethiopia	+0.28	No significant trend	+1.1-3.1	+1.5-5.0	Increase, though ann average unavailable. OND rainfall to increase by 10-70	Up to +18
Gabon	+0.14	-46	+0.9-2.5	+1.3-4.1	(-)22-(+)25 Median +/-1	Up to +11
Ghana	+0.21	-29, though long term trend uncertain	+1.0-3.0	+1.5-5.2	No consensus	General increase but no data available
Guinea	+0.18	Decline, not annual data available	+1.1-3.0	+1.6-5.3	Wide range, no data available, but decline	No data available
Malawi	+0.21	No significant trend	+1.1-3.0	+1.6-5.3	(-)13-(+)32	Up to +19
Kenya	+0.21	No significant trend	+1.0-2.8	+1.3-4.5	(-)1-(+)48	Up to +13
Liberia	+0.18	Overall decrease but no consistent trend	+0.9-2.6	+1.4-4.7	Increase, but no annual figures available. JAS (-)15-(+)23 OND (-)12-(+)32	Increase, but no data available
Mozambique	+0.13	-30	+1-2.8	+1.4-4.6	No substantial change; increase in wet season offset by dry season increase	Up to +15
Nigeria	+0.18	-42	+1.1-2.5	+1.4-4.6	(-)18-(+)17	Up to +13
Tanzania	+0.23	-34	+1.0-2.7	+1.5-4.5	(-)4-(+)30 Median (+)7-14	Up to +14
Uganda	+0.28	-41	+1.0-3.1	+1.4-4.9	(-)8-(+)46 Median (+)7-11	Up to +15
Zambia	+0.29	-23	+1.2-3.4	+1.6-5.5	No substantial change; decrease in SON rainfall and increase in DJF rainfall	No data available

[1]Heavy rain is defined by McSweeney et al (2010) as *a daily rainfall total which exceeds the threshold that is exceeded on 5% of rainy days in* (the current climate) *of that region and season*

[2]JFM – January, February, March; AMJ – April, May, June; JAS – July, August, September; OND – October, November, December

Table 2: SSA Country exposure to Climate Change (World Bank 2008)

Level of Change	Wetter Climate	Drier Climate	Increased Frequency of Cyclones
Highest Change	Kenya	Botswana	Mozambique
	Eritrea	Namibia	Madagascar
	Somalia	Lesotho	Mauritius
	Sudan (eastern)	Angola (southern)	Comoros
	Ethiopia	Zambia	
	Angola (northern)	Zimbabwe	
Moderate Change	Guinea	Guinea-Bissau	
	Gabon	South Africa (west)	
	Congo		
	Burundi		
	Rwanda		
	Uganda		
	Tanzania		
	Mozambique		
	Malawi		
	South Africa (east)		
Lowest Change	Nigeria		
	Central African Republic		
	DR Congo		

For the middle of the range greenhouse gas concentration scenario (RCP 4.5) and the median percentile range of model predictions, October – March rainfall for west and east Africa is expected to increase by between 0-10% between 2005 and 2100 with large areas showing no anticipated change beyond the current (1985-2005) levels of variability (Stockler 2013). Parts of the horn of Africa are predicted to experience 10-20% increases in winter rain, with very localised areas reaching 20-30%. For April to September rainfall, anticipated changes range between -10% and +10%, again with large areas showing no significant change above current variability. No information is given in the Working Group 1 contribution to the Fifth Assessment report for predicted average annual changes.

To conclude, the recent historical trend of increasing temperature in SSA is expected to continue throughout this century. The trend since 1960 of reducing rainfall is expected to be reversed for countries outside the Sahelian climatic region. Although there is a very wide range in predicted outcomes, the average of predictions suggests that annual rainfall may increase by up to 14% by the end of the century, though the high levels of uncertainty require extreme care when applying these figures. There is general consensus among models that there will be an increase in the 'heaviness' of annual rainfall, manifested in increased seasonal variation and shorter, more intense, rain when it does occur.

2.3 Past and Future Climate Change in Ethiopia

2.3.1 Past Trends

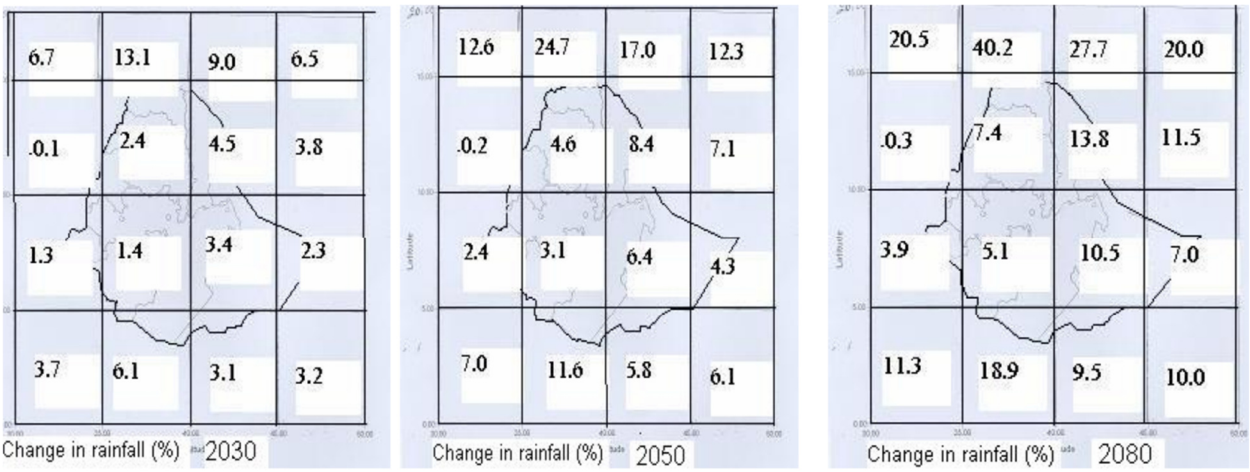
Records of climate change prior to the commencement of meteorological monitoring can be obtained from proxies. A chronology of more than 130 years of tree ring growth has been developed from *Juniperus procera* obtained from multiple sites (Wills et al 2011, Couralet 2005, Eshetu 2006). The tree ring growth chronology from Tigray (Eshetu 2006) suggests that there have been about 22 drought years in northern Ethiopia during the 132 years between 1874 and 2005. This indicates an average cycle of drought every six years and some of these correspond to drought events documented in historical records. Kassa (2008) studied the rainfall variation during the last century from climate archives (stable isotopes and trace elements) of stalagmite from the Mechara Karst (South-Eastern Ethiopia). The Oxygen isotope (^{18}O) and trace element ratios (Sr/Ca, Mg/Ca) in stalagmite growth band chronology were interpreted as proxies for dry spells, and comparison of these proxies with historical records revealed dry spells in 1912-1913, 1921, 1992, 1977-1979, 1983-1984, 1991-1993. These years also corresponded with periods of drought interpreted from tree ring chronology.

The Ethiopia National Meteorological Agency (NMA 2007)) report on climate change adaption describes how average annual temperatures have increased by about 0.37^{o}C/decade between 1951 and 2006 while rainfall has been more or less constant. Analysis of climate records between 1950 and 1998 from 42 meteorological stations (Tesfaye 2009) shows a declining trend in rainfall for the northern and southern parts of the country and an increasing trend in the central part. The extreme variability in rainfall is illustrated by annual rainfalls +/- 25% around the mean and in Tigray, for example, where rainfalls 50% above the annual average have been recorded.

2.3.2 Predictions for the Future

The NMA predicts that, using the IPCC mid-range indices, mean annual temperature will increase by 0.9-1.1^{o}C by 2030, 1.7-2.1^{o}C by 2050 and 2.7-3.4^{o}C by 2080, compared to the 1961-1990 average. An approximate increase in annual rainfall is also predicted by the NMA (Figure 2). For the country as a whole this approximates to 2% per decade, though among the greatest increases are predicted for the northeast and south of the country. However, Jury and Funk (2013) predict that the declining rainfall over southwest Ethiopia will continue until 2050, so there remains significant uncertainty in any predicted figures.

Figure 2: Composite (average for 19 GCMs) percentage change in rainfall relative to the 1961-1990 norm for A1B emission scenario (balanced fossil-non-fossil fuel)



Recent climate change and the future prognosis for Ethiopia provided by McSweeney et al (2010) are summarized in Text Box 1. As far as annual rainfall is concerned, compared to the 1970-1990 record, McSweeney et al (2010) predict that by the 2090s average country-wide increases will be 5% under the A1B emission scenario and 9% under the A2 emission scenario for median model predictions. This average increase is made up of significant regional variation, comprising an approximate increase of 240mm per year in the southwest of the country, 120mm per year in the centre and between 0 and 72mm per year in the north and northeast of the country. However, some models predict increases of 350mm per year while others predict reductions of 250mm per year for the same analytical grid cell, thus illustrating the range and uncertainty in predictions.

Box 1: Summary of climate trends and predictions for Ethiopia (McSweeney et al 2010)

Climate trends between 1960-2006

Mean annual temperature has increased by 1.3°C between 1960 and 2006, an average rate of 0.28°C per decade.

The strong inter-annual and inter-decadal variability in Ethiopia's rainfall makes it difficult to detect long-term trends. There is not a statistically significant trend in observed mean rainfall in any season in Ethiopia between 1960 and 2006. Decreases in JAS rainfall observed in the 1980s have shown recovery in the 1990s and 2000s.

Projections to 2090

- The mean annual temperature is projected to increase by 1.1 to 3.1°C by the 2060s, and 1.5 to 5.1°C by the 2090s.
- Projections from different models in the ensemble are broadly consistent in indicating increases in annual rainfall in Ethiopia. These increases are largely a result of increasing rainfall in the 'short' rainfall season (OND) in southern Ethiopia. OND rainfall is projected to change between + 10 and70% as an average over the whole of Ethiopia.
- Percentage increases in OND rainfall in the driest, eastern most parts of Ethiopia

are large.

- Projections of change in the rainy seasons AMJ and JAS which affect the larger portions of Ethiopia are more mixed, but tend towards slight increases in the south west and decreases in the north east.
- The models in the ensemble are broadly consistent in indicating increases in the proportion of total rainfall that falls in 'heavy' events, with annual changes ranging from -1 to +18%.
- The largest increases are seen in JAS and OND rainfall. Model simulations show wide disagreements in projected changes in the amplitude of future El Niño events (Christensen et al 2007). East Africa's seasonal rainfall can be strongly influenced by El Niño Southern Oscillation (ENSO), and this contributes to uncertainty in climate projections, particularly in the future inter-annual variability, for this region

The Ethiopian Roads Authority (ERA) Drainage Design Manual (2013a) has based its assessment of future climate change for flood forecasting purposes on the McSweeney et al (2010) information. The manual states that 'The central estimates of annual changes in precipitation show increases of 3% (B1 emission scenario) to 9% (A2 emission scenario) by the 2090s for Ethiopia as a whole. The upper end of this projection shows this increase could be as much as 42%...The central estimates for rainfall in the 'short' rainfall season (October-November-December) season show increases of between 17 to 36% by the 2090s, but up to 70% at the upper end of the projections'.

In conclusion, there is general agreement that the average annual temperatures in Ethiopia have been increasing at a rate of between 0.25°C and 0.4°C per decade. Most observers indicate no overall trend in rainfall. This is confirmed by Shang et al (2011) with regard to extreme precipitation in the northwest highlands and also by the studies of Tesemma et al (2010) in the Blue Nile basin who report no significant trend in either annual or seasonal rainfall between 1964 and 2003. Jury and Funk (2013) report a similar rise (0.3°C/decade) between 1948 and 2006 and a slight downward trend in annual rainfall in the southwest of the region over the same period. Seleshi and Zanke (2004), using 1965-2002 data, report that for central northern and northwest Ethiopia there has been no change in annual rainfall. They report a decline, however, in JAS rainfall in the east, south and southwest of the country.

For the future, the predictions are less clear due to the wide variation in model estimates and the range in greenhouse gas emission/concentration input scenarios. Temperature is expected to increase, by up to approximately 0.4-0.6°C per decade. Average annual country-wide rainfall is expected to increase, perhaps by up to between 9% (McSweeney et al 2010) and 16% (NMA 2007) by the 2090s (though predictions vary considerably according to emission scenario and model), and a significant amount of this increase may be attributable to increases in OND rainfall and rainfall occurring in the southwest of the country.

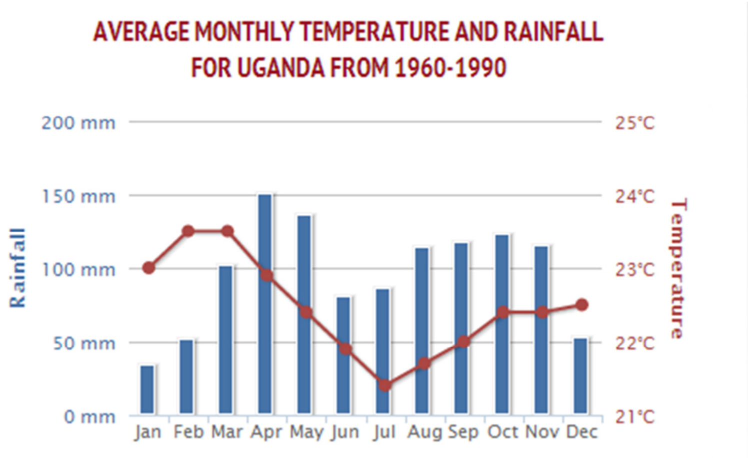
There is expected to be an increase in the intensity of the rainfall, regardless of whether annual totals increase or decrease.

2.4 Past and Future Climate Change in Uganda

2.4.1 Present Climate

Uganda's climate is heavily shaped by its own topography and that of surrounding regions. High mountains along some of its border, an elevated plateau and a number of lakes exert a major influence on its climatic condition (UMS 2014). Generally, the lowlands are warm while the highlands are cool. Accordingly, Uganda is subdivided by the Uganda Metrological Service (UMS) into 16 climatic zones which are usually condensed into 5 regional zones (UMS 2014). These are the North, West Nile, Central, Southwest, and East. The Central and Southwest zones experience a tropical bi-model rainfall pattern with monthly peaks occurring in April (150 mm) and October (125 mm) respectively (Figure 3). The North, West Nile and North East zones experience a uni-model rainfall pattern and a semi-arid climate (World Bank 2014). In the North, West Nile and North East zones rainfall is at its maximum in August with mean monthly rainfall typically between 150 mm – 170mm (World Bank 2014). The historical modelled temperature for Uganda (1960 – 1990) shows distinct average monthly temperature and rainfall variations. February is the hottest month at an average of 23.7°C and July is the coolest month 21.5°C (World Bank 2014).

Figure 3: Average monthly temperature and rainfall for Uganda from 1960 to 1990 (World Bank 2014 online)



Rainfall in Uganda is influenced greatly by the migration of the Inter-Tropical Convergence Zone (ITCZ), the relatively narrow belt of very low pressure and heavy precipitation that forms near the Earth's equator (McSweeney et al, 2010). The position of the ITCZ changes over the course of the year, migrating southwards through Uganda in October to December, and returning northwards in March, April and May. This causes Uganda to experience two distinct wet periods namely; the 'short' rains in October to December and the 'long' rains in March to May. The amount of rainfall received in these seasons is generally between 50-200mm per month but varies greatly, exceeding 300mm per month in some localities. Changes in ITCZ movements are sensitive to variations in the Indian Ocean sea-surface temperatures and vary from year to year leading to variations inter-annually. The El Niño Southern Oscillation (ENSO) has been noted to cause greater than average rainfalls in the short rainfall season (OND), whereas cold phases (La Niña) are associated with a drier than average season.

Uganda's national average maximum temperature is 23.5 °C and an analysis of the climatic zones shows that the Northern and West Nile regions have the highest average maximum daily temperatures of 25.5 °C and 26.8 °C respectively. The average maximum daily temperature in the East is 24 °C, the Central zone is 23 °C whilst the South West zone is the coolest with an average maximum daily temperature of 19.8 °C.

2.4.2 Climate Change

A number of climate change models developed for Uganda are described in the literature for the A2 and B1 emission scenarios. Fifteen of these are available from World Bank (2014 online) and their predictions are summarised by Randall et al (2007). Figures 4 and 5 show the results of a synthesis of a number of these by USAID (2011). There is however some variability amongst the models in predicted levels of both precipitation and temperature for 20 year analysis periods of 2020- 2039, 2040 - 2059, 2060 – 2079 and 2080 – 2099. For the 2020 – 2039 period for example, the ensemble mean rainfall for the peak months of April and November are 150 mm and 205 mm respectively. However, the minimum predictions for April and November are 95 mm and 130 mm respectively while the corresponding maximum predicted precipitation values are 240 mm and 285 mm respectively.

The median projected mean temperatures for the 2020 – 2039 period show an expected increase in temperature for the hot months of January February and March from the average of 32°C for the period 1980 – 1999 to 30 °C (with a minimum predicted value of 28°C and a maximum predicated value of 33^{O}C). In the coolest period (October – December) the median average maximum temperature is 28.5^{o}C, compared to the current average maximum temperature for the three months of 27 °C. The maximum average maximum temperature of the 15 models is 30.5 °C whilst the minimum is 27°C.

Recent climate change and the future prognosis for Uganda provided by McSweeney et al (2010) are summarized in Box 2. As far as rainfall is concerned, McSweeney et al, (2010) noted that observations of rainfall over Uganda show statistically significant decreasing trends in annual and March, April, May (MAM) rainfall. Annual rainfall has decreased at an average rate of 3.4mm per month (3.5%) per decade, but this trend is strongly influenced by particularly high rainfall totals in 1960-61. MAM rainfalls have decreased by 6.0mm (4.7%) per month per decade in this period. Trends in the extreme indices based on daily rainfall data are mixed with no significant trend in the proportion of rainfall occurring in heavy events. The 5-day rainfall maxima show small, non-statistically significant increasing trends in all seasons except June - August when the trend is decreasing.

According to McSweeney et al (2010), the mean annual temperature has increased by 1.3°C since 1960, at an average rate of 0.28°C per decade. This increase in temperature has been most rapid in January – February at a rate of 0.37°C per decade.

Figure 4: Smoothed 1900–2009 March–June and June–September rainfall and air temperature time series for crop-growing regions (USAID, 2011)

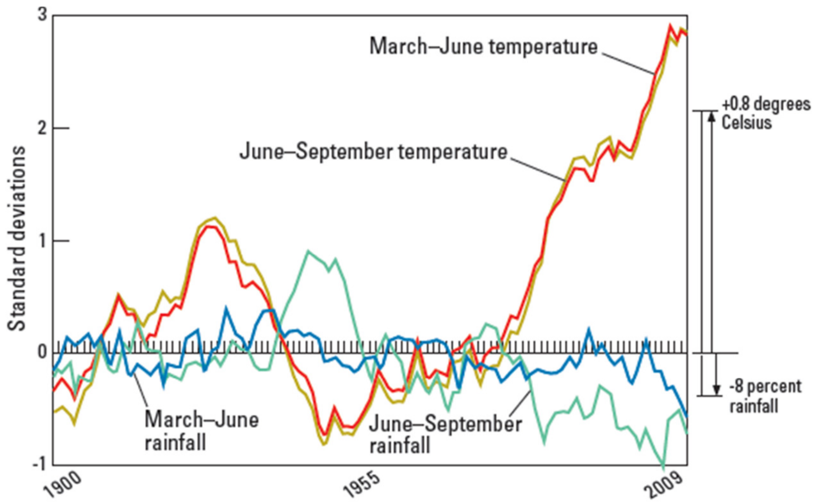
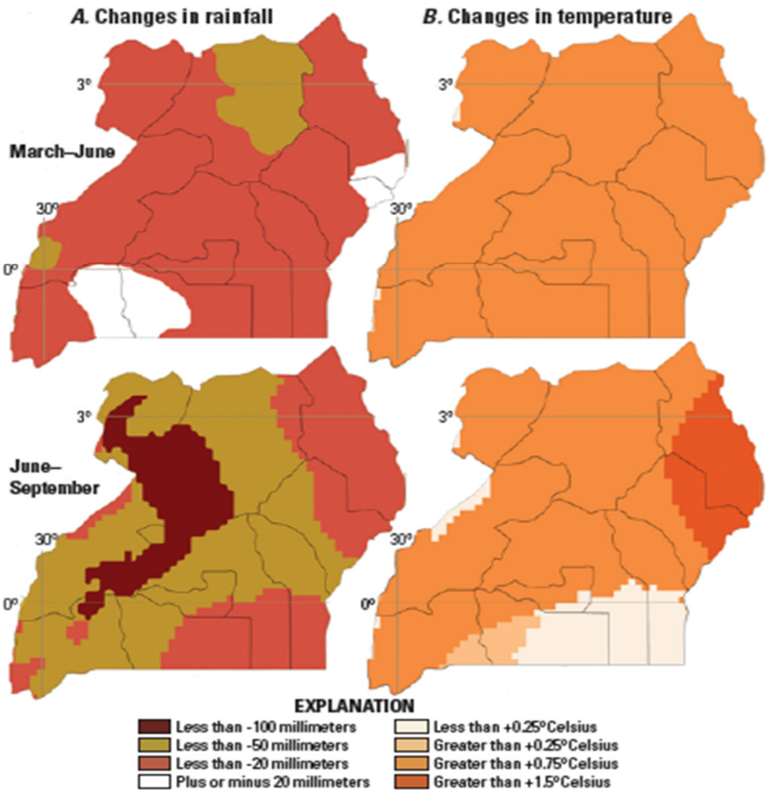


Figure 5: Observed (1960–2009) and projected (2010–2039) changes in March–June and June–September rainfall and temperature (USAID, 2011)



Box 2: Summary of climate trends and predictions for Uganda (McSweeney et al 2010)

Climate trends between 1960 and 2006

Mean annual temperature has increased by 1.3°C between 1960 and 2006, an average rate of 0.28°C per decade.

- Daily temperature observations show significantly increasing trends in the frequency of hot days, and much large increasing trends in the frequency of hot nights.
    - Average number of hot days / year increased by 20%.
        - The rate of increase greatest in July – August (28%)
        - The average number of 'hot' nights per year increased 38%.
        - The rate of increase greatest in July – August (44%)
    - Frequency of cold days has decreased significantly in all seasons except December - January.
        - Frequency of cold nights decreased more rapidly and significantly in all seasons.
        - Average number of cold days per year has decreased by 6%
        - Rate of decrease is most rapid in September – November (7%) over this period.
        - Average number of cold nights per year has decreased by 11%.
        - Rate of decrease is most rapid in December- February (11%).

Observations of rainfall show statistically significant decreasing trends in annual and Mean rainfall.

- Annual rainfall has decreased at an average rate of 3.4mm per month (3.5%) per decade (although it should be noted that this is strongly influenced by particularly high rainfall totals in 1960-61)
- MAM rainfalls have decreased by 6.0mm per month per decade (4.7%).
- There is no significant trend in the proportion of rainfall occurring in heavy events.
- 5-day rainfall maxima show small, non-statistically significant increasing trends in all seasons except for June – August when the trend is decreasing.

Projections to 2090

Temperature

The mean annual temperature is projected to increase by 1.0 to 3.1°C by the 2060s, and 1.4 to 4.9°C by the 2090s.

- Rates of warming predicted to be largest in the coolest seasons (June – September increasing by 1.5 – 5.4°C.

Precipitation

Rainfall is project to increase by up to 46% by 2090s with:

- Increases in proportion of precipitation occurring in heavy events. Up to 15% of annual rainfall is predicted to occur in such events throughout the whole of the country
- Increases in 1 and 5 day rainfall maxima of up to 27 mm in 1 day events and up to 37 mm in 5 day events. The largest increases are predicted to occur in the rainy seasons (March – May; October – December)

3. CLIMATE-RELATED GEO-HAZARDS

3.1 Introduction

The Quaternary Period of the Earth's history (last 2.6 million years) contains irrefutable evidence of the linkage between climate change, geology and geomorphological hazards (for example McGuire 2013). These relate primarily to the mega-geospheric processes of ice advance, ice cap melting, sea level rise and fall, and links between meteorology/hydrology and seismicity/ volcanology, for example. However, it is noted that 'modelling studies and projections of current trends point towards increased risk in relation to a range of geological and geomorphological hazards in a warmer world..' Although Africa is not mentioned at all (and neither is it in a similar publication by Liggins et al 2010) there are important linkages between projected anthropogenic climate change, geomorphological activity and geo-hazard intensity in Africa that have significant implications for rural access in the region.

Geo-hazards that are caused or intensified as a result of climate change or climate extremes in the SSA are summarised in Table 3. This table indicates the level of significance that each geo-hazard category has from a rural roads perspective. Obviously, most of these geo-hazards are topography-dependent and are likely to be more relevant to some parts of the region that others. Further consideration of the capacity of rural roads to accommodate these geo-hazards is given in Section 4.

Table 3: Climate-related geo-hazards and their significance to road construction and operation (refer to the Ethiopian Route Selection Manual (Hearn and Hunt 2013) for explanations of geo-hazards

Climate driver of geo-hazard	Geo-hazard sub-category	Impact type	Significance to rural road construction and operation in SSA		
			Low	Moderate	High
Heavy/ prolonged rain	Direct rainfall/runoff	Surcharge of side drains	✓		
		Raised water tables and surface ponding		✓	
		Raised water tables induce collapse in meta-stable soil structures	✓		
	Flooding in streams and rivers	Surcharge of drainage crossings	✓		
		Flood plain inundation		✓	
		Embankment overtopping		✓	
	Erosion	Slope erosion	✓		
		Scour in stream channels	✓		
		Scour beneath culverts		✓	
		Scour of embankments		✓	
		Erosion/scour contributes significant quantities of sediment to drainage system			✓
		Erosion in streams and rivers triggers landslides		✓	

Climate driver of geo-hazard	Geo-hazard sub-category	Impact type	Significance to rural road construction and operation in SSA		
			Low	Moderate	High
		Seepage erosion in dispersive soils			
	Sediment transport	Contributes to scour through abrasion		✓	
		Raising of stream and river channel bed levels giving rise to reduced waterway and apparent increased flood stage			✓
		Deposition of debris on fans causing bridge blockage and damage or inundation to other structures		✓	
	Landslides	Rock falls and soil falls in cut slopes and natural slopes	✓		
		Blockage to road due to cut slope/natural slope failure		✓	
		Subsidence/removal of road due to slope failure below		✓	
		Debris flows damage sections of road and drainage crossings	✓		
		Landslides contribute significant quantities of sediment to drainage systems		✓	
Drought	Drying of soils	Desiccation of clay soils causes shrinkage and settlement. May enhance shrink-swell cycles in expansive soils	✓		
	Die-back of vegetation	Increased potential for soil erosion during following rains	✓		
		Increased potential for wind-blown/aeolian hazards	✓		
Increased temperature	Drying out of soils	Desiccation of clay soils causes shrinkage and settlement. May enhance shrink-swell cycles in expansive soils	✓		
	Higher construction material temperatures	Bleeding and melting/softening of asphalt road surfaces	✓		
		Thermal expansion and spalling of concrete	✓		

3.2 Climate Change, Climate Variability, Land Use Change and Geo-Hazards in SSA

From Table 3 it is anticipated that the predicted increments in annual rainfall, and especially the increase in the 'heaviness' or intensity of rainfall when it does occur, will lead to increased flooding, erosion and probably landslide hazards. Some parts of the region may also experience an increase in aeolian hazards, namely dune migration and wind-blown sands. These hazards are discussed in Sections 3.2.1 – 3.2.4.

One of the key hurdles is incomplete datasets in many parts of the world with which to assess climate variability and climate change. Not enough is known of the existing climate to be able to adequately determine the frequency of high magnitude and extreme events within it, plus there is the added factor of land use change which often appears to have the effect of accentuating the effects of climate extremes, primarily through deforestation and changes to drainage patterns. These issues are discussed below in relation to the main geo-hazards identified in Table 3.

3.2.1 Floods and related hazards

Past and present record

Severe flooding in SSA is closely correlated with rainfall events controlled by meteorology. Kundzewicz et al (2013) for example refer to the severe flooding of 2011 in Namibia, Mozambique, Uganda and South Africa that was associated with the El Niño phase of the ENSO (El Niño Southern Oscillation). Korecha and Barnston (2007) describe how rainfall prediction in Ethiopia, for example, is driven by the ENSO. Given the apparent decrease in recorded annual rainfalls between 1960 and 2006 (Section 2.1) and the lack of robust evidence to suggest that rainfall has become more intense over the region during this period, it is not surprising in hydrological terms that major flooding also does not appear to have become more frequent. Di Baldassarre et al (2010) for example found no evidence to suggest that the magnitude of African floods had increased during the 20th century. Nevertheless, some river-specific studies over shorter time-frames would appear to contradict this overview. Descroix et al (2012) for example note that the Niger River's right bank tributaries have experienced a sharp increase in runoff since the 1970s which is attributable to land uses change, and no significant changes are reported to have occurred in the last few decades in terms of monthly amounts or the distribution of rainy events. Cornelissen et al (2013) describe how increases in surface runoff in Benin are probably due more to land use change than to climate change. De La Paix et al (2013) concluded that soil degradation and altered flood risk in Rwanda were a consequence of land use change, and not climate change *per se*. Billi et al (2013) note the increasing threat posed by flash floods in Ethiopia in recent decades. These authors analysed the rainfall records in two areas of the country (Dire Dawa and Kobo-Alamata) and concluded that the increased flash flood frequency was not controlled by climate change but more by land use change and poor drainage management. Similarly, in the Blue Nile basin of Ethiopia Tesemma et al (2010) found significant increases in JAS discharge in the Blue Nile between 1963 and 2003 despite there being no significant trend in seasonal and annual rainfall. Interestingly, Nyssen et al (2004) suggest that changing geomorphology of the Ethiopian highlands in the last 5000 years or so, that had previously been attributed to climate change, might have been associated more with human impact. Vandecasteele et al (2009) however attribute increased landslides, flash floods and severe erosion in the DR Congo in recent decades to a combination of seismicity, land use change and an increasing frequency of large rainstorms.

FDRE (2013) refers to an increase in both floods and droughts in Ethiopia during the last ten years. This document refers to work undertaken by GCAP 2012 (reproduced here as Figure 6) that clearly shows how the incidence of recorded floods has increased across the country between 1990-1999 and 2000-2009.

Discussions with the Ministry of Water, Irrigation and Energy in Addis Ababa led to the observation that apparent increasing flood levels in streams and rivers might be due to the increase in bed levels due to sedimentation rather than increased flood discharges *per se*. Professor Tenalem Ayenew of Addis Ababa University was of the opinion that stream and river base flows had become lower and springs were drying up. There may also have been an increase in the peakedness of stream and river flow due to a more rapid response of runoff to rainfall brought about by changing land use patterns and the effects of concentrated drainage along roads (Figure 7). Increased levels of sediment production as a result of natural (Figure 8), land use and engineering factors (Figure 9) also significantly affect stream and river hydraulics. Combined, these factors lead to higher maximum flood stages for the same rainfall. The consensus of opinion in the literature accessed during this review, and in the discussions held in Addis Ababa with relevant specialists during

February 2014, is that apparent increases in flooding hazard are probably due more to changes in land use than climate change.

Figure 6: Recorded increase in flood events at Woreda level Ethiopia (from FDRE 2013)

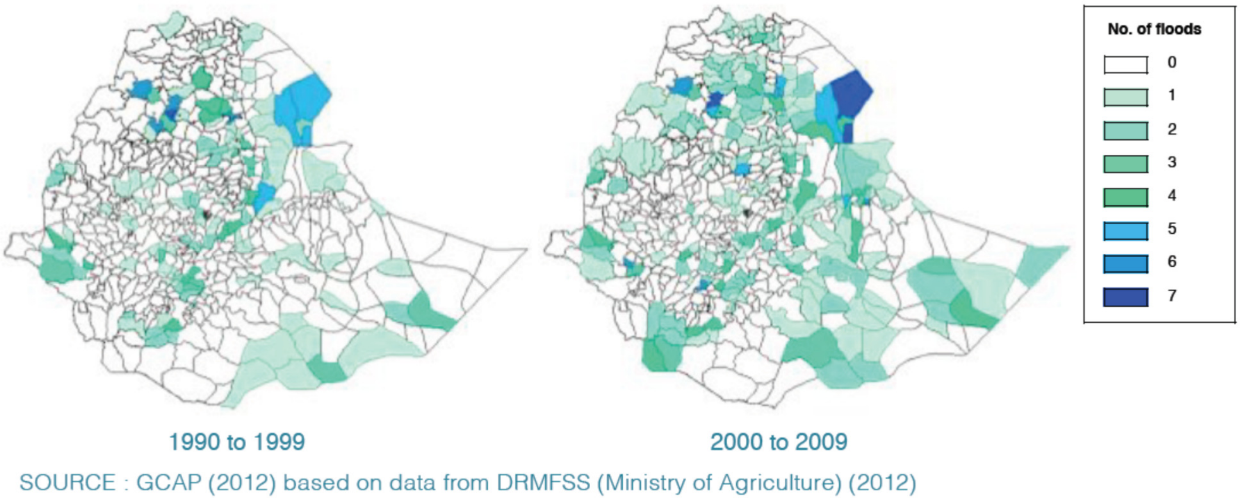


Figure 7: Erosion beneath culvert outlet due purely to road runoff (note lack of stream channel above the road)

Figure 8: Debris fans generated as part of a catchments *natural* degradation

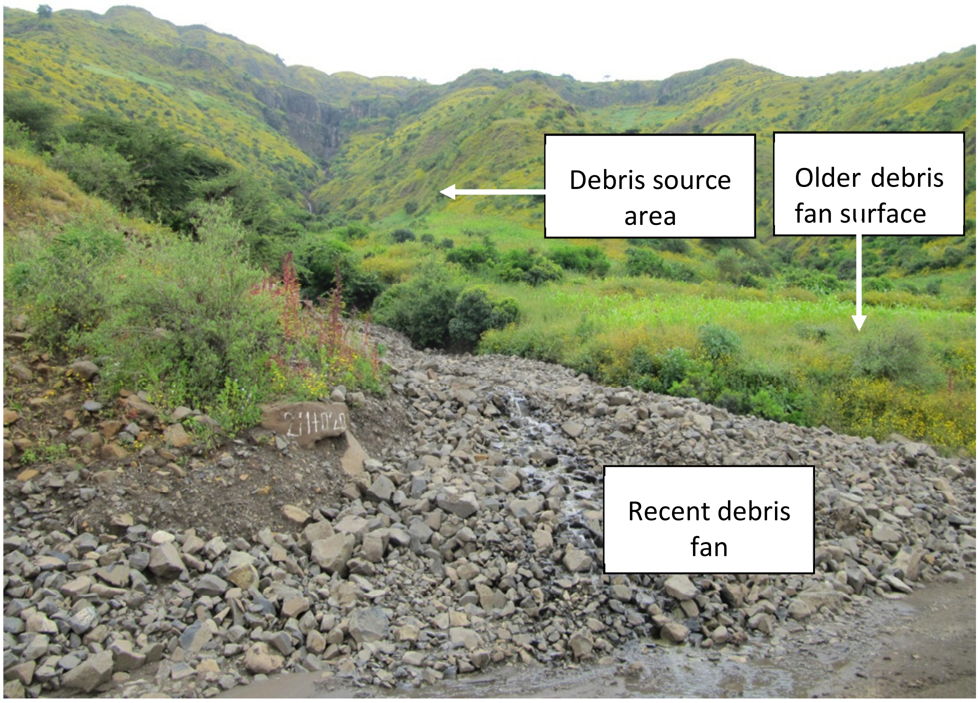


Figure 9: Large quantities of sediment generated by spoil disposal and erosion below roads

Prospects for the future

The projected population increase in SSA of approximately 2% per annum and the drive for rapid expansion of infrastructure in most countries of the region suggests that land use effects may increasingly outweigh those of predicted climate change. The most likely scenario is that a combination of either increasing annual rainfall or increasing variability and extremes of annual rainfall, or both, combined with increased peakedness of runoff response and higher erosion and sediment yields from catchments associated with land use change and engineering works will result in a greater risk posed by flooding and related hazards.

Increased levels of river scour are anticipated to accompany these trends. Furthermore, deposition of entrained sediment in the lower reaches of stream and river channels and on fan surfaces will tend to result in more frequent inundation of neighbouring areas and an increased tendency for uncontrolled runoff.

3.2.2 Landslides and Related Hazards

Past and present record

Landslides are significant hazards in many parts of SSA, and impact a wide range of human resources, including infrastructure and rural roads. Broothaerts et al (2012) for example describe studies undertaken by various authors on landslides affecting Ethiopia, Uganda, Kenya, Rwanda, Tanzania and the DR Congo. Major landslides in Uganda in 2010 and 2012, for example, led to significant loss of life and landslides are a major disruption to road access in that country. In the Gilgel Gibe catchment of southern Ethiopia Broothaerts et al (2012) concluded that landslides can result in the displacement of up to 50 tons/ha/yr of slope material, of which 11 tons/ha/yr finds its way into stream channels, causing sedimentation hazards downstream. These authors identified land use change as a major preconditioning factor in landslide initiation. Rainfall and rainfall thresholds are considered among the most important factors in triggering landslides (see for example Ayalew 1999, Hearn 2011, Hearn and Hart 2011, Broothaerts et al 2012), and therefore any progressive increase in rainfall should lead to an increase in landslide activity. Ayalew (1999) observed that there had been an increase in the number and size of landslides during the last three decades of the 20th century but did not state whether this was due to land use or climate change effects. As far as rainfall is concerned there are essentially two parameters to consider. The first is rainfall intensity which, combined with soil permeability, helps to determine whether transient positive pore water pressures are likely to develop during individual rainstorms, thus triggering (usually shallow) slope movement. The second is the antecedent rainfall that controls the build-up of groundwater and pore pressures within aquifers in slopes over periods of days, weeks or months that eventually trigger (usually deep-seated) slope movement.

Prospects for the future

Vandecasteele et al (2009) attributed landslide activity in the DR Congo to seismicity, climate change (namely higher magnitude and more frequent rainstorms) and land use effects. Seismicity in SSA is mostly confined to the Rift Valley and equatorial West Africa, but rainfall extremes and changing land use effects will continue to create conditions conducive to landslides and continued ground movements in the hilly and mountainous parts of the region (Figure 1). Whether or not landslide activity will increase above present-day levels is difficult to predict with confidence, but the indications are that it will.

3.2.3 Aeolian Hazards

Aeolian hazards, predominantly dune migration and wind-blown sand, are limited to the arid and semi-arid parts of the region. An increase in the incidence of drought and higher temperatures may lead to an increased potential for aeolian hazards in these and neighbouring areas. For example, Goudie (2010) suggests that by 2099 dune fields from South Africa in the south to Zambia and Angola in the north may become reactivated as a result of higher temperatures and a reduction in the stabilising influence of vegetation. In these areas the critical relationship between vegetation cover and sand movement is highly susceptible to changes in climate. Parts of the Kalahari, for example, may be particularly prone to climate change due to their being in a threshold condition between dune stability and activity. Knight et al (2004) and Goudie (2010) also note that current Global Circulation Models (GCMs) provide little indication as to how wind characteristics might be modified by future climate change and future predictions are fraught with uncertainty, although Ashkenazy et al (2012) predict that the Kalahari sand desert will remain largely stable during the 21st century.

For the vast majority of SSA aeolian hazards are unlikely to increase significantly in the foreseeable future.

3.2.4 Natural and Engineering Materials

Expansive soils, collapsing soils, dispersive soils and saline soils pose difficulties when encountered during the construction of buildings and linear infrastructure. They are all present to varying degrees in SSA and their occurrence is controlled by underlying geology, topography and climate (Hearn and Hunt 2013). Although these soil hazards can prove extremely expensive to rectify if not dealt with adequately by route selection and mitigation design, their extent and severity are unlikely to be significantly influenced by the rates of climate change envisaged in Section 2.2. Expansive soils are residual soils developed on basalt rocks with high smectite clay content. Their effects may become more prevalent where climate change results in enhanced cycles of wetting and drying brought about by higher and more frequent rainfall and increased drying out caused by higher temperatures. Collapsing soils are low density soils that occur most frequently in arid and semi-arid areas and they can be residual, alluvial or aeolian in origin. They lose strength when wet (hydro-compaction) due to the loss of clay bonds between soil particles, or when loaded by embankments and other structures. Raised water tables and increased soil moisture brought about by higher rainfalls might therefore influence the stability of these soils. Saline soils, that are aggressive to concretes and steel, may become more widespread in areas where rainfall reduces, allowing chlorides and sulphides to build up in soil horizons.

4. ABILITY OF RURAL ROADS TO ACCOMMODATE GEO-HAZARDS

Rural access can be considered in two forms; road access and pedestrian access. Most rural communities of any size will usually have a motorable access, although this may comprise a very rudimentary track. Pedestrian access is much less constrained by terrain, with the exception of non-fordable rivers.

4.1 Road Access

Cowi (2010) consider that the biggest problems affecting current roads in Ethiopia, Ghana and Mozambique are the overloading of vehicles and poor maintenance of roads, including lack of repair. By contrast they consider that the success of new roads will depend on taking into account the choice of alignment, design and construction, the climate and topography in which the road is situated, the need for axle load restrictions, and the need for proper maintenance.

Climate change predictions for rainfall in SSA are very variable, but there is some agreement that precipitation will decrease from June to August in southern Africa, and increase from December to February in eastern Africa. The intensity of extreme weather is also predicted to increase, with the result that an increase in rainfall intensity seems likely.

Warming in SSA is expected to be greater than the global average. In Ethiopia, for instance, the mean maximum temperatures are predicted to increase by about 3° C by the 2060s and by 5° C by the 2090s (Section 4 and ERA 2013a).

Costs associated with climate change in SSA are by their nature very speculative. Robinson et al (2013) estimate that, for Ethiopia, maintenance on paved (sealed) roads directly attributable to climate change ranges from US$ 5 million to US$ 13 million per year depending on the chosen climate change model, and for unpaved (unsealed) roads the comparable figures are US$ 2 million to US$ 14 million. However, these figures pale into insignificance compared to costs arising from repairs due to more severe and frequent flood events, with the annual average figures ranging from US$ 250 million to US$ 340 million.

One aspect that needs to be taken into consideration is the design life of the road <u>without</u> taking climate change into account. Most rural roads will be designed for predicted traffic levels over a period of perhaps 15 years, so that in theory the road pavement will at least need replacing/strengthening at the end of that period. The increase in traffic levels due, for instance, to population or standard of living increases may also create the need for a new road geometry – widening or a less tortuous alignment for example. During that same period, other weaknesses in the original design may have become apparent – e.g. inadequate drainage in certain locations, heavy erosion in others associated with the effects of climate variability. Under these circumstances, it is very difficult to isolate costs attributable to climate change from those associated with costs that would have occurred anyway without climate change. Furthermore, within a period of say, 50 to 100 years – by which time climate change might have had a noticeable effect on the original overall road structure, the road is likely to have undergone several design updates anyway. The obvious point to make, however, is that all design upgrades should take into account the latest climatic data.

The tables contained in Appendix 1 are concerned with:

- Table 1 The effects of climate change on existing roads;
- Table 2 Adaptation of existing roads to allow for the effects of climate change;
- Table 3 Adaptation of the design of new roads to allow for the effects of climate change.

4.1.1 Types of Road

Three types of road are considered: sealed, gravel and earth.

- Earth roads may be ‘unformed’ or ‘formed’. Unformed roads are non-engineered roads that mainly comprise a track cleared of vegetation but with minimal earthworks. They are generally only capable of carrying very light traffic and may become impassable in wet weather. Formed roads are engineered roads that typically comprise excavated material from the vicinity of the alignment which is shaped to form a camber and includes side drainage. If properly constructed and maintained, they will normally carry higher volumes of traffic compared to unformed roads. Earth roads typically carry up to 50 AADT (Average Annual Daily Traffic, defined as the total annual traffic summed for both directions and divided by 365).

- Gravel roads are often the first stage in the making of all-weather access that are designed to a specific alignment standard and traffic-carrying capacity. They normally comprise a gravel wearing course on top of a structural base. Gravel roads carry a higher maintenance commitment compared to earth roads. Gravel roads are typically designed for AADTs from 25 to 150.
- Sealed roads will normally comprise a surfacing material (which may be structural or non-structural) on top of a structural base and subbase. The sealed surface may comprise a structural asphalt layer or a non-structural layer such as surface dressing or otta seal. Sealed roads can be designed up to major trunk road standards, but in rural access terms, they are typically designed for AADTs from 75 to 300.

4.1.2 Climate Change Scenarios

In the tables contained in Appendix 1, two climate change scenarios are examined:

- Increased rainfall
- Increase in temperature.

While predictions suggest that some areas will experience a decrease in rainfall this is unlikely to have a significant negative influence on road serviceability except perhaps through an increased possibility that the subgrade soils could dry out. However, this aspect is covered in the increased temperature scenario. One factor that needs to be emphasised here is the lack of basic climatic data for drainage design in many sub-Saharan African countries, particularly in rural areas. In the absence of good rainfall and runoff data, drainage designs are based on assumed values, which may or may not be appropriate in the first place, let alone taking climate change predictions into account. Furthermore, in mountainous areas in particular, rainfall can be notoriously variable, with locations only a few km apart experiencing very different rainfall events. In the absence of nearby rainfall gauges monitored over several years, rainfall estimation is more of an art than a science.

The tables in Appendix 1 cover the following geo-hazards in relation to road serviceability:

- Flooding
- Landslides
- Erosion
- Sedimentation
- Windblown sands and dust
- Expansive soils
- Temperature damage to sealed road surfaces.

Flooding

Flooding may become more frequent with higher peaks for the same rainfall. Flooding of roads is unlikely to do any serious harm as such; it is the effect of traffic using the road that may cause damage. Earth roads will generally be impassable to traffic in flood conditions, the road surface becoming seriously disrupted. Gravel roads will normally suffer less harm, but the squeezing of water through the gravel surface by tyre action can lead to potholing, rutting and loss of subgrade support. Sealed roads will fare best, but any weakness in the surfacing, particularly in the case of thin surface seals, may again result in potholing and loss of subgrade support. Where flooding occurs on a regular basis, then raising the road on embankment is likely to be the only practical solution.

In respect of cross drainage, if the lack of cross drainage is actually creating flood conditions, then it will be necessary to increase the number of cross culverts and/or increase bridge openings (either by rebuilding the bridge with a greater or additional spans, or by increasing the soffit level). For new roads it may be advisable to base the cross drainage design on enhanced rainfall/runoff values. The ERA Drainage Design Manual (ERA 2013a) for example suggests increases of 10% to 2030 and 20% between 2030 and 2090. Where flooding results in high river flows and increased erosion and scour, these are dealt with below.

Landslides

Landslides will occur in cut and fill slopes and as a very general rule, the larger the volume of earthworks per unit length of road, the greater the number of landslides. As a consequence, sealed roads are possibly more likely to experience landslide problems than gravel or earth roads, since the former are designed to higher design speeds resulting in larger volumes of earthworks, compared with gravel or earth roads designed to low design speeds. Conversely, the greater design input for sealed roads might result in more conservative (safer) side slopes. The occurrence of landslides may be reduced by flattening side slopes, by making adequate provision for slope drainage and slope protection (e.g. vegetation cover), and by constructing toe retaining walls (e.g. Hearn 2011). However, for existing rural access roads, other than repairing areas of obvious distress on slopes, it will usually be more economical to repair slope failures after they happen rather than to put in place preventive measures before failure occurs. With respect to new roads, the emphasis should be to design alignments that do not result in major cuts and fills (see also, for example, the ERA Route Selection Manual (Hearn and Hunt 2013).

Erosion

Erosion is considered for normal soils, for collapsible soils, and for dispersive soils. Erosion usually occurs during and after periods of heavy rainfall and can particularly affect cut and fill slopes, side drains (if unlined), and active watercourses. For normal soils (i.e. those that are not collapsible or dispersive) anti-erosion measures can include bio-engineering techniques (e.g. the establishment of vegetation cover on bare slopes), the construction of check dams in small active watercourses, the construction of culvert inlets and outlets, concrete or masonry lining of side drains, etc. Where erosion is the result of high watercourse velocities, then river training measures may be necessary to protect the road from scour. These could include the use of gabion revetments and protective mattresses, groynes, riprap armouring etc. These measures can be very expensive and in extreme cases it may be appropriate to realign the road away from the problem area.

Problematic Soils

Problematic soils (expansive, collapsing and dispersive) are best avoided, if possible, or the effects mitigated by excavation/replacement and/or careful roadside drainage design.

In expansive soils volume changes are confined to the upper few metres of a soils deposit where the seasonal moisture content varies due to wetting and drying cycles. An increase in temperature is likely to lead to a greater depth of drying and therefore additional cracking of the road surface. Subsequent rain will lead to expansion and unevenness of the road surface. Under these conditions, earth, gravel and sealed roads will all suffer trafficability problems, the only foolproof remedy being to avoid aligning the road on these deposits in the first place. Where an existing sealed road is located on expansive soils, movements may be minimised by extending the shoulders a few metres on each side so that the variation in moisture content of the underlying soil only occurs beneath the shoulders and not underneath the road.

Sedimentation

If erosion can be minimised, then sedimentation will be minimised as well. Sedimentation will be prevalent where flooding occurs, and if flooding can be reduced, then so too will sedimentation. Where sedimentation does occur, often at the base of escarpments or where rivers enter floodplains, it will usually be appropriate to place the road on embankment whilst making provision for adequate cross drainage. If sedimentation is resulting in rising river bed levels such that the freeboard to bridges becomes critical, then consideration should be given to raising bridge deck levels or realigning the road to a new crossing where sedimentation is not occurring.

Windblown Sand

Increases in temperature, particularly if combined with reduced rainfall are likely to lead to drought conditions and the formation of windblown sands. The essential element in avoiding the accumulation of windblown sands is to make the cross section profile of the road as streamlined as possible. In this manner the windblown sands cross the road and accumulate elsewhere. It is therefore particularly important to ensure that all cut and fill slopes are as shallow as possible, to avoid the use of box cuts, and to clear shrubs and other such vegetation from the immediate roadside, particularly on the upwind side of the road. Sand accumulation on existing roads may be minimised by experimenting with the location of sand fences upwind of the accumulation. Where dust is specifically generated by traffic on an unsealed road, consideration should be given to sealing the surface through settlements and other inhabited areas.

Damage to Sealed Road Surfaces

Although not strictly a geo-hazard, it is convenient to deal with this issue here. Obviously not applicable to unsealed roads, increased temperatures may result in premature hardening and embrittlement of the bitumen used in both asphalt concrete and surface dressings. This will lead to surface cracking and consequent loss of waterproofing, resulting in potholing and a deterioration of the pavement. More frequent reseal treatments will mitigate the problem, but at an increased cost. In asphalt concrete pavements, bitumen softening and subsequent surface rutting are a possibility. If and when this does occur, then the only practical solution will be to reconstruct or resurface the pavement with a higher grade of bitumen (higher temperature resistant). It is possible that some blinding of the existing road surface will be necessary before resurfacing to prevent the upward migration of the bitumen into the new surface.

Austroads (2004) provides a comprehensive overview of the effects of temperature rise on surface seals and asphalt overlays.

4.1.3 The Way Ahead

Cowi (2010) make a number of recommendations which although directed towards roads in Ethiopia, will generally apply to all SSA countries. These include:

- Investigate the need for river training and increased channel maintenance and bridge scour protection
- Investigate the use of spot improvements in high risk areas

- Design gravel roads and community roads with a variety of materials suitable for the climate and topography
- Prioritize maintenance and drainage upgrades in areas that are most at risk of flooding
- Repair and clean channel and drainage structures in high risk areas before the rainy season
- Research the use of more initially robust scour prevention compared to long term maintenance savings
- Since new climate resilient roads are more costly to build, so investments budgets have to be increased or the quantity of new roads to be constructed will have to be reduced.
- Review design parameters every 5 to 10 years search for the optimal balance between climate risks and adaptation costs
- Based on research into the accuracy of design parameters in predicting sedimentation and runoff, the design storm parameters for new roads and structures should be adjusted to reflect significant climate changes - after due consideration of an acceptable future safety level
- Investigate the feasibility of altering and/or enlarging the drainage system in specific areas prone to erosion and flooding to reduce the risk of total failure and consequential damage, and to decrease the climate change-related need for increased maintenance.

As noted above, there is some debate (e.g. World Bank 2010) as to whether in an SSA country such as Ethiopia it would more economical to reduce the scope of its planned expansion of the gravel rural access road network in favour of expansion by constructing fewer sealed roads. The justification for this being the limited design life of a gravel road compared to a sealed road and its much greater susceptibility to damage from flooding (or the effects of increased rainfall). Although there is a clear engineering case for this, the political and social aspects are likely to outweigh pure economics. Perhaps a better way forward would be to design and construct gravel roads that are more able to withstand the effects of prolonged rainfall (e.g. selective use of geotextiles), together with improved and regular routine and periodic maintenance and enforcement of restrictions on over-weight vehicles. As for earth roads, these are likely to become increasingly disrupted by rainfall and any expansion should only be contemplated in currently very dry areas.

4.1.4 Other Issues

As described in Section 3, and according to the Population Reference Bureau website[2] the population of SSA will expand from its present 0.9 billion to 2.2 billion in 2050 (i.e. it will more than double). The consequences of such growth is likely to result in increased desertification in the more arid areas, more deforestation and intensive farming in the wetter areas, and more settlements in the rural areas. It is suggested that this pressure on land is likely to have a much greater influence on rural access sustainability than climate change, as well as exacerbating the effects of climate change listed in the tables. Increased human activity will result in increased erosion (and hence sedimentation), more rapid runoff will cause greater flooding, land clearance may result in greater desertification causing more windblown sands, and increased traffic will put greater stress on existing road pavements unless they are upgraded.

4.2 Pedestrian Access

With the exception of flooding, river crossings, and to a lesser extent landslides, the other effects of climate change are not considered to have a material effect on rural access. Footpaths can range from well-engineered paved paths perhaps used for many decades to indistinct unmade trails through the bush. Local

[2] http://www.prb.org/Publications/Datasheets/2013/2013-world-population-data-sheet/data-sheet.aspx

knowledge will usually ensure that paths pass over or though the easier terrain, encountering streams or rivers only where absolutely necessary and at locations where a safe crossing can be made for most months of the year.

Pedestrian bridges, where present, are usually locally built and are very vulnerable to being damaged or swept away during high flood stages of a stream or river. Increased and higher intensity rainfall will result in greater vulnerability; the only sensible remedy being to rebuild the bridge by raising and increasing the span – often beyond the capability of the villagers.

The higher incidence of flooding may have less impact on foot access since pedestrians will usually be able to circumnavigate around the flooded area. Although the access time will be longer, total disruption may be unlikely.

In respect of landslides, although increased rainfall will increase their incidence, most footpaths would only be affected by naturally occurring landslides (rather than those resulting from man-made activities) in steeper terrain. Although some disruption would occur, a new path over the landslide or located above it would normally be established within a few days. Landslides could also prevent passenger-carrying vehicles on roads from passing the slide area until emergency roadworks had been undertaken. Although pedestrian access across or around slide areas can normally be established within hours, further difficulties could occur if there are no vehicles available on the other side of the slip.

5. SOCIO-ECONOMIC IMPACTS ASSOCIATED WITH REDUCED RURAL ACCESS

5.1 Introduction

According to IFAD website: 'In Sub-Saharan Africa, more than 218 million people live in extreme poverty. Among them are rural poor people in Eastern and Southern Africa, an area that has one of the world's highest concentrations of poor people. The incidence of poverty in Sub-Saharan Africa is increasing faster than the population. Overall, the pace of poverty reduction in most of Africa has slowed since the 1970s.' Of the 2.4 billion increase in the world's population expected by 2050, 46% will be born in SSA (UN 2011). The region will contribute 77% of the total increase in world population by 2100. Over 70% of the region's population live in rural areas and, while urbanisation is expected to increase significantly, the need to provide the necessary infrastructure to sustain rural livelihoods is clear.

However, 'despite substantial investments in infrastructure in the recent past, rural populations in many countries of SSA remain poorly served. Inadequate investment in physical infrastructure limits the pace of economic development in many areas of SSA. Water supply, sanitation, and reliable electricity services are available in too few villages and districts. Paved roads, railroad networks, and easily accessible market centres are rare. In many countries, there are fewer than 1 000 km of paved roads per 1 000 persons, a level of service that is an order of magnitude smaller than the amount of paved roads in many industrialized nations' (Faures and Santini 2011). The potential impact of climate change on roads in SSA is considered to be far more significant than other regions of the world due to the relatively low density of road access provision in the region (Chinowsky et al 2011).

As far as remote communities are concerned, the most important elements of rural access probably include established pedestrian footpaths, farm tracks and village tracks, earth roads and gravel roads. Sealed roads have the lowest density of all forms of access and are probably the least important from the point of view of the day-today livelihoods of rural communities. It is usually the more highly-trafficked sealed roads that receive the greatest and most urgent attention as far as response to geo-hazard impacts are concerned; the lower standard forms of access, upon which most rural communities are probably more reliant, receive significantly less attention and therefore may remain impassable or unsafe for longer periods of time when affected by flooding, landslides and other geo-hazards. While it can be demonstrated (Section 5.2) that there is a strong link between the provision of rural access and the socio-economic and livelihood development of rural communities, there appear to have been no studies carried out that investigate the effects of potential climate-induced loss of access on community well-being.

This section of the literature review comprises four themes which include:

i) rural access and utilization of social infrastructure;

ii) vulnerability of rural communities to reduced reliability of access;

iii) the differential impact of rural access on gender;

iv) the context of Ethiopia.

5.2 Rural Access and Utilization of Social Infrastructure

Rural access plays a central role in the socio-economic development of SSA. The region has suffered from poorly developed social infrastructure which limits access to markets and basic services for the majority of its rural population. Off-road villages are inevitability disadvantaged in terms of access to service provision and livelihood opportunities (World Bank 1999; Mohammed 2007). Improved access through the expansion and maintenance of rural roads offers considerable potential for the utilization of local resources and existing social infrastructure thus contributing to poverty reduction and socio-economic development. However, the challenge remains in maintaining this access due to the impacts of climate-related geo-hazards (Sections 3 and 4).

5.3 Vulnerability of Rural Communities to Reduced Reliability of Access

Road deterioration due to poor quality of construction and lack of proper maintenance is an issue in many part of rural Africa, and is a function of remoteness, limited funds and the effects of climate extremes of rainfall and, to a lesser extent, temperature on road serviceability. Climate change projections for SSA in general indicate an overall increase in average annual rainfall with potential increase in flood related hazards that might affect rural transport infrastructure. In particular rural roads, which are the backbone of the region's transport system, are often impacted by large floods (Sections 3 and 4), which cause serious infrastructure damage and disruptions to supply chains (Robinson et al 2013).

Poor infrastructure and high transport costs are often identified as key constraints for rural development in low-income countries (Shiferaw et al 2013). Accessibility is a good indicator of the impact of rural poverty on socioeconomic development (Donnges 2003). Poor accessibility constrains social and economic development (Bryceson 2006). A more reliable and an expanded network of rural access is therefore a significant component of the drive towards poverty alleviation but it must be interfaced with interventions in other sectors in order to effectively alleviate poverty (Shiferaw et al 2013).

The following factors are among the more significant in creating an enviornment conducive to poverty:

- an ineffective and inefficient agricultural marketing system;
- under-developed transport and communications networks;
- under-developed production technologies;
- limited access of rural households to support services, including health;
- environmental degradation, caused by natural and man-made processes;
- lack of participation by rural poor people in decisions that affect their livelihoods.

5.4 The differential Impact of Rural Access on Gender

Without maintaining gender equality a nation is highly unlikely to attain its required development goals. The role that women play in socio economic development, and particular in agricultural activities, is paramount. In addition to farm work, women are responsible for day to day household duties and for taking care of children. They also carry agricultural products to the market place for sale or in exchange for household commodities. Women account for about 75 % of the transport burden in rural Africa. However, their involvement and role in decision making, management of resources and development planning is often minimal (UNDP 2007 and Hausmann et al 2011). As well as time and energy, transport can adversely affect the wellbeing of women and therefore the family (Kudat 1990). Lack of time is a key constraint in the ability of women to build their assets and reduce their vulnerability (World Bank 1999).

In rural areas of developing countries, women and girls spend significant periods of time travelling and face greater safety and security risks than would otherwise be the case. In addition women have less access to alternative means of transport, such as wheel barrows, carts, draft (pack) animals, bicycles, and motor cycles (Mashiri et al 2005). As rural women shoulder the burden of the household and the community and disadvantaged in all aspect of their life, the benefit of infrastructure should be focused to lighten their burden and enable them to share equal development opportunities and benefits with men (UNDP, 2007). Planning and investment interventions must recognize and address differences in travel patterns and transport needs between the sexes and age groups, ensuring that services are provided in such a way that benefit rather than constrain different vulnerable groups (IAAE, 2012). Gender mainstreaming should be considered as a critical factor in ensuring that women do not become worse off both absolutely and in relation to men (World Bank 2008).

As described in the World Bank and ESRC Centre study (2006) in developing countries distance is a direct barrier to attending primary school among children living in rural areas, particularly young girls. High illiteracy rates (50% for men and 75% for women) limit economic activity. Experience from many countries also shows that girls' school enrolment, in particular, is dependent on transport:

- girls generally have to take on a greater part of the household work. With improved accessibility more time can be put aside for education (Plan International 2011).
- It is common for a family to be worried about letting their daughters walk far on their own.

5.5 Ethiopia

Ethiopia is predominantly a rural country with about 80% of its over 80 million people living in rural areas engaged primarily in subsistence crop and livestock production. Of 15 countries listed in the SSA region by the World Bank (World Bank website 2013) with road density figures, Ethiopia had the equal second lowest density with $4km/100km^2$ in 2011. Although the country has made significant progress in the development of rural infrastructure in recent years, rural accessibility remains a serious challenge constraining socio-economic development. According to Foster and Morella (2011), only 10% of Ethiopia's rural population lives within two kilometres of an all-weather road which is only half of the benchmark level for low-income countries in SSA. For example, it can take women and their daughters up to 6 hours to collect firewood, 1-2 hours to collect water and 2 hours to access basic health facilities. Furthermore, limited market access, due to long travel distances, poor roads, and lack of transportation (including lack of pack animals) contributes to lower selling prices for goods (Seraje, 2007). According to ERA (2013b) the average distance between rural communities and an all-weather road is 6.4km, or 2.1 hours walking time. This is a significant improvement on recent decades, but the government is committed to further expansion.

The implication for improved and sustainable rural access in Ethiopia to develop and maintain rural livelihoods is evident. The issue of market access is more relevant for a country like Ethiopia where the economy is largely rural (Worku 2011). In recognition of this fact, the Ethiopian government has set targets for the improvement and expansion of the roads sub-sector in its Growth and Transformation Plan (MoFED 2010). In this five-year development plan, the road network is planned to increase from 49,000 km to 64,500 km by 2015. Hence, high-quality asphalt roads and rural community roads have been constructed and the expansion has increased road density from 29 km per 1,000 km^2, according to official figures for fiscal year 2000/01, to 44.5 km in 2009/10 (IFAD 2012). Nevertheless, rural access is still a major obstacle to poverty reduction and achieving the Millennium Development Goals in the country. According to the 2013 MDG report, although Ethiopia has made great improvements, its overall performance in terms of meeting the targets is far behind that of many African countries. Geo-hazards, especially floods, take their toll on rural roads and local communities in the meantime loose access to villages, markets and even to farmland (Aklilu et al 2013).

Rural communities in Ethiopia have also been challenged by poor access to health services. Underdeveloped rural road infrastructure considerably impairs access to available health services in nearby villages and towns. The problem is worsened by climate change induced road and bridge damage (Section 4). Women, children and persons with disabilities are among the most vulnerable groups of the rural community (Chaya 2007). Considerable time is spent by women and their families waiting for transportation and emergency travel to reach a health facility, and often this is undertaken on foot or by other forms of non-motorized transport (Tesfazghi 2007).

A survey commissioned by Ethiopia Roads Authority (ERA 2013c) indicated that there is a need for gender mainstreaming in strategic planning, implementation, and monitoring and evaluation activities. The study also indicated the gap that exists in exploiting opportunities and encouraging women's participation in road projects as a means of poverty reduction and encouraging cultural changes related to gender disparities in society.

6. COMMUNITY VULNERABILITY TO CLIMATE-RELATED IMPACTS ON RURAL ACCESS

Vulnerability to natural hazards is generally regarded in the literature as a means for potential loss and a function of exposure, sensitivity and the ability to adapt (i.e. resilience). Accordingly, the most vulnerable communities are those with high exposure, high sensitivity, and low adaptive capacity (for example Cutter 1996, Cutter et al 2000, Wisner et al 2003, USAID 2013). However, while Section 5 above has focused on the linkage between livelihood, health, socio-economic development and the provision of rural access, this literature review has uncovered very little published work that assesses the impact of lost or reduced access on rural communities as a result of geo-hazards. One exception to this is the work of Maharaj and Kravatzky (1999) with respect to climate-related geo-hazards in Haiti. They noted that flooding affects roads which causes major disruptions in people's ability to travel to work, markets and school. Surveys were undertaken to gauge community perception of infrastructure vulnerability to these hazards. Fears of losing road access coincided with those communities located in flood-prone areas. Most other publications focus on direct community vulnerability to geo-hazards and the role of roads, for example, in facilitating emergency evacuation and improved access to relief and recovery mechanisms. For example, the research undertaken by Scott Wilson Ltd and the University of Durham (Hearn et al 2003) for DFID into 'Landslide Risk Assessment in the Rural Access Sector' focused on the direct impacts of landslides and related geo-hazards on rural access and community infrastructure, and not on the effects of lost or diminished access on community livelihood and prosperity. Nevertheless, it can more or less be accepted that loss of access, either totally or partially, will have a negative effect on community livelihood and prosperity and that this will impact certain sections of the community more than others, in accordance with the discussion in Section 5.

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APPENDIX 1

Road Engineering Tables

Table A1: The effects of climate change on existing roads

Climate Change	Geo-hazard	Road Type		
		Sealed	Gravel	Earth
Increased rainfall	Flooding a) roads	Usually small impact on pavement since design usually based on soaked subgrade conditions.	Moderate impact depending on type and number of vehicles using the road during flood conditions. Potentially major impact on roads used by heavy vehicles causing major rutting.	Major impact on trafficability, roads become impassable, road surface severely disrupted.
	b) cross drainage	Provision for cross drainage likely to be quite comprehensive, so reduced susceptibility to damage/loss of cross drainage structures. Where damage/loss does occur however, costs and traffic disruption are likely to be significant.	Provision for cross drainage likely to be more limited, resulting in moderate susceptibility to damage/loss of cross drainage structures.	Provision for cross drainage likely to be very limited, resulting in increased susceptibility to damage/loss of any cross drainage structures.
	Landslides	Very dependent on nature of surrounding topography. Could be significant since sealed roads more likely to be designed to a higher standard and require significant cuts and fills. However, if earthworks are well designed and constructed then landslide risk may be reduced.	Very dependent on nature of surrounding topography. Could be moderate since earthworks are likely to be smaller than for a sealed road.	Very dependent on nature of surrounding topography. Could be small risk since earthworks are usually relatively minor.
	Erosion a) Normal soils	Can be significant if cut and fill slope surfaces are not protected, particularly during periods of increased rainfall intensity. Erosion/scour as a result of increased stream or river flow may affect roads and bridges.	As for sealed roads	Can be significant in hilly areas where erosion may occur within the road surface, or where roads are located close to watercourses .
	b) Collapsing soils	Where present, could be significant if cut slopes are not protected or provided with adequate slope drainage.	As for sealed roads	Unlikely to be a problem due to limited earthworks
	c) Dispersive soils	Where present, significant surface and internal erosion of exposed natural soil surfaces.	As for sealed roads	Usually less of a problem due to limited earthworks.
	Sedimentation	Unlikely to be a significant problem except in pediment areas adjacent to escarpments, or floodplains associated with significant watercourses and eroding tributaries.	As for sealed roads	Could be a high risk of disruption to road travel due to minimal earthworks
Increased temperature	Windblown sands and dust	Usually small impact if road cross section designed to minimise sand accumulation.	Usually small impact if road cross section is designed to minimise sand accumulation. Dust from traffic may cause problems in inhabited areas.	Usually small impact since earthworks are likely to be very limited, but traffic generated dust may cause problems in inhabited areas.
	Expansive soils	Shrinkage of soils beneath the subgrade may result in cracking of the road surface and subsequent deterioration of the entire pavement.	Permeable road surface may permit wetting and drying of the soils beneath the subgrade resulting in cracking and swelling and subsequent deterioration of the entire road surface.	Wetting and drying of the underlying soils likely to result in a very uneven riding surface.
	Sealed road surface	Possibility of embrittlement of bituminous pavements, resulting in cracking, potholing and possible rutting. Possible softening of asphalt concrete pavements resulting in rutting.	Not applicable	Not applicable

Table A2: Adaptation of existing roads to allow for the effects of climate change

Climate Change	Geohazard	Road Type		
		Sealed	Gravel	Earth
Increased rainfall	Flooding b) Roads	Check pavement design based on soaked subgrade conditions. If not, then allow for redesign prior to resurfacing/upgrade	Moderate impact depending on type and number of vehicles using the road during flood conditions. Consider increased structural layer thicknesses, and possible surface sealing in flood-prone areas	Major impact on traffickability, roads become impassable, road surface severely disrupted.
	b) cross drainage	Check adequacy of cross drainage using enhanced rainfall/runoff values. If inadequate, then consider increasing number of cross culverts and raising/increasing bridge spans during next road upgrade.	As for sealed roads, particularly when considering road upgrading.	Consider increasing provision for cross drainage, particularly at significant watercourses.
	Landslides	Very dependent on nature of surrounding topography. Assess stability of existing cut, fill and natural slopes and make provision for increasing the stability of marginal slopes by decreasing slope angles and/or constructing retaining walls.	Very dependent on nature of surrounding topography. As for a sealed road but could be less problematic since earthworks are likely to be smaller than for a sealed road.	Very dependent on nature of surrounding topography. Could be small risk since earthworks are usually relatively minor.
	Erosion d) Normal soils	Carry out visual survey and determine cause of erosion. Where appropriate, install mitigation measures such as additional surface drainage, establishment of vegetation cover, gabion catch dams, river revetments etc. If stream or river erosion/scour is becoming excessive and affecting the road, consider realigning the road.	As for sealed roads. Where erosion is occurring or likely to occur in the road surface in hilly areas, consider sealing the surface.	Where erosion is occurring or likely to occur in the road surface in hilly areas, consider gravelling or sealing the surface.
	e) Collapsing soils	Carry out visual survey and determine cause of erosion. Where appropriate, install mitigation measures such as additional surface drainage, establishment of vegetation cover	As for sealed roads	Unlikely to be a problem due to limited earthworks
	f) Dispersive soils	As for normal soils	As for sealed roads	Usually less of a problem due to limited earthworks.
	Sedimentation	Particularly in areas of shallow sidelong terrain at the foot of major topographic features such as escarpments, consider raising road on embankment. Assess need for raising/lengthening crossings of watercourses susceptible to sedimentation.	As for sealed roads	Unlikely to be economic to carry out any mitigation works.
Increased temperature	Windblown sands and dust	Ensure that the existing road cross section is as streamlined as possible to minimise sand accumulation.	As for sealed roads but consider sealing through inhabited areas to minimise dust problems.	Unlikely to be economic to carry out any mitigation works.
	Expansive soils	Consider extending shoulder widths to lessen moisture change beneath the subgrade so as to minimise cracking of the road surface, or realigning the road away from the soil deposits.	Unlikely to be a satisfactory solution other than realigning the road.	Unlikely to be a satisfactory solution other than realigning the road.
	Sealed road surface	Consider using a higher grade of bitumen when the need for resurfacing arises.	Not applicable	Not applicable

Table A3: Adaptation of the design of new roads to allow for the effects of climate change

Climate Change	Geohazard	Road Type		
		Sealed	Gravel	Earth
Increased rainfall	Flooding c) Roads	Ensure pavement design based on soaked subgrade conditions. Consider placing the road on embankment where flooding might be possible.	As for sealed roads, but consider use of geotextiles, greater structural thicknesses and surface sealing in flood-prone areas.	Avoid flood-prone areas where possible.
	b) cross drainage	Design cross drainage using enhanced rainfall/runoff values.	As for sealed roads.	Avoid watercourses where possible.
	Landslides	Minimise requirement for large cut and fill slopes by careful route alignment. Avoid steep natural side slopes where possible. Consider need for slope drainage to reduce effects of erosion leading to instability. Assess need for retaining walls at base of slopes.	Very dependent on nature of surrounding topography. As for a sealed road but could be less problematic since earthworks are likely to be smaller than for a sealed road.	Very dependent on nature of surrounding topography. Could be small risk since earthworks are usually relatively minor.
	Erosion g) Normal soils	Make provision for gabion catch dams in steep watercourses above the road, consider need for bioengineering measures (particularly vegetation cover) on bare slopes. If active river erosion/scour is likely to affect the road, river training works such as revetments may be appropriate.	As for sealed roads. Where erosion is likely to occur in the road surface in hilly areas, consider sealing the surface.	Where erosion is likely to occur in the road surface in hilly areas, consider gravelling or sealing the surface.
	h) Collapsing soils	Avoid collapsing soil deposits where possible. Otherwise as for normal soils except side drains may need to be lined.	As for sealed roads	Unlikely to be a problem due to limited earthworks
	i) Dispersive soils	Avoid dispersive soil deposits where possible. Otherwise as for normal soils except side drains may need to be lined.	As for sealed roads	Usually less of a problem due to limited earthworks.
	Sedimentation	If sedimentation is inevitable, place road on embankment where sedimentation is likely to occur. Assess need for raising/lengthening	As for sealed roads	Unlikely to be economic to carry out any mitigation works.

Climate Change	Geohazard	Road Type		
		Sealed	Gravel	Earth
		crossings of watercourses susceptible to sedimentation and design accordingly.		
Increased temperature	Windblown sands and dust	Ensure that the existing road cross section is as streamlined as possible to minimise sand accumulation. Avoid cuts where possible.	As for sealed roads but seal road through inhabited areas to minimise dust problems.	Follow existing contours where possible.
	Expansive soils	Avoid expansive soil deposits where possible. Otherwise extend shoulder width to lessen moisture change beneath the subgrade to minimise future cracking of the road surface.	Avoid expansive soil deposits where possible.	As for gravel roads
	Sealed road surface	Ensure grade of bitumen used for surfacing suitable for anticipated temperatures.	Not applicable	Not applicable