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Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa

Recommendations for Phase 2

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Council of Scientific and Industrial Research (CSIR), Paige-Green Consulting (Pty) Ltd and St Helens Consulting Ltd

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Abstract

The African Development Bank states that Africa is one of the most vulnerable regions in the world to the impacts of climate change. The majority of both bottom up and top down studies suggest that damages from climate change, relative to population and Gross Domestic Product, will be higher in Africa than in any other region in the world. In the past four decades, African countries have experienced more than 1,400 recorded weather related disasters (meteorological, hydrological and climatological). These disasters have resulted in the death of more than 600,000 people (95 per cent due to droughts), left 7.8 million people homeless (99 per cent due to flooding and storms) and affected an estimated 460 million people.

In order to help address this significant threat to Africa's development, the Africa Community Access Partnership, a research programme funded by UKAid, commissioned a two-phased project that starting in April 2016 to produce regional guidance on the development of climate-resilient rural access in Africa through research and knowledge sharing within and between participating countries. The output will assist the development of a climate resilient road network that reaches fully into and between rural communities.

The study addresses the issues of appropriate and economic methodologies for vulnerability and risk assessments; prioritisation of adaptation interventions; and optimisation of asset resilience in the context of low volume rural access roads. In addition, evidence of cost, economic and social benefit links to rural communities arising from more resilient rural access will be provided to support wider policy adoption across Africa.

The aim of Phase 1 of this study is to provide methodologies and guidance on the assessment of climate threats and for the identification and prioritisation of adaptation options. These are contained in two reports, namely a *Climate Threats Report* and a *Climate Adaptation Options Report*.

A further aim of Phase 1 is to provide the basis for the implementation of demonstration sections in three countries, namely Ethiopia, Ghana and Mozambique, and to deliberate the guideline documents as well as the recommendations for the implementation of demonstration sections at workshops that will be held in these three countries. The outputs of these workshops will define the objectives and scope for Phase 2 of the study.

In this report, preliminary recommendations for the climate adaptation of three roads, one in each of the above countries, are presented. These roads, which will form the basis of the demonstration programme, are representative of the range of potential hazards that low volume access roads are likely to be exposed to in AfCAP Partner Countries. The roads were selected following site visits undertaken in these three countries. The report also contains field notes on other roads inspected during these visits.

The report also presents preliminary recommendations for Phase 2 of the study, focussing on: (a) demonstrating appropriate engineering and non-engineering adaptation procedures, and the assessment of the socio-economic impacts of adopting more climate resilient adaptations; (b) sustainable enhancement in the capacity of three AfCAP partner countries; (c) sustainable enhancement in the capacity of additional AfCAP partner countries; and (d) uptake and embedment across AfCAP partner countries.

The preliminary recommendations made in this report will be discussed at workshops that will be held in Ethiopia, Ghana and Mozambique in early February 2017.

Key words

Capacity Building; Climate Adaptation; Climate Change; Climate Impact; Climate Resilience; Climate Threat; Climate Variability; Demonstration; Risk; Rural Access Road; Vulnerability.

AFRICA COMMUNITY ACCESS PARTNERSHIP (AfCAP)

Safe and sustainable transport for rural communities

AfCAP is a research programme, funded by UK Aid, with the aim of promoting safe and sustainable transport for rural communities in Africa. The AfCAP partnership supports knowledge sharing between participating countries in order to enhance the uptake of low cost, proven solutions for rural access that maximise the use of local resources. AfCAP is brought together with the Asia Community Access Partnership (AsCAP) under the Research for Community Access Partnership (ReCAP), managed by Cardno Emerging Markets (UK) Ltd.

See www.research4cap.org

Glossary (within the context of this project)

Adaptation	Autonomous or policy-driven adjustments in practices, processes or structures to take account of changing conditions.
Adaptive Capacity	The degree to which adjustments in practices, processes and structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change [in climate].
Adaptation Needs	The circumstances requiring actions to ensure safety of populations and security of assets in response to climate impacts.
Adaptation Options	The array of strategies and measures that are available and appropriate for addressing adaptation needs. They include a wide range of actions that can be characterised as structural, institutional, or social.
Capacity Building	The ability of enhancing strengths and attributes of. And resources available to, an individual community, society, or organisation to response to change.
Climate Change	Change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity.
Climate Variability	Variations in the mean state and other statistics of the climate on all spatial and temporal scales beyond those of individual weather elements. Variability may be due to natural internal processes within the climate system (internal variability) or to variations in natural or anthropogenic external forcing (external variability).
Disaster	Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery.
Early Warning Systems	The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities, and organisations threatened by a hazard to prepare to act promptly and appropriately to reduce the possibility of harm or loss.
Exposure	The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.
Extreme Weather Events	An event that is rare at a particular place and time of year. Definitions of rare vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (e.g., drought or heavy rainfall over a season).
Flood	The overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods.

Hazard	The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. In this report, the term hazard usually refers to climate-related physical events or trends or their physical impacts.
Impacts (Consequences, Outcomes)	Effects on natural and human systems. In this report, the term *impacts* is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts.
Impact Assessment	The practice of identifying and evaluating, in monetary and/or nonmonetary terms, the effects of [climate] change on natural and human systems.
Likelihood	The chance of a specific outcome occurring, where this might be estimated probabilistically.
Mitigation	The lessening of the potential adverse impacts of physical hazards (including those that are human-induced) through actions that reduce hazard, exposure, and vulnerability.
Resilience	The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation.
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard. In this report, the term 'risk' is used primarily to refer to the risks of climate impacts.
Risk Assessment	The qualitative and/or quantitative scientific estimation of risks.
Risk Management	Plans, actions, or policies to reduce the likelihood and/or consequences of risks or to respond to consequences.
Stressors	Events and trends, often not climate-related, that have an important effect on the system exposed and can increase vulnerability to climate related risk.
System Sensitivity	The degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise).
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.
Vulnerability Assessment	Process which attempts to identify the root causes for a system's vulnerability [to climate variability and change).

Acronyms, Units and Currencies

°C	Degrees Celsius
AASHTO	American Association of State Highway and Transportation Officials
ACCESS	Australian Community Climate Earth-System Simulator
AfCAP	Africa Community Access Partnership
AfDB	African Development Bank
ANE	Administração Nacional de Estradas (National Roads Administration, Mozambique)
ARTReF	African Road and Transport Research Forum
AsCAP	Asia Community Access Partnership
ASTM	American Society for Testing and Materials
BS	British Standards
CBR	California Bearing Capacity
CCAM	Conformal Cubic Atmospheric Model
CMIP3	Coupled Model Inter-comparison Project Phase 3
CMIP5	Coupled Model Inter-comparison Project Phase 5
CNRM	Centre National de Recherches Météorologiques
CORDEX	Coordinated Regional Downscaling Experiment
CRED	Centre for Research on the Epidemiology of Disasters
CRU	Climate Research Unit, CSIR
CSIR	Council for Scientific and Industrial Research, South Africa
DFID	Department for International Development, UK
DFR	Department of Feeder Roads (Ghana)
DRFI	Disaster Risk Financing and Insurance
EIA	Environmental Impact Assessment
EM-DAT	Emergency Events Database
ERA	Ethiopian Road Authority
GCM	Global Climate Model
GDP	Gross Domestic Product
GGBS	Ground Granulated Blast-furnace Slag
GIS	Geographic Information System
GPS	Global Positioning System
HABP	Household Asset Building Program
IPCC	Intergovernmental Panel on Climate Change
ITHACA	Information Technology for Humanitarian Assistance, Cooperation and Action
MDD	Maximum Dry Density
NGL	Natural Ground Level
PSNP	Productive Safety Net Program
RCM	Regional Climate Model
ReCAP	Research for Community Access Partnership
SADC	Southern African Development Community
SNNPR	Southern Nations, Nationalities, and Peoples Region (Ethiopia)
SSA	Sub-Saharan Africa
TMH	Technical Methods for Highways
TRL	Transport research Laboratory, UK
UK	United Kingdom (of Great Britain and Northern Ireland)
UKAid	United Kingdom Aid (Department for International Development, UK)
UN	United Nations
UN ESA	United Nations, Department of Economic and Social Affairs
UNISDR	United Nations International Strategy for Disaster Reconstruction
WCRP	World Climate Research Programme

Contents

1. Executive Summary

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2. Background and Objectives

2.1 Project background

2.1.1 Climate vulnerability

The African Development Bank (AfDB) states that Africa is one of the most vulnerable regions in the world to the impacts of climate change. The majority of both bottom up and top down studies suggest that damages from climate change, relative to population and Gross Domestic Product (GDP), will be higher in Africa than in any other region in the world (AfDB, 2011). Its studies suggest adaptation costs in Africa in the region of $20-30 billion per annum are required over the next 10 to 20 years. There is a pressing need to mobilise resources to address the continent's current limitations to deal with climate events, as well as resources to deal with future climate change. Beyond this a series of more targeted adaptation investments are required and it is crucial that African decision-makers factor climate change into all long term strategic decisions.

In the past four decades (1975 to 2015), African countries have experienced more than 1,400 recorded weather related disasters (meteorological, hydrological and climatological). These disasters have had significant impacts on countries' economies and in particular on rural communities and their livelihoods. The high social vulnerability and low adaptive capacity of these communities as well as their high exposure to natural hazards has resulted in the death of more than 600,000 people (95 per cent due to droughts), left 7.8 million people homeless (99 per cent due to flooding and storms) and affected an estimated 460 million people (CRED, 2015).

In many African countries, limited or non-existent funds for adaptation and mitigation are challenging these countries to identify the threats that are posed by climate change, develop adaptation approaches to the predicted changes, incorporate changes into mid-range and long-term development plans, and secure funding for the proposed and necessary adaptations. Existing studies have attempted to quantify the impact of climate change on infrastructure assets that will be affected by climate change in the coming decades.

2.1.2 Rural access

Sub-Saharan Africa (SSA) has one of the lowest rural road densities in the world, which is significantly stifling its potential for agricultural growth and development. In addition, less than 40 per cent of rural Africans live within two kilometres of an all-weather road, making social, medical and educational interventions timely, costly and unreliable. The majority of the road networks contributing to agricultural and social development in these rural areas can be classified as low volume.

Low-volume rural road networks in these countries vary from underdeveloped roads (tracks and un-engineered earth roads) to reasonable, high standard paved roads built to "conventional" standards. Irrespective of their quality, these roads are frequently rendered impassable as a result of periodic extreme weather events. Associated with these roads are water crossing structures, ranging from drifts/fords to culverts of varying sizes and larger bridges. High water velocities could damage these structures, rendering road links impassable. Flooding would lead to similar consequences. Whereas road pavements can usually be reinstated fairly quickly to restore rideability after extreme events, road closures caused by flooding can take several hours to weeks before water levels subside and accessibility can be restored. However, severe impairments of water crossing structures caused by destructive water velocities could take several weeks to months to reinstate, depending on the emergency response capability and adaptive capacity of the road authority.

With the expected changes in climatic conditions (le Roux et al, 2016) resulting from global climate change (greater frequency of extreme events, together with expected changes in precipitation and temperatures), the on-going and periodic deterioration of the existing low volume rural road networks in SSA can thus be expected to continue on a more frequent and increasing scale, somewhat more than for conventional higher trafficked roads. Instances of impassability while roads and structures are waiting to be repaired will increase, and communities and local economies are expected to be affected accordingly.

It is thus urgent that steps are taken to make rural roads, inclusive of drainage and bridge structures, more resilient to extreme weather events and to ensure all-weather passability on critical road links as far as possible. Resilience here is defined as the capacity to anticipate, prepare for, respond to, and recover from the impacts or consequences of significant hazard or multi-hazard threats with minimum damage to social well-being, the economy and the environment.

It is unlikely that all such occurrences can be avoided without significant cost implications. However, new road projects, inclusive of their drainage and bridge structures, as well as rehabilitation and upgrading projects, should ideally be planned and designed (within reasonable limitations) to incorporate greater climate resilience so as to minimise the potential for road closures.

All road development projects currently require an Environmental Impact Assessment (EIA) to evaluate the impact of the proposed road on the environment. These vary from relatively rudimentary assessments to highly sophisticated, time consuming and costly exercises. However, it is becoming increasingly important that the converse effect of the environment on proposed (and existing) roads is evaluated equally.

A number of the climatic impacts are exacerbated by other factors. Vehicle overloading for instance results in rapid deterioration of the pavement structure, but when combined with higher pavement moisture contents, the deleterious influence is increased exponentially. Similarly, poor maintenance of drains affects the moisture content in the road. With higher rainfall, this effect is amplified.

This report concentrates on the future road scenarios in Mozambique, Ghana and Ethiopia, for which detailed climate projections have been developed within this overall project (le Roux et al, 2016). The general findings, however, cover a wide range of scenarios and should be applicable to similar scenarios that unfold in other sub-Saharan countries.

Many of the climate related problems are not within the provenance of one government institution, such as a roads authority. Cooperation with other government departments such as irrigation, water resources, flood control, environment, agriculture and emergency services may often be essential. The construction (and routine maintenance) of flood control structures and dams (usually by different departments), for instance, may be necessary to minimise damage to the road infrastructure (and local communities).

2.2 Scope and purpose of report

To contribute towards addressing this significant threat to Africa's development, the Africa Community Access Partnership (AfCAP), a research programme funded by UKAid, commissioned a project, which started in April 2016, to produce regional guidance on the development of climate-resilient rural access in Africa through research and knowledge sharing within and between partner countries. The output will assist in the development of a climate-resilient road network that reaches fully into and between rural communities.

As part of this programme, research is being conducted on understanding regional climate threats; identifying appropriate risk and vulnerability assessment methods; prioritising adaptation options; and optimising asset resilience in the context of rural access sufficiency. Evidence of economic and social benefit, or increased resilience of rural communities as a result of improved rural access, will be required to support wider policy adoption across Africa.

In this report, preliminary recommendations for the climate adaptation of three roads, one in each of the above countries, are presented. These roads, which will form the basis of the demonstration programme, are representative of the range of potential hazards that low volume access roads are likely to be exposed to in AfCAP Partner Countries. The roads were selected following site visits undertaken in these three countries. The report also contains field notes on other roads inspected during these visits.

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2.2.1 Demonstration projects

Following site visits undertaken to Ethiopia, Mozambique and Ghana, roads (one in each country) have been identified for the installation of climate resilience adaptation measures. Summary field visit reports are provided in:

1) ***Annex A*** for Ethiopia;
2) ***Annex B*** for Mozambique; and
3) ***Annex C*** for Ghana.

The three roads identified as candidates for the demonstration programme are:

1) The ***Tullo Bollo to Kela Road***, south of Addis Ababa in Ethiopia;
2) ***Road R448 from Chokwe to Macarretane*** in the Gaza Province of Mozambique; and
3) The ***Tampion-Tibognaayili-Tidjo Road***, north of Tamale in Ghana.

Preliminary recommendations for the adaptation of these roads are provided in Chapters 3, 4 and 5, respectively. Each of the these Chapters provide an overview of the country and a description of the project site, as well as proposed remedial actions to render sections of these roads more climate resilient.

As all three roads are currently on upgrading/improvement programmes, it is recommended that most the length of the roads be constructed in accordance with the currently proposed designs. However, certain selected sections that have suffered similar problems to adjacent sections should be constructed differently to improve their climate resilience, in line with the recommendations given in the three Chapters. This will allow a direct comparison of the effectiveness of each adaptation measure with the standard practice to determine whether it is practical, successful and cost-effective. It is essential that the additional costs associated with the adaptation measures, compared with the normally designed costs, are carefully monitored and quantified as well as any additional or reduced maintenance costs on all sections. This will allow a comparison of the total costs of installing and maintaining climate resilience with conventional design, which can be used to calculate total life-cycle costs after exposure to severe climatic conditions.

The three Chapters indicate the types of adaptation measures that should be installed and provide preliminary designs where appropriate. However, they do not go into the detailed design or specification of these measures at this stage. This will be carried out as part of Phase 2 of the project. In future revisions of this report, approximate estimates of quantities involved will be provided in Annex D (based on actual measurements and survey data). Costs for the proposed adaptations will then also be provided. A request for copies of recent tenders for these roads or roads nearby has been made to the individual countries in order to obtain estimates of actual costs that will be incurred.

It should be noted that distances referred to in Sections 3.3, 4.3 and 5.3 of Chapters 3, 4 and 5 are based on odometer readings of the vehicles used and may vary from the exact distance measured using accurate equipment. In some cases, geographic coordinates have been provided to identify locations more accurately.

2.2.2 Objectives and scope for Phase 2 of the study

Preliminary recommendations on the objectives and scope for Phase 2 of the project *Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa* are provided in Annex E.

The recommendations for Phase 2 cover the following main activities to be conducted over a period of 70 weeks:

- PART 1: demonstrate appropriate engineering and non-engineering adaptation procedures

  Identify, characterise and demonstrate appropriate costed engineering and non-engineering adaptation procedures that may be implemented to strengthen the long-term resilience of rural access. Assess the socio-economic impacts of adopting more climate resilient adaptations.

- PART 2: sustainable enhancement in the capacity of three AfCAP partner countries

  Engage meaningfully, from project inception onwards, with relevant partner-country Road and Transport Ministries, Departments and Agencies/Authorities in a knowledge dissemination and capacity building programme based on the outputs from the research. Capacity building should include a wide range of targets from central government agencies to village groups.

- PART 3: sustainable enhancement in the capacity of additional AfCAP partner countries

  Carry out situational analysis and initiate capacity building programme in additional countries.

- PART 4: uptake and embedment across AfCAP partner countries

  From informing national policies, through regional and district planning, down to practical provision of guidance on adaptation delivery at rural road level.

- PART 5: Phase 3 recommendations

  Set out proposals for long term monitoring and evaluation.

The proposed activities, deliverables and programme are also provided in Annex E.

3. Climate Resilience Adaptation Recommendations: Ethiopia

3.1 Contextual information on Ethiopia

3.1.1 Ethiopia observed weather-related disaster impacts

Ethiopia is the most populous country in east Africa and second most populous on the African continent. The landlocked country is also one of the least urbanised countries in Africa with 81 per cent of people (±79 million) living in rural areas.

Ethiopia has a diverse topography, complex climate with significant variability in rainfall and temperature and its population and economy is exposed to severe and frequent weather related hazards. According to UN HABITAT (2014), Ethiopia is amongst the 15 most vulnerable countries in the world. The country is especially vulnerable to natural hazards and has seen 67 weather related disasters (CRED, 2016) affecting an estimated 73 million people over the past four decades. Floods and droughts are the two most notorious natural disasters that have impacted on the countries development trajectory and livelihoods of its citizens. Droughts have been particularly devastating on loss of lives and livelihoods; 300,000 people have died and 71 million people have been affected due to 13 drought disasters in the past four decades.

Floods (in the form of flash floods in the highland areas and riverine floods in the lowlands) are the most frequent natural hazard that the country had to deal with; 51 flooding disasters have affected 2.6 million people, displaced almost 200,000 and killed an estimated 2,000 people between 1975 and 2015 (CRED, 2016).

Figure 1 shows the recorded location of flooding events highlighting the geographical location and extent of riverine and flash flooding. In addition to the disruption in agricultural production and contribution of flooding to erosion, soil loss and sedimentation, Hearn (2014) states that flooding in Ethiopia has also affected rural communities by isolating them from villages, markets and farmland.

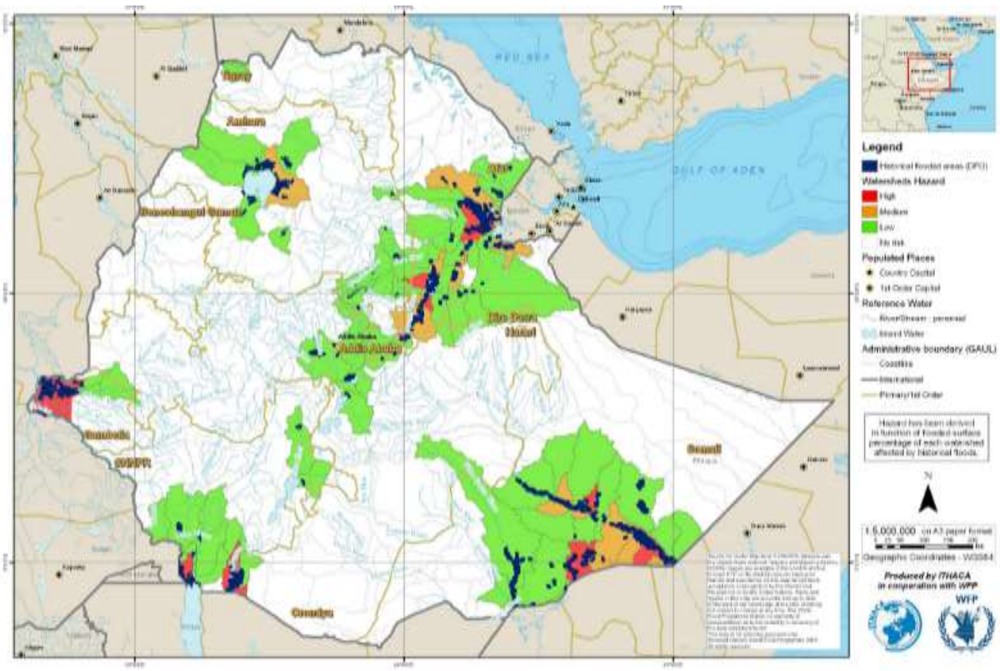


Figure 1: Recorded flooding events. (Map extracted from ITHACA database)

Agriculture forms the foundation of the Ethiopian economy and employs an estimated 80 per cent of the labour force. The agriculture sector is mainly made up of subsistence farming predominately rain fed agriculture and is thus extremely vulnerable to climate variability and change. The high socio-economic dependency on rain-fed agriculture makes the country especially vulnerable to hydrological, climatological and meteorological hazards. High dependency on natural resources, high rural isolation and significant environmental degradation (due to unsustainable land use practices) has exacerbated the vulnerability of the country's rural population.

Ethiopia is projected to experience rapid urbanisation and a substantial urban growth rate in the coming three decades (UN ESA, 2014) but despite this, the country will predominantly remain rural (65 per cent) by 2050 (UN ESA, 2014). The rural population is expected to grow to 117 million people adding 38 million additional people in rural areas by 2050, placing enormous pressure on land and natural resource management.

3.1.2 Projections of future climate change over Ethiopia for the mid and far-future

General temperature increases are projected for Ethiopia under low mitigation, across all seasons, and occurring in association with increases in heat-wave days and higher rates of evaporation (Conway and Schipper, 2011; Niang et al., 2014).

The CMIP5 and CMIP3 (*Coupled Model Intercomparison Project Phase 5 (CMIP5) and Phase 3 (CMIP3)*) are indicative of a generally wetter climate over the larger East African region towards the end of the 21st century (Moise and Hudson, 2008; Niang et al., 2014). These rainfall increases are projected to occur in association with the more frequent occurrence of seasons with heavy rainfall, and fewer seasons with severe drought. The number of days associated with extreme rainfall is correspondingly projected to increase under climate change (Seneviratne et al., 2012; Vizy and Cook, 2012). It may be noted that there is a contradiction between the projections of a generally wetter East Africa and the trends that have been observed in the East African climate over the last five decades (Funk et al., 2011&2012; Williams and Funk, 2011), and that the dynamic or thermodynamic mechanisms for this contradiction are not fully understood.

Over Ethiopia, most Global Climate Model (GCM) projections are indicative of generally wetter conditions, consistent with the changes projected for the larger East African region (Niang et al., 2014). However, the projected changes are generally small in amplitude. Comparatively, few Regional Climate Model (RCM) studies have been performed for Ethiopia, but from such studies there are indications of a shortening of the spring rainfall period over the eastern parts of the country (Cook and Vizy, 2013).

The 8 km resolution model simulations of ***present-day climatology (1971-2000)*** over Ethiopia are displayed in Figure 2. The simulated climatologies for annual average maximum temperatures (°C), very hot days (number of events per grid point per year), annual rainfall totals (mm) and extreme rainfall events (number of events per grid point per year) are shown[1]. Annual average maximum temperatures in the low twenties (°C) are simulated to occur over the Ethiopian highlands, with significantly higher annual average maximum temperatures occurring over eastern Ethiopia and also to the west of the highlands - in correspondence with observations. More than 100 very hot days are simulated to occur annually in the southeast, the coastal in the northeast (Eritrea) and to the west of the Highlands, but less than 10 of these days are simulated to occur annually over the highlands. High average annual rainfall totals of more than 1,000 mm per year are simulated to occur over the highlands region, with significantly lower totals and in fact semi-arid conditions simulated for the eastern part of the country. That is, the model simulations realistically represent the significant east-west rainfall gradient observed over Ethiopia. The simulated pattern in annual average numbers of extreme rainfall events over the area of interest closely follows that of the simulated rainfall totals.

[1] In this study, a very hot day is defined as a day when the maximum temperature exceeds 35°C, whilst an extreme rainfall event is defined as an event when the daily rainfall total (24-hours accumulated rainfall) exceeds 20 mm.

More than 12 extreme rainfall events are simulated to occur annually at locations in the highlands region (Figure 2).

For the ***mid-future period of 2021-2050*** two simulation models (ACCESS1-0 and CNRM-CM5 downscalings) are consistently indicating projected temperature increases of 1 to 2°C in the south-eastern parts of Ethiopia (see Annex F). However, over the highlands there are some discrepancies between the different models, with increases projected to be less than 1°C by one model and more than 1°C, reaching values as high as 3°C over some areas by the other model. Over the south-eastern parts, large increases in the number of very hot days, reaching values of 100 days per year, are consistently projected by the models. Both models are indicative of pronounced rainfall decreases occurring over the highlands regions already by the mid-future, but with compensating and pronounced increases in rainfall projected over the eastern parts. Extreme rainfall event changes are projected to follow a similar pattern than the projections of rainfall totals. An increase of four of these events or more per year (an increase of 30 per cent or more in the frequency of occurrence of such events) is projected in particular over the eastern highlands region, with smaller increases projected further to the east.

Drastic temperature increases, of more than 5°C are projected for the ***far-future (2071-2100)*** over the highlands region of Ethiopia by one of the models (ACCESS1-0 downscaling). However, in the other model (CNRM-CM5) the projected increases for this region are only in the order of 3°C (Annex F). Both models are indicative of drastic increases in the number of very hot days in the southeast (increased of as many as 100 days per year). In the ACCESS1-0 downscaling, these drastic increases in the number of very hot days also extend westwards to and over the highlands. Both models are indicative of pronounced rainfall decreases over the highlands and pronounced increases over the eastern parts, with extreme rainfall events exhibiting corresponding patterns of change over these regions.

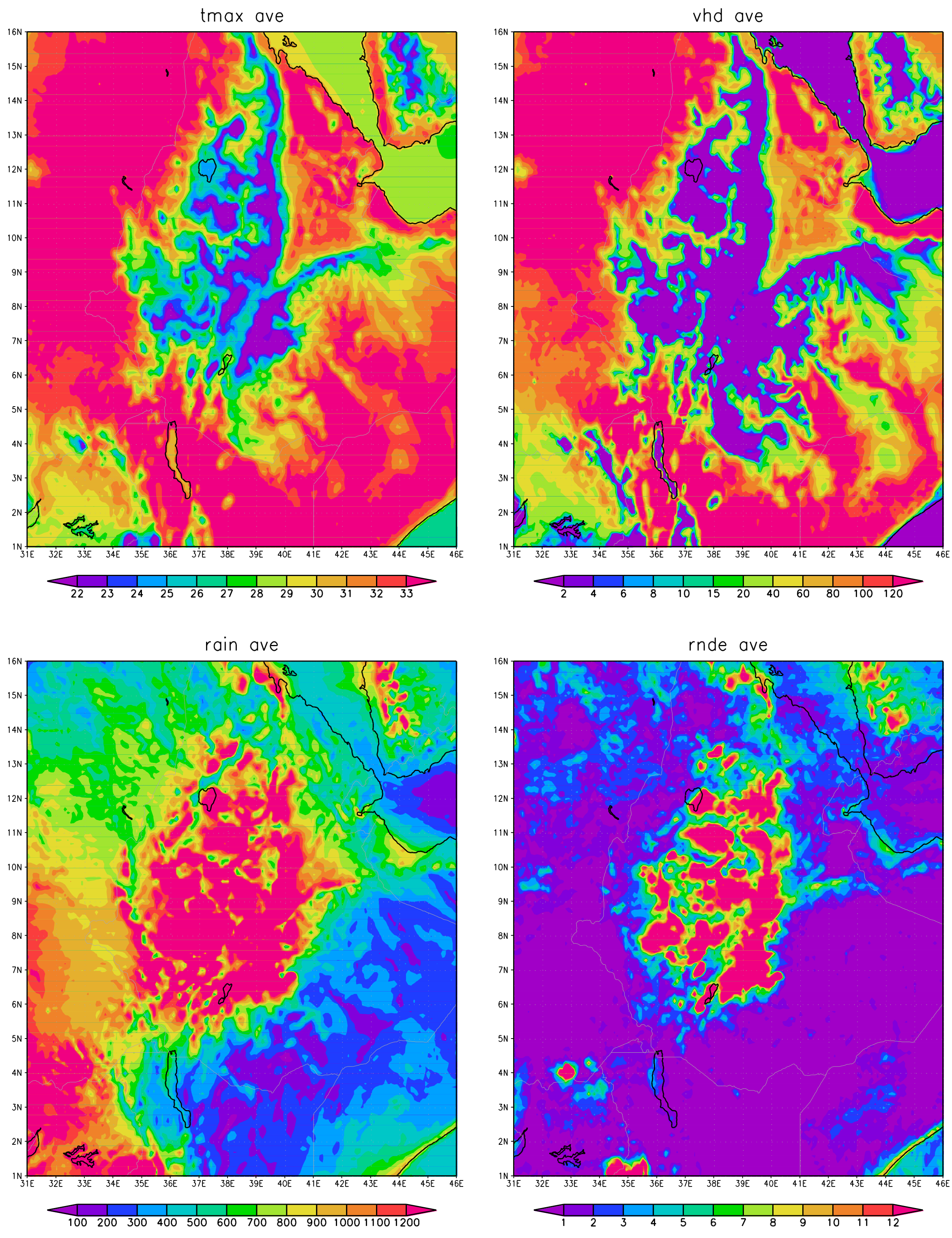


Figure 2: CCAM downscaled climatologies (averaged over the ACCESS1-0 and CNRM-CM5 downscalings) for the period 1971-2000 over the 8 km resolution area of interest over Ethiopia, for maximum temperature (°C), very hot days (number of events per grid point per year), rainfall (mm) and extreme rainfall days (number of events per grid point per year).

3.2 Contextual information on the project site: Tullu Bollo to Kela Road

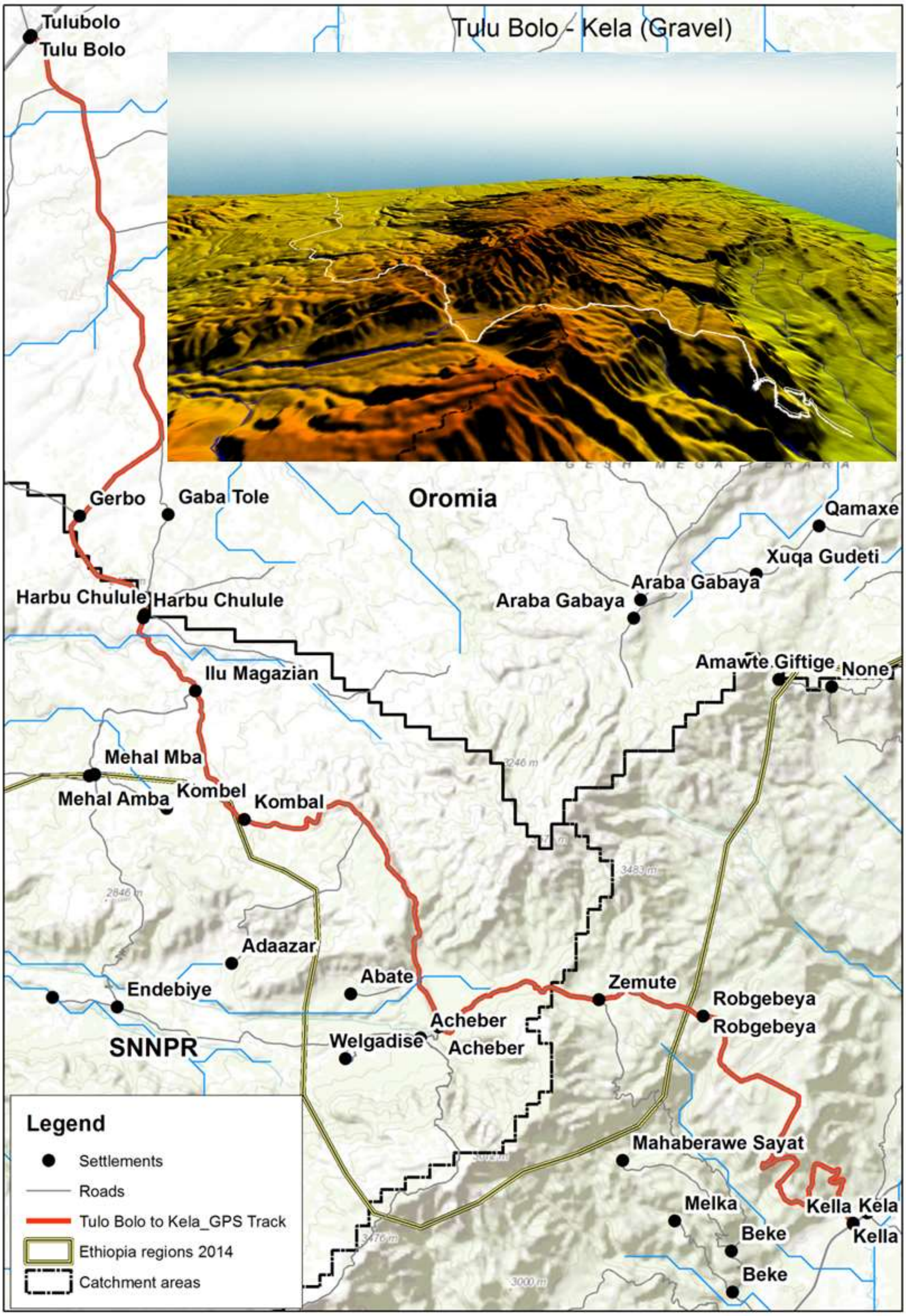


Figure 3: Geographical outline of the Tullu Bollo to Kela Road in Ethiopia

The Tullu Bollo to Kela rural access road is situated south of Addis Ababa and is 81.96km long. The road is located on the Ethiopian central highlands, and cuts through three catchment areas and several rivers and streams. The gravel road stretches from the town of Tullo Bollo (located at 2,189m above sea-level) and meanders through the hilly landscape of the Gesh Mega Terara (mountain range) reaching altitudes above 3,100m before descending steeply to the village of Kela (located at 1,920m above sea level) (Figure 4). The road services primarily rural villages and communities and facilitates access to larger towns, markets, health and educational amenities.

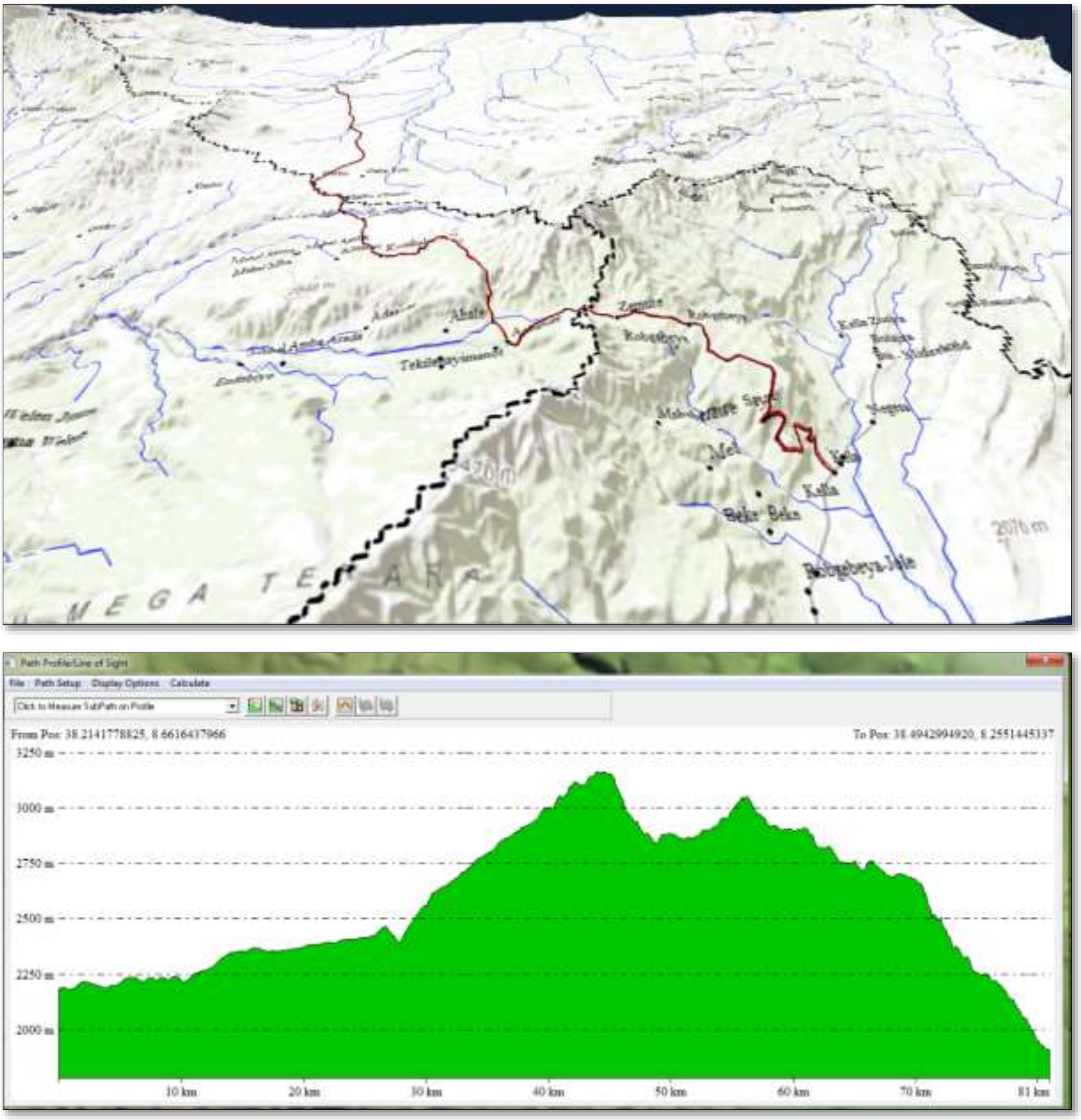


Figure 4: Topographic information on the Tullu Bollo to Kela Road

The road cuts through the Oromia (to the North) and Southern Nations, Nationalities, and Peoples Region (SNNPR) (to the South), two of the nine Ethiopian regions. The road spans across three districts (Woreda's) in two distinct zones and regions. The districts of Becho and Seden Sodo are located in the south-west Shewa zone in the Oromia Region, and the Sodo Woreda in the Gurage zone located in the SNNDR region. Population density in the region varies between 100 and 200 people per square kilometre, with small villages and towns clustered along the road with densities of between 200 and 300 people per square kilometre (Figure 5).

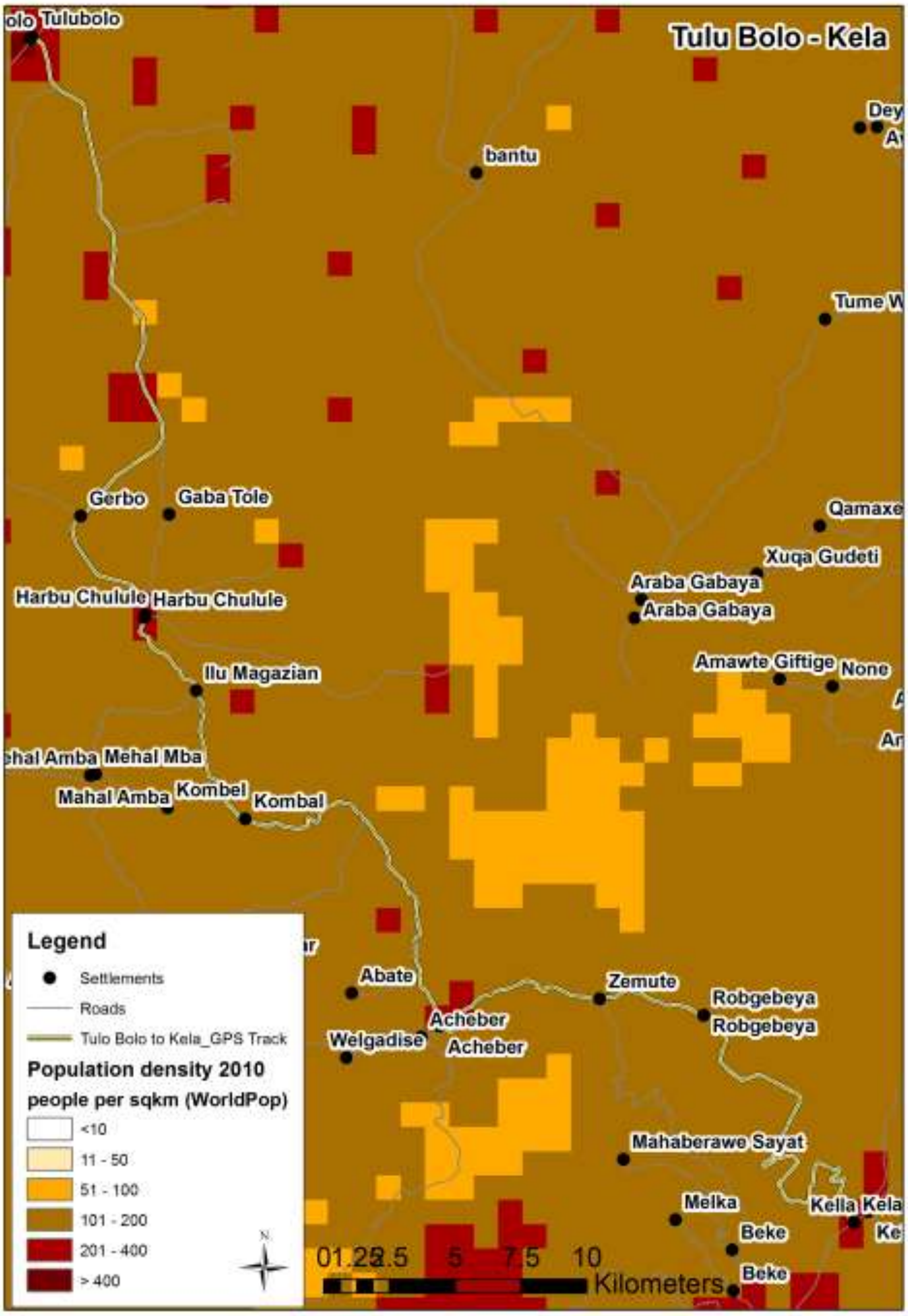


Figure 5: Population density along the Tullu Bollo to Kela Road

Land use in the area is predominantly characterised by subsistence farming with farmers dependent on rain-fed agriculture to sustain their livelihoods (Figure 6). Land degradation, overgrazing and unsustainable land use practices have resulted in erosion, nutrient depletion and sedimentation, and have also contributed to increases in flooding events.

The rural population in Ethiopia grew from an estimated 36 million to 81 million between 1985 and 2016 (UN-HABITAT, 2014) placing enormous pressure on natural resources. An example of such changes (deforestation/clearing of land to make way for a growing rural population and their food needs) is clearly visible in Figure 7 below. These changes (if not managed well) can contribute to flooding and sedimentation (as is the case in several sections along the road). Several adaptation plans and policies have however been implemented recently in Ethiopia to address these issues. The Productive Safety Net Program (PSNP) and the Household Asset Building Program (HABP) are two examples of climate-smart initiatives where climate adaptation have been mainstreamed. The PSNP is a good example of where adaptation measures such as building terraces, conserving soil, digging drainage channels and tree planting have restored some watershed catchments to reduce sedimentation in streams by as much as 40 to 50 per cent.

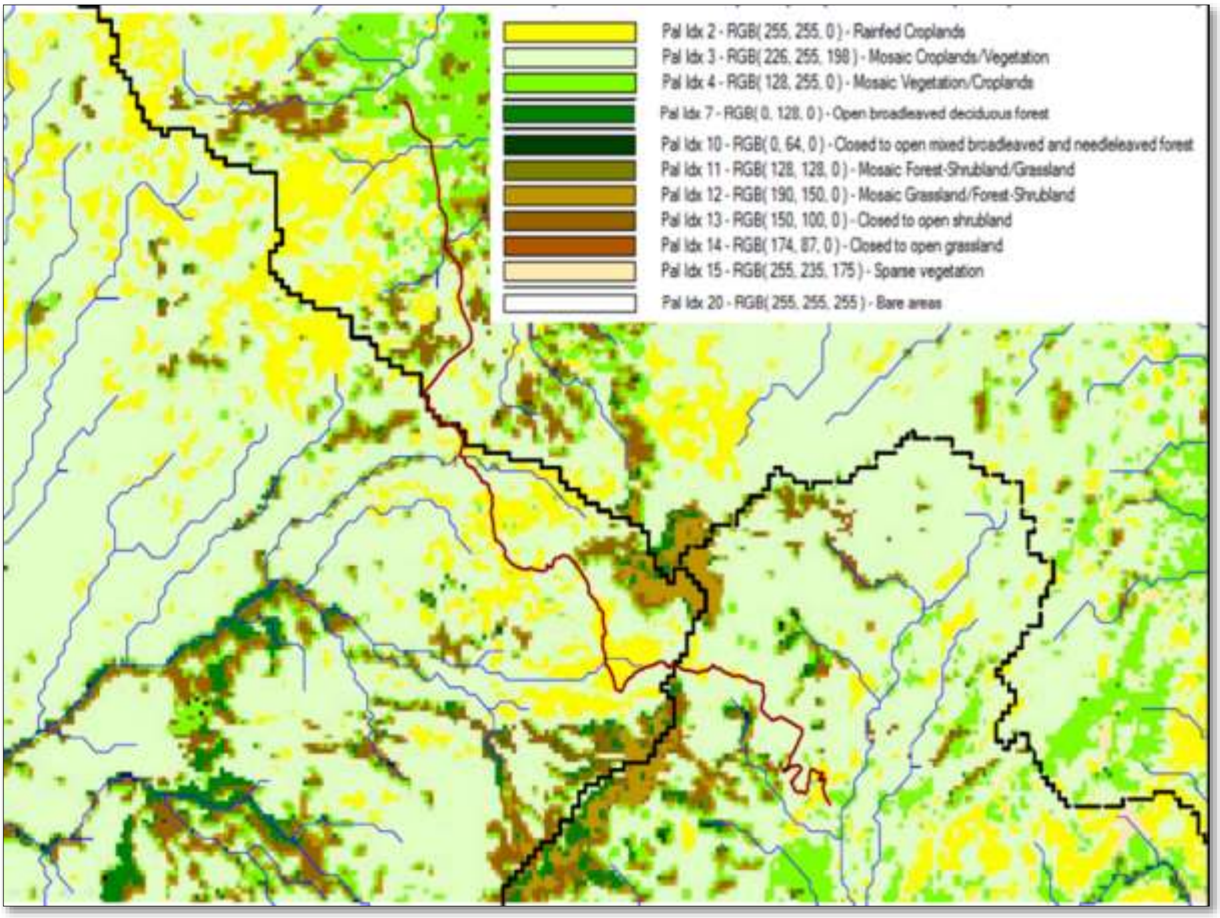


Figure 6: Land use along the Tullu Bollo to Kela Road

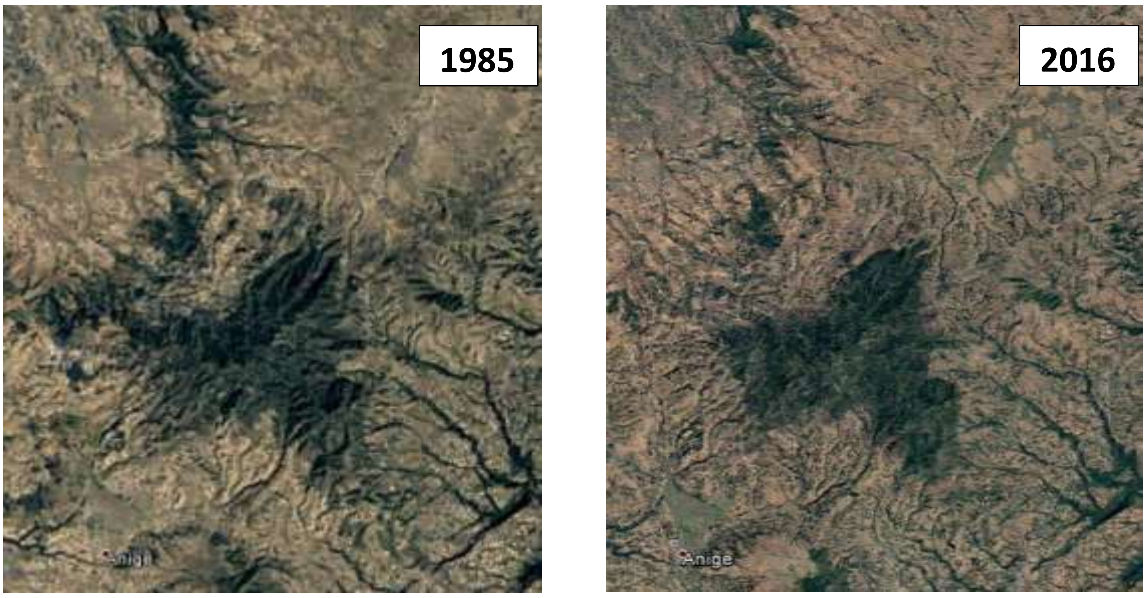


Figure 7: Impact of land use practices (deforestation) between 1985 and 2016

There are two rainy seasons in Ethiopia, namely from June to September, during the boreal summer, and in February (Selishi and Zanke, 2004). The road is predominantly located in the highlands, which generally exhibits a cool climate with high annual rainfall.

The rate of temperature increase over Ethiopia over the last five decades has been reported to be about 2.5°C/century in the northeast, 2°C/century in the southwest and somewhat less in the remainder of the country (Engelbrecht et al., 2015).

The results of the 8 km resolution projections of future climate change over the case study area in Ethiopia are displayed in Figure 8 (extreme rainfall events) and Figure 9 (annual rainfall totals).

Figure 8 displays the 8 km model simulations of present-day climatology (1961-1990) for both the ACCESS and CNRM-CM5 model downscalings (left) for the number of extreme rainfall events (number of events per grid point per year) over the case study area. Both downscalings are indicative of decreases in extreme rainfall events occurring in the case study area by the mid-future (middle) and far future (right).

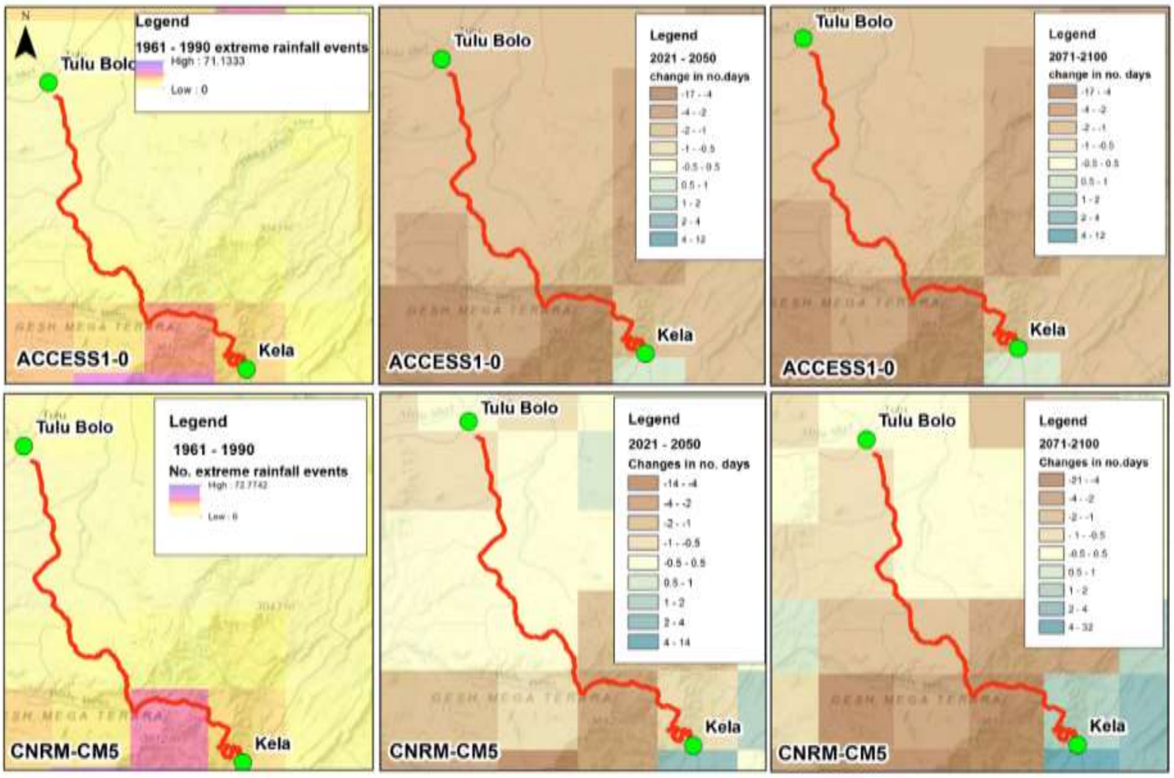


Figure 8: Present day (left), and mid-future (middle) and far-future (right) projections for extreme rainfall events along the Tullu Bollo to Kela Road

Figure 9 displays the 8 km model simulations of present-day climatology (1961-1990) for both the ACCESS and CNRM-CM5 model downscalings (left) for the number of annual rainfall totals (mm) over the case study area. Both downscalings are indicative of decreases in annual rainfall occurring in the case study area by the mid-future (middle). However, for the far future (right) one of the models (ACCESS) indicates an increase in annual rainfall, whereas the other model (CNRM-CM5) indicates a decrease in annual rainfall. Hence, the annual rainfall projections for the far-future are uncertain at this stage and would require further investigation.

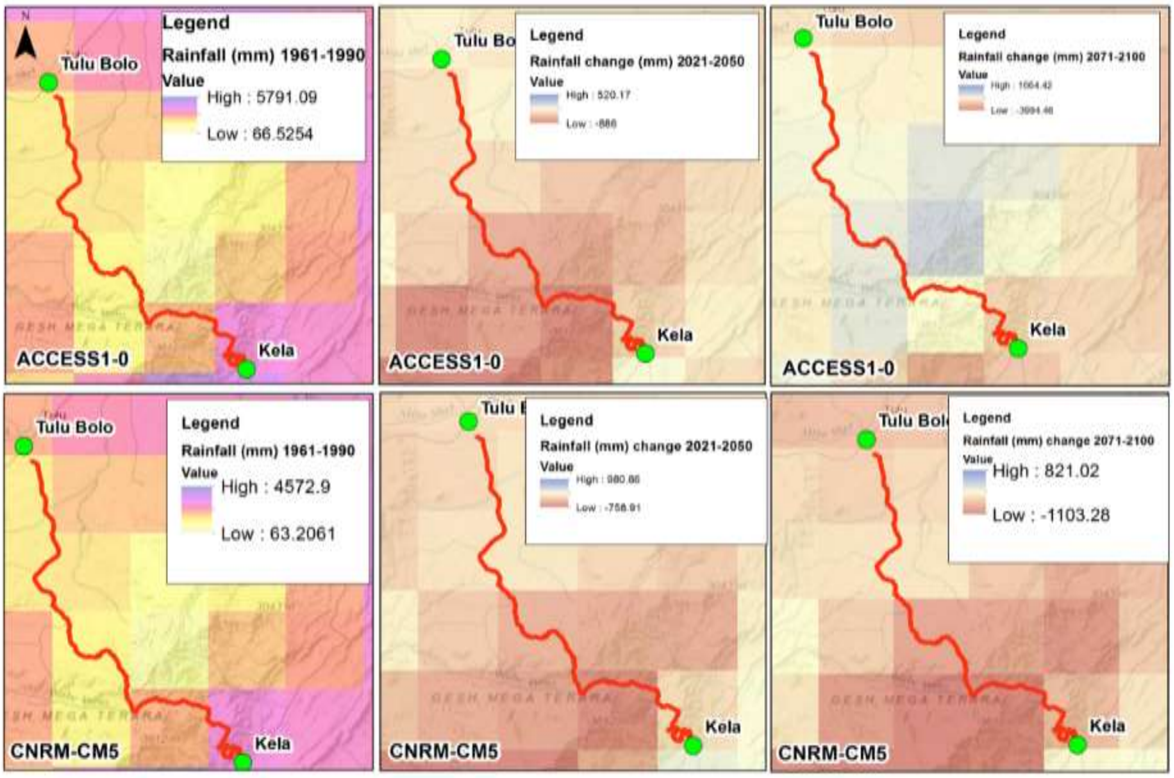


Figure 9: Present day (left), and mid-future (middle) and far-future (right) projections for annual rainfall totals along the Tullu Bollo to Kela Road

Based on the present-day climatology and future projections presented above, it would appear that, from an adaptation perspective, the primary focus of the Tullu Bollo to Kela Road is to render the road resilient to present-day climate conditions and impacts. The road is already on a programme to upgrade the entire length to paved standard.

3.3 Climate resilience adaptation recommendations: Tullu Bollo to Kela Road

Five dominant problems were identified along this road:

1. Shear failure due to excessive subgrade moisture
2. Erosion of wearing course and side-drains on grades
3. Slope instability
4. Erosion of embankments near structures
5. Collapse of structures

Upgrading of the road to a paved standard will improve or alleviate some of these problems.

3.3.1 Shear failure due to excessive subgrade moisture

It is essential that areas where the subgrade has become weak are identified and appropriate drainage measures are installed at these points. The existing unpaved road shows localised failures where the subgrade (expansive clay) moisture content has increased significantly. These areas will need to be identified and remedied before any paved road is constructed. In addition, the paved road should take the normal precautions against potential expansive clay damage, to minimise the damaging effects of prolonged higher temperatures and less frequent precipitation events.

Recommendation:

The section of road between coordinates 8.519833°N and 38.255542°E and 8.515891°N and 38.249841°E (about 700 m) should be constructed to minimise both volumetric movements and subgrade shear failures. As this is a low volume road, differential volumetric movements are not as critical as for conventional roads. However, longitudinal cracking associated with subgrade movement must be avoided as far as possible. The two problems can be best minimised by raising the formation at least 500 mm above natural ground level and flattening the slopes of the embankment to not steeper than 1:4 (V:H). The material excavated from the side drains can be used for this to give a section as shown in Figure 10. It is important that the side drains are carefully graded to avoid ponding and feed into appropriately spaced mitre drains. As severe erosion of some side-drains was observed during the visit, the spacing of the mitre drains must be such that erosion is minimised, probably no more than 40 m between each one. Where this spacing is impracticable, the use of water flow retarders or check dams must be considered.

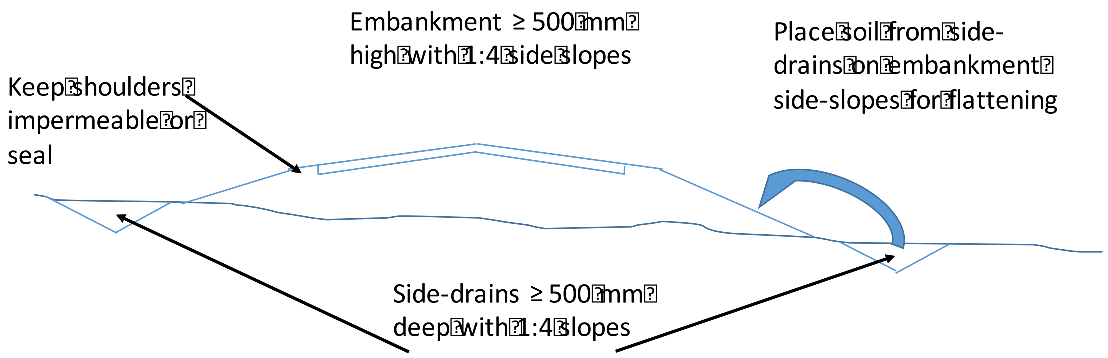


Figure 10: Handling expansive soils

3.3.2 Erosion of wearing course and side-drains on grades

This problem of erosion will mostly be avoided on a paved road, although unpaved shoulders will still be susceptible to erosion. This is particularly likely to occur at the edges of the surfacing if maintenance is delayed. Careful selection of the shoulder material so that it conforms with the gravel wearing course requirements (Annex G) will minimise the problem, but regular maintenance will be necessary both before and during the wet season.

Recommendation:

The local materials available for shoulder construction will be similar to the existing gravel wearing course (crushed weathered basalt or cinder ash), which is highly erodible on steeper grades (Figure 11). The section of road shown in Figure 11, just past the village of Harbuchulule, indicates the erodibility of the local materials and the well-designed cross-drain, the only one on the slope.

Figure 11: Erosion of shoulders and side drains on steep grade

It is proposed that this section of road, from just outside the town (38.251692°E, 8.456395°N) to the Wonga River (38.257022°E, 8.450464°N), be constructed as proposed in the current design. However, the shoulders should be constructed using material that complies with Annex G, compacted to 98% MDD heavy compaction and carefully graded to 4% camber, leading into re-shaped side drains. The current road has minimal cross-drainage leading to the extensive erosion of the side drains. It is recommended that cross-draining culverts (single 900 mm pipes) are installed every 40 to 50 m down the hill, with similar culvert inlets to that illustrated in Figure 10.

3.3.3 Slope instability

A number of areas of obvious instability and one significant landslide were noted between about km 44.6 and km 46.0. It was clear that most of the fallen debris had been removed and dumped over the opposite edge of the road. The risk of failures on this road leading to loss of life or major disruptions is relatively low and it is probably not practicable nor economically viable to install sophisticated slope stabilisation measures. Recent research has shown that the incidence of increased landslides due to climate change is unlikely to increase significantly, as it is the top-soil that is most susceptible to sliding (as is the case in these areas), and this takes millennia to form.

Recommendation:

It is recommended that the existing failed slope at about km 46.0 is cleaned/reshaped without removing excess material from the toe (this will reduce the current support and may trigger an additional failure) and a series of rock-filled Gabion baskets be installed as a catch-wall (Figure 12). These should be placed on a stable platform within the current drainage area and should be 3 m at their base and 3 m high, with all the baskets attached to each other. The mass of the filled baskets will provide additional toe support. It is also recommended that grass be established on the landslide scar and *eucalyptus sp* trees be planted on the stable slope above the landslide and around the perimeter of the failed area.

Figure 12: Sketch of proposed Gabion basket stabilisation measure

3.3.4 Erosion of embankments near structures

The fast flow of water at some drainage structures had resulted in damage to the adjacent fills and head and wing walls. In these cases, (e.g. at about km 46.0) the water flow paths need to be better controlled and the capacity of the structures increased where possible. The flow of water through the culvert, over the road and down an access road adjacent to the culvert at km 46.0 have resulted in significant erosion in the area and damage to the culvert (Figure 13).

Figure 13: Erosion around, below and adjacent to culvert

Recommendation:

In this area, it is proposed that the drains (side and catch-water) on the upslope side of the road be reshaped and graded with some enlargement. The existing pipe needs to be replaced and a second similar one installed next to it (or a cast in situ concrete box culvert of dimension 2 x 2 m may be more economical). The access path/road to the left of the culvert in Figure 13 should be reshaped, grassed and the access moved away from the culvert (it is currently badly eroded and too steep for most forms of transport). Anti-erosion measures need to be installed at the outlet of the culvert – these could be a stilling pod, or a concrete spillway with flow retarding structures.

3.3.5 Collapse of structures

Although minimal damage to most structures was observed, one small concrete bridge had collapsed totally. Observations of the cause were limited by the presence of water in the stream, but it appeared that the left abutment (in Figure 14) had been eroded/undercut causing collapse of the left side. Erosion of the approach fill (probably due to tilting of the deck) was evident on the right side. The collapsed section of the bridge has been filled with soil to allow continued passability. It was also clear that attempts to create a diversion channel with a new bridge had been made (Figure 15) but this appeared to be unsatisfactory with no possible water flow. On closer inspection from the upstream side (Figure 16), it was noted that the diversion passed through three pipes that were completely silted up on the downstream side.

Figure 14: Collapse of small bridge and erosion of approach fill

Figure 15: Construction of a river diversion (downstream side view)

Figure 16: Upstream view of diversion channel

Recommendation:

It is proposed that the collapsed bridge be removed and a slightly larger capacity bridge with the deck at a higher level (1 m higher) be constructed. The diversion channel is unlikely to be successful, as it is seldom possible to force a stream to change direction so radically without significant bank reconstruction and reinforcement. As it currently stands, the existing river has a small direction change at the bridge, which will require careful stone pitching on the eastern abutment to provide some protection in this area.

3.3.6 Summary

The suggested adaptation measure to be incorporated along this road are thus as follows:

Problem	Adaptations
Shear failure due to excessive subgrade moisture	Constructed to minimise both volumetric movements and subgrade shear failures Raise the formation at least 500 mm above natural ground level and flattening the slopes of the embankment to not steeper than 1:4 (V:H). Use material excavated from the side drains to give a better cross-section Side drains to be carefully graded to avoid ponding and feed into appropriately spaced mitre drains. Spacing of mitre-drains selected to minimise erosion (< 40 m)
Erosion of wearing course and side-drains on grades	Constructed according to current design. Shoulders must be constructed using appropriate wearing course material, compacted to 98% and carefully graded to 4% camber, leading into re-shaped side drains.

Problem	Adaptations
	Cross-draining culverts (single 900 mm pipes) to be installed every 40 to 50 m down the hill
Slope instability	Clean/reshape existing failed slope at km 46.0 without removing excess material from the toe Place a series of rock-filled Gabion baskets as a catch-wall. These should be on a stable platform within the current drainage area and should be 3 m at their base and 3 m high, with all the baskets attached to each other. Plant grass on the landslide scar and *eucalyptus sp* trees on the stable slope above the landslide and around the perimeter of the failed area.
Erosion of embankments near structures	Reshape and grade drains (side and catch-water) on the upslope side of the road be with some enlargement. Replace existing pipe and install a second similar one installed next to it. The adjacent access path/road should be reshaped, grassed and the access moved away from the culvert. Anti-erosion measures need to be installed at the outlet of the culvert – stilling pod, or a concrete spillway with flow retarding structures.
Collapse of structures	Remove the collapsed bridge and replace with a slightly larger capacity bridge with the deck at a higher level (1 m higher) The existing river has a direction change at the bridge – this will require stone pitching on the eastern abutment to provide erosion protection

4. Climate Resilience Adaptation Recommendations: Mozambique

3.4 Contextual information on Mozambique

3.4.1 Mozambique observed weather-related disaster impacts

Mozambique is exposed to weather related natural hazards such as drought, floods and cyclones. Rural isolation, poor infrastructure, high subsistence rain-fed agriculture and frequent exposure to intense weather related hazards arguably makes it the SADC country most vulnerable to weather related disasters (Van Niekerk & le Roux, 2016). Thirty nine per cent of its population live in coastal areas below 100m elevation (Van Niekerk & Le Roux, 2016) and climate projections indicate potential increases in the number of cyclones, flooding, storm surges as well as drought events (UN-Habitat, 2013; UN-Habitat, 2014). Since agriculture is largely based on subsistence farming, droughts and shifts in rainfalls patterns can lead to severe food and water insecurity. Mozambique is a country with a history of conflict and insecure land tenure and this is likely to lead to resource conflicts (Van Niekerk & Le Roux, 2016). Figure 17 shows the three most devastating weather related hazards and the table below indicates the devastating impacts that these three hazards have had on the country the past four decades.

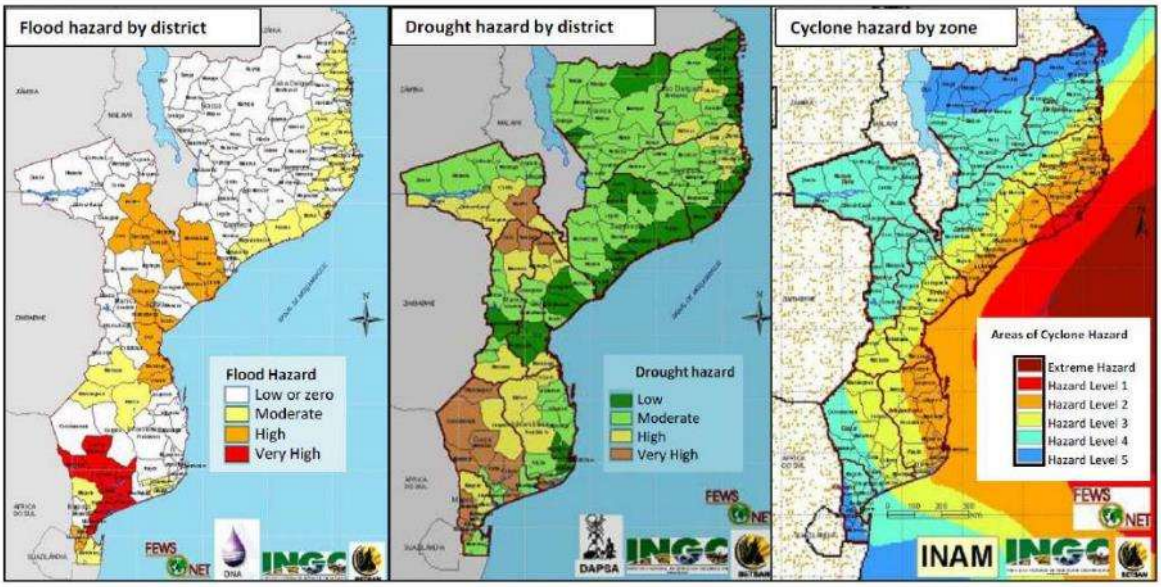


Figure 17: Hazard risk maps for flood, drought and cyclones (extracted from DRFI Country Notes)

Disaster Type	Occurrence	Total deaths	Total affected
Floods	31 (20 due to riverine flooding)	1 738	8 985 003
Storms	21 (15 due to tropical cyclones)	577	3 689 326
Droughts	12	100 068	17 757 500

3.4.2 Future climate change projections for Mozambique (mid and far-future)

The southern African region is likely to become generally drier under low mitigation (Christensen et al., 2007; Niang et al., 2015; Engelbrecht et al., 2015). Drastic temperature increases are projected to occur in conjunction with the rainfall decreases, approaching values of 6°C in the far-future over the subtropical interior regions. Over Mozambique, far-future increases are projected to range between 3 and 4°C over the eastern coastal areas, with larger increases projected for the western interior regions (Niang et al., 2014; Engelbrecht et al., 2015). For southern Mozambique, rainfall decreases are consistently projected across the majority of CMIP5 GCMs, with a mixed signal of rainfall increases and decreases projected for the northern parts (Niang et al., 2014). Very few regional RCM projection studies have to date been obtained for Mozambique. A northward shift in tropical cyclone tracks is projected by the ensemble of RCM downscalings generated by Malherbe et al. (2013), with implications of general rainfall increases and more flood events for central to northern Mozambique, with an associated decrease in such events projected for southern Mozambique.

The 8 km model simulations of ***present-day climatology (1971-2000)*** over Mozambique are displayed in Figure 18. The simulated climatologies for annual average maximum temperatures (°C), very hot days (number of events per grid point per year), annual rainfall totals (mm) and extreme rainfall events (number of events per grid point per year) are shown. Annual average maximum temperatures over 30°C are projected across Mozambique in correspondence to observations (Figure 18). More than 100 very hot days are simulated to occur annually over parts of the Limpopo river basin in the south, and also over a larger area in the Zambezi river basin in the north. High average annual rainfall totals of more than 1,000 mm per year are simulated to occur along the coastline, exhibiting a pronounced sea-breeze pattern. The southern part of the country, located in the Limpopo river basin, is semi-arid. The simulated pattern in annual average numbers of extreme rainfall events over the area of interest closely follows that of the simulated rainfall totals. More than 12 extreme rainfall events are simulated to occur annually at locations along the coast (Figure 18).

For the ***mid-future period of 2021-2050*** the models (ACCESS1-0 and CNRM-CM5) are consistently indicating projected temperature increases of 1 to 2°C in the southern parts of the country, with increases less than 1°C projected over the northern parts (cf. Annex H). The number of very hot days are projected to increase by 20 to 40 days per year across the county, with the largest increases projected for the Limpopo river basin in the south. Both models are indicative of pronounced rainfall increases as well as increases in extreme rainfall events over northern Mozambique, with smaller increases, or decreases, projected over the southern parts.

Temperature increases of about 4°C are projected for ***the far-future (2071-2100)*** over northern Mozambique by one of the models (ACCESS1-0 downscaling), with somewhat smaller increases projected by the other model (CNRM-CM5 downscaling). Relatively smaller temperature increases are projected to occur over the southern parts of the country (cf. Annex H). More than 40 very hot days per year projected to occur in the far-future compared to the present-day baseline climatology, with increases of more than 80 days per year projected over northern Mozambique by one of the models. The models are indicative of rainfall increases spreading to southern Mozambique by the far-future, with associated increases in extreme events. In the ACCESS1.0 downscaling model, however, it is projected that northern Mozambique will become drier under low mitigation for the far-future period (largely in contradiction with the CNRM-CM5 downscaling model).

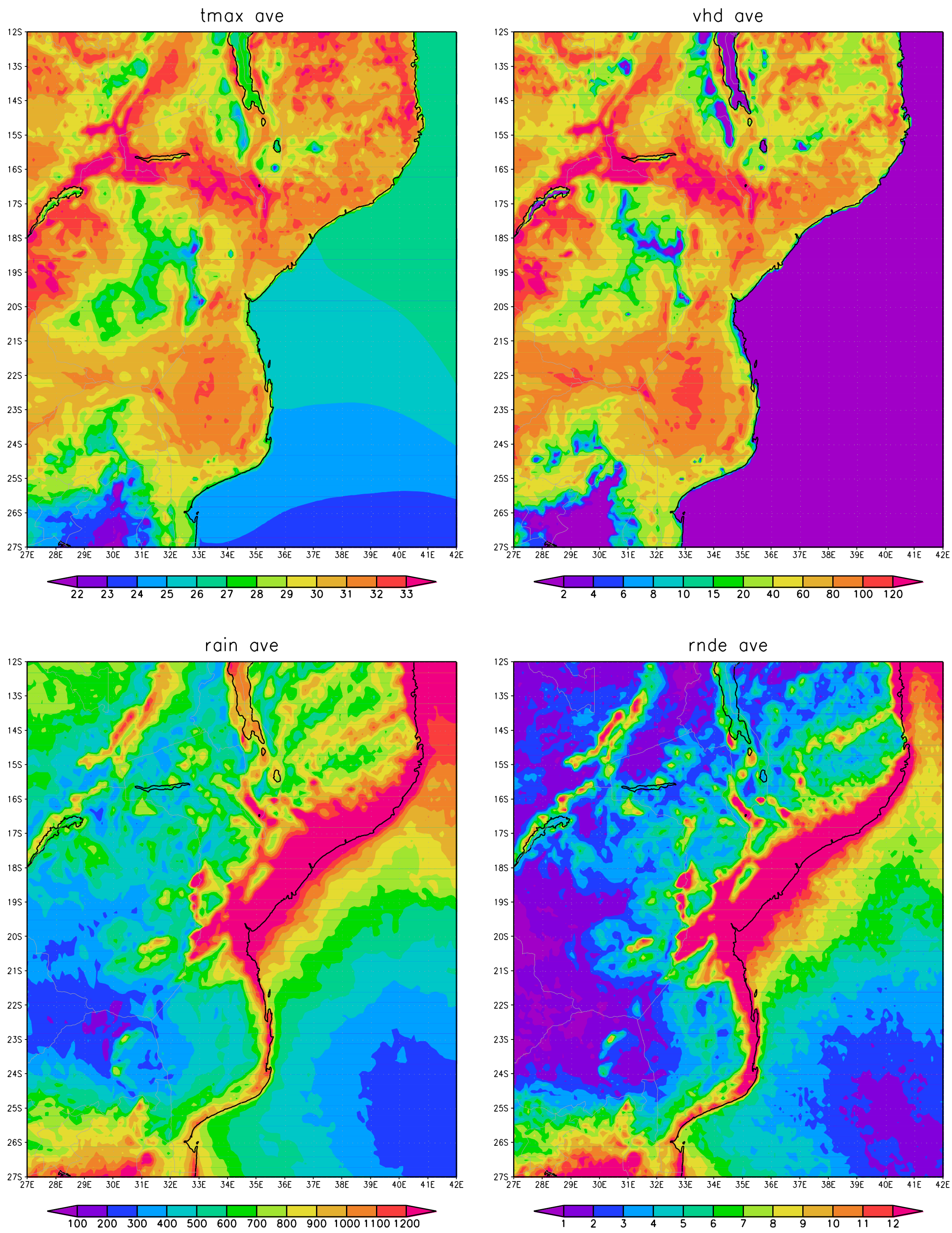


Figure 18: CCAM downscaled climatologies (averaged over the ACCESS1-0 and CNRM-CM5 downscalings) for the period 1971-2000 over the 8 km resolution area of interest over Mozambique, for maximum temperature (°C), very hot days (number of events per grid point per year), rainfall (mm) and extreme rainfall days (number of events per grid point per year).

3.5 Contextual information on the project site: Chokwe to Macarretane (R448)

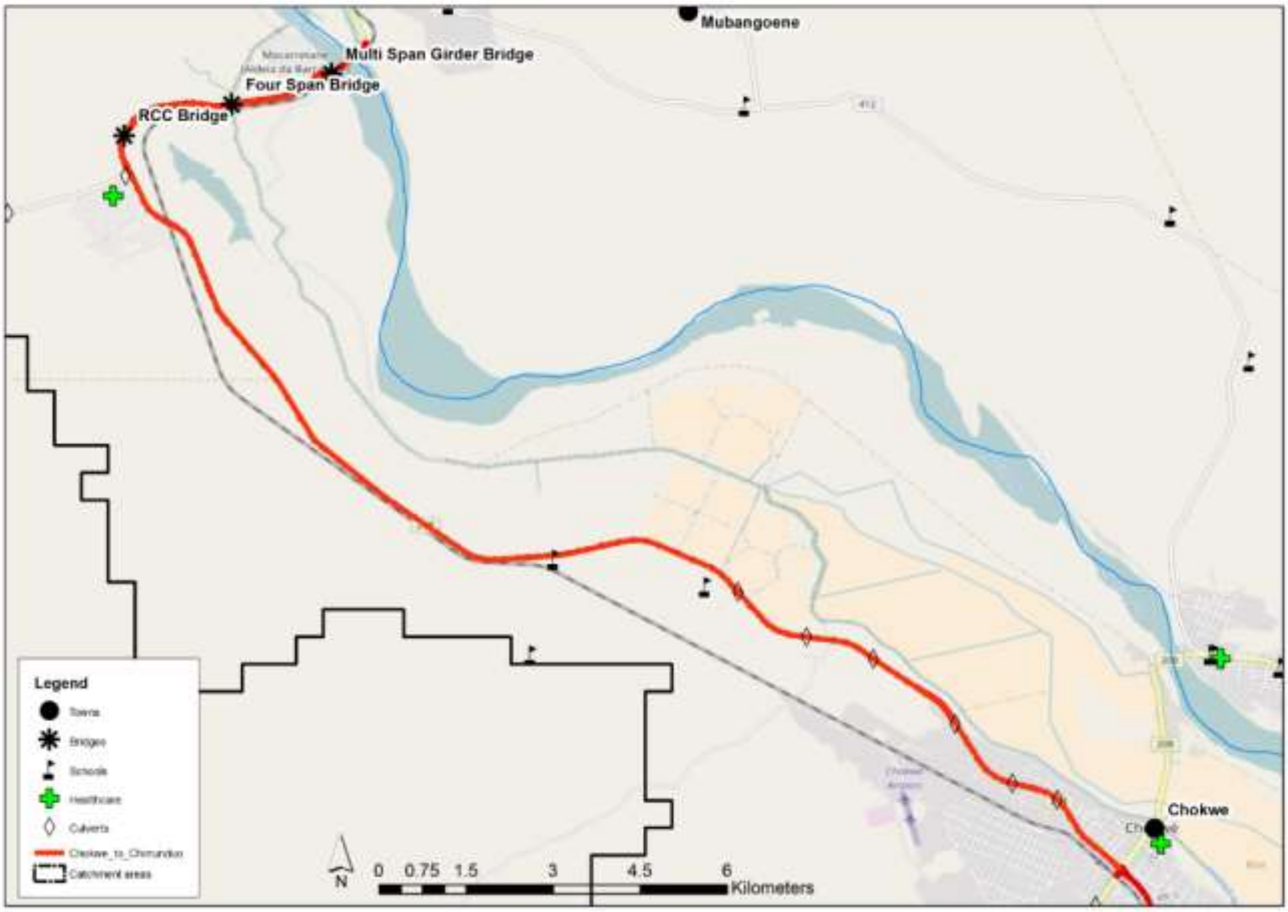


Figure 19: Geographical outline of the Chokwe to Macarretane Road in Mozambique

The Chokwe to Macarretane rural access road is situated roughly 90km (131km by road) north-west of Xai Xai and is 25km long. The road is in the Chokwe District within the Gaza province, and runs parallel with the Limpopo River, crossing it just outside Chokwe and Chirrunduo. The paved road is located in the Limpopo River Basin and is 2 to 5km west of the Limpopo River and about 22km east of the Rio Dos Elefantes (Olifants River). The section between Chokwe and Massingir has gone from a bad condition in 2009 to a fair condition in 2011; to a very bad condition in 2012 and back to a good condition in 2013; and again, to a fair condition in 2014 and a good condition in 2015. This is indicative of the very vulnerable nature of this rural access road, which has frequently been exposed to riverine flooding and has been devastated by flooding events in 2000, 2010 and more recently in 2013.

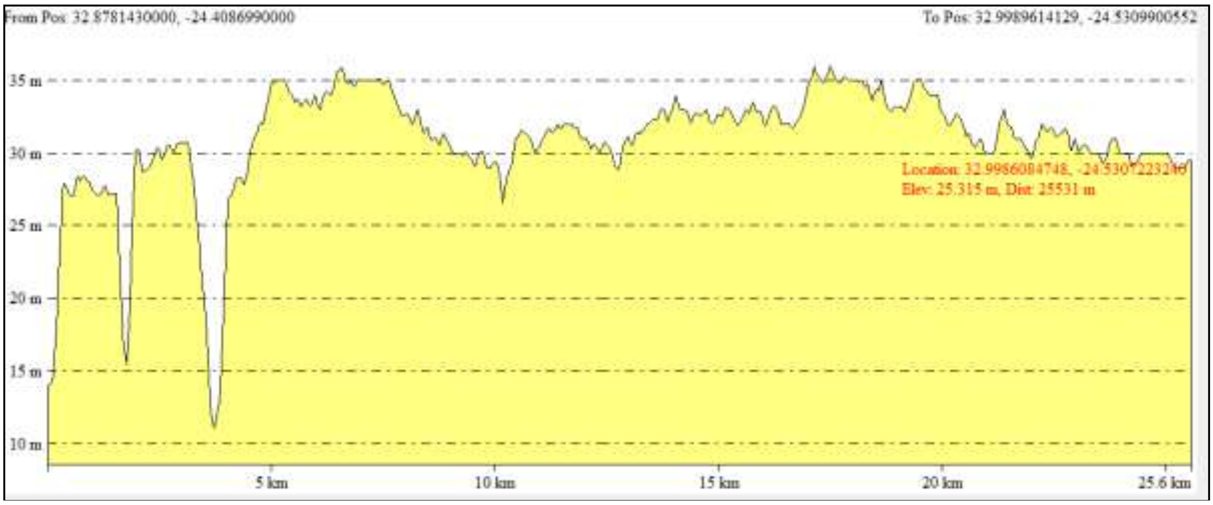


Figure 20: Topographic information on the Chirrunduo to Chokwe road

The road is located on a very flat topography with a minimum altitude of 27m and a maximum altitude of 36m. The road crosses an irrigation channel and a stream with two bridges.

Towns are clustered along the road and tends to expand exclusively south-west (away from the flood plains of the Limpopo River). The town of Chokwe has a density of as high as 3,500 people per square kilometre, and the town of Macarretane reaches densities close to 800 people per square kilometre. Both towns experienced devastating socio-economic losses from the 2000, 2010 and 2013 floods.

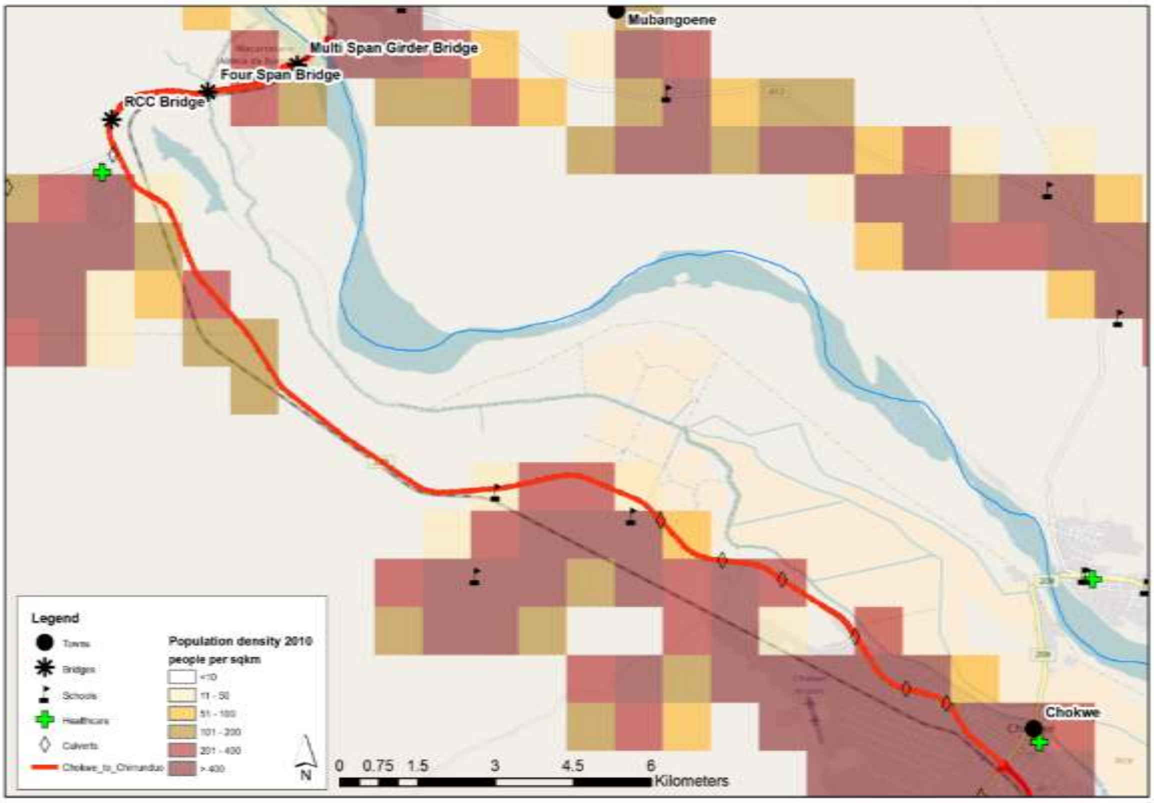


Figure 21: Population density along the Road

Land use in the area is predominantly characterised by agricultural farming. The Chokwe district also boasts the largest irrigation scheme in the country and supports a large number of small-scale farmers. However, repeated flooding, poor maintenance and salinization have had a significant impact on the effectiveness of the schemes.

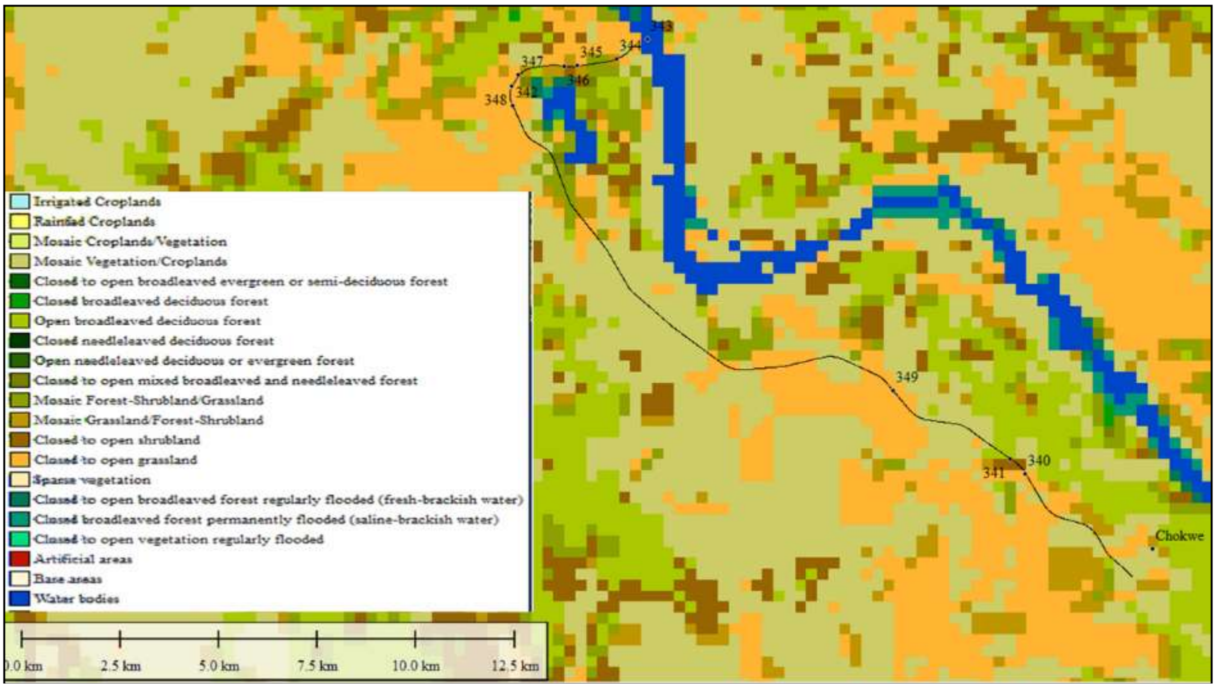


Figure 22: Land use along the Road

Figures 23 and 24 display the 8 km model simulations of present-day climatology (1961-1990) for both the CNRM-CM5 and ACCESS model downscalings (left) for the number of extreme rainfall events (Figure 23) and annual rainfall totals (Figure 24) over the case study area. The circles in Figures 23 and 24 indicate the location of the selected trial road.

Whereas the CNRM-CM5 model indicates a decrease in both extreme rainfall events and rainfall totals in mid-future (2021-2050) and in the far-future (2071-2100), the ACCESS model projects increases in those, especially in the far-future.

However, riverine flooding, in view of the size of catchment areas of the Elefantes and Limpopo rivers, should be of greater concern. The estimated catchment areas are as follows:

- Elefantes River at Massingir Dam: 64,390 km^2
- Limpopo River at Combomune: 241,000 km^2
- Limpopo River at Chokwe: 326,000 km^2

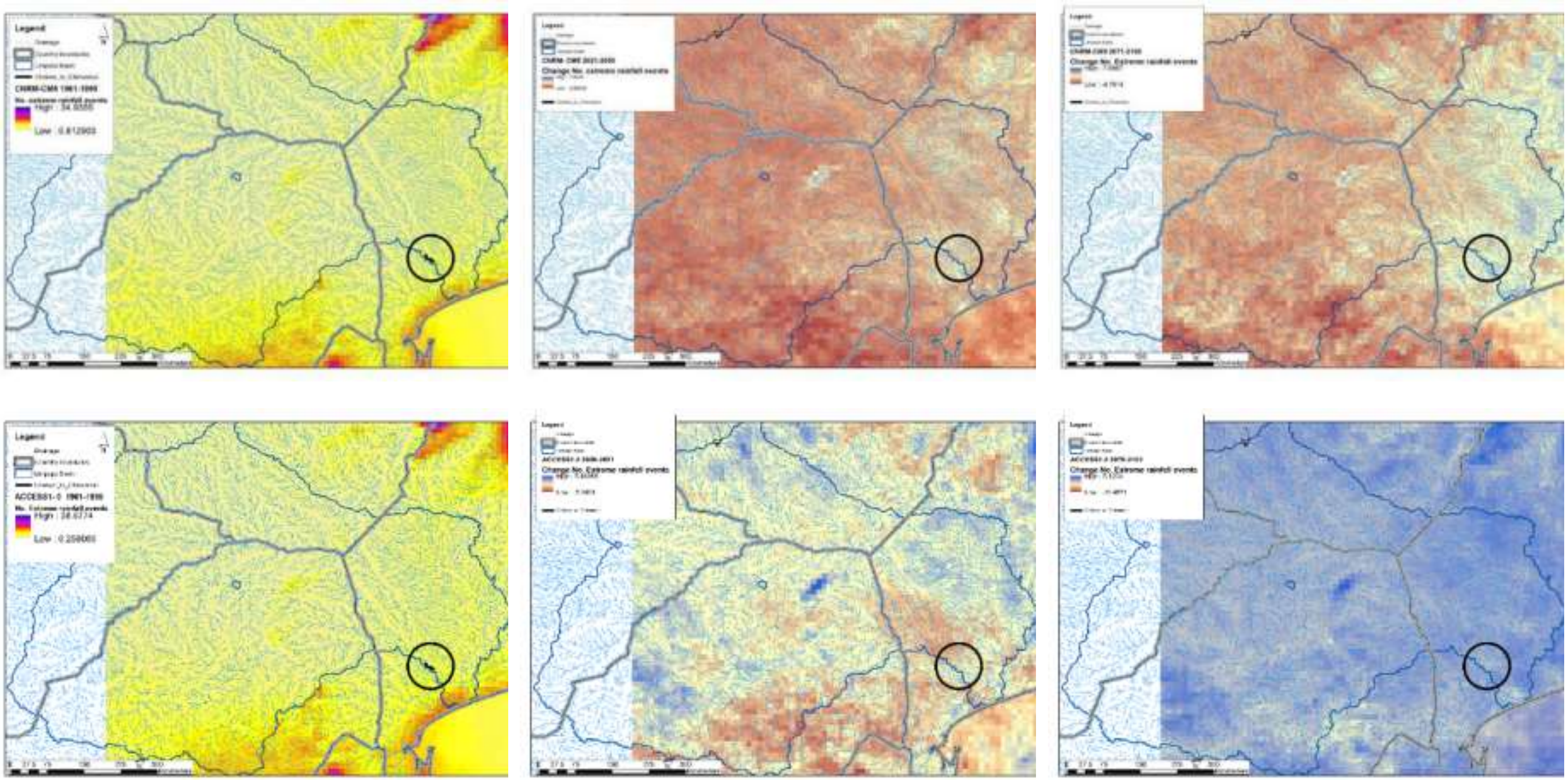


Figure 23: Present day (left), and mid-future (middle) and far-future (right) projections for extreme rainfall events in the vicinity of the project site for two downscaling models: CNRM-CM5 (top) and ACCESS1-0 (bottom)

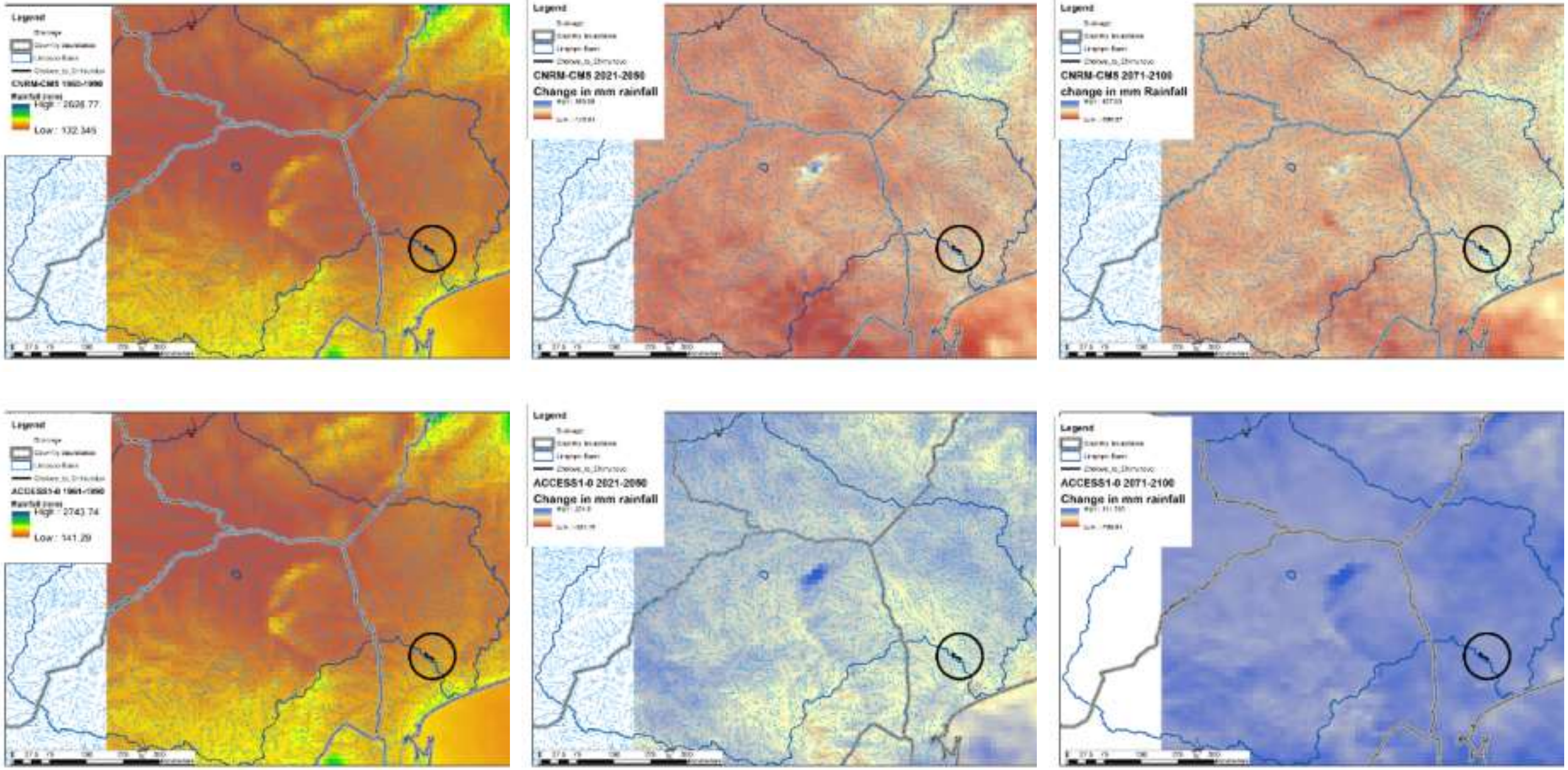


Figure 24: Present day (left), and mid-future (middle) and far-future (right) projections for annual rainfall totals in the vicinity of the project site for two downscaling models: CNRM-CM5 (top) and ACCESS1-0 (bottom)

3.6 Climate resilience adaptation recommendations: Road R448

Five dominant problems were identified along Road R448 (from Chokwe to Macarretane):

1. Loss of surfacing on low lying roads during overtopping
2. Pavement failures due to raised moisture contents in sub-layers
3. Erosion of high embankments and loss of surfacing during flooding
4. Undermining of embankment due to flooding

3.6.1 Loss of surfacing during overtopping

The surfacing at two places close to Chokwe was lost as the road was overtopped from the south west due to localised flooding. According to the ANE staff, this was apparently caused by rain falling in the catchment above the road and moving towards the Limpopo River (from left to right in Figure 25) and not from flooding of the Limpopo River. It was apparent that the velocity of the water flowing across the road removed the surfacing and washed away a part of the road.

Figure 25: Loss of surfacing due to overtopping

Recommendation:

It is suggested that the current gravel wearing course (the paved road has not been repaired yet) be replaced with a 100 mm thick “rollcrete” surface between 24°30’28.73”S and 32°58’20.25”E and 24°30’18.83”S and 32°58’11.02”E coordinates. The rollcrete is considered to be cheaper than conventional concrete and easier to construct, and should have a strength of 30 MPa. The use of flyash or Ground Granulated Blastfurnace Slag (GGBS) can assist in reducing the cost of the rollcrete, which will essentially replace the base course and the double seal.

The rollcrete should be the same width as the existing road although the road should be lowered slightly to form a drift at about natural ground level (remove the base course). The existing road shoulders (or preferably material complying with those for a good gravel wearing course as shown in Appendix G) should be ripped and re-compacted (at the lower levels of the drift) to refusal with the heaviest plant available and should lead into a properly shaped V-drain at least 0.6 m deep and on a 1: 2 (V: H) or preferably a 1:3 slope where space allows on the down-stream side of the road. The drains can be led into the lowest point in the area diverging away from the road towards this point. The purpose of these is to slow down water flows and to act as a stilling pond to reduce erosion as far as possible. It may be necessary to include some mitre drains off the side drain to reduce water flows, but this can only be decided when on site during construction. Unfortunately, it is not possible to indicate these on the GoogleEarth image as the road in this area is beneath the trees. However, a sketch of the layout is shown below.

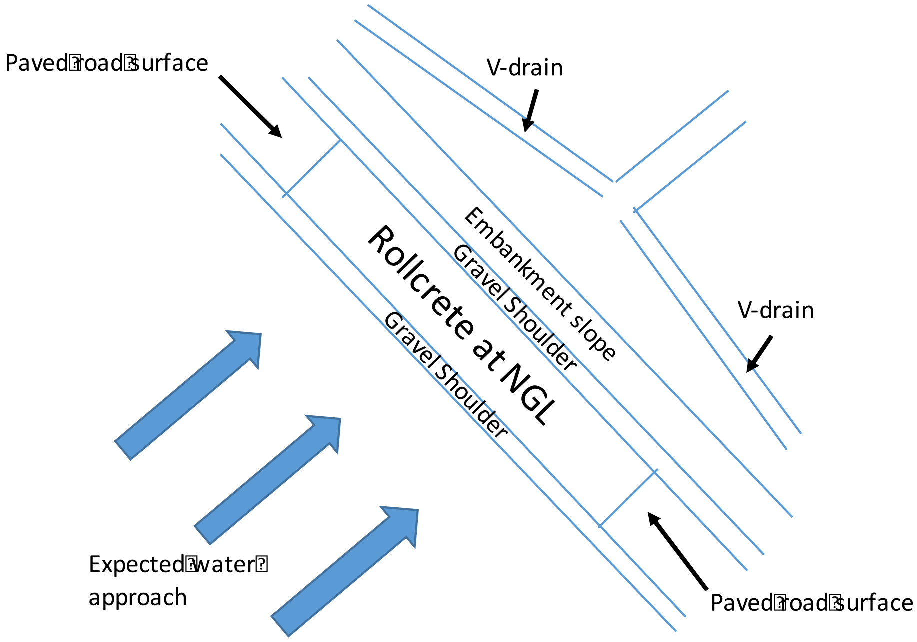


Figure 26: Sketch of proposed road and drain layout

3.6.2 Pavement failures due to raised moisture contents in sub-layers

A section of road about 16 km from Chokwe (from coordinates 24.442553°S and 32.857301°E to about 24.43557°S and 32.85446°E) showed several failures in the outer wheel track of the lane going towards Chokwe (apparently the heavier loaded of the two lanes). These areas exhibited significant crocodile cracking, rutting and shear failures. This was attributed to a build-up of water on the upslope side of the formation, which then soaked beneath the formation weakening the subgrade, which failed under heavy loads.

It is significant that the railway line running parallel to and uphill of the road has significantly more (and larger) culverts than the road (Figure 27). The road has only one or two single 600 mm pipe culverts in this section while the railway line has five box culvers each one consisting of 3 x 1m boxes.

The road failures have probably been exacerbated by the poor shape and condition of the shoulders in these areas (lack of maintenance), allowing moisture to accumulate alongside the bituminous surfacing.

Figure 27: Google Earth image of road and railway line comparing cross-drainage structures

Recommendation:

It is proposed that a section of road from the railway crossing extending back for one kilometre be upgraded. This will entail the side drains on the upslope side of the road being improved with better shape and grade. These should be unlined V-drains, at least 450 mm deep parallel to the road and about 1 m from the base of the formation/fill. They should be carefully graded on a 2% slope and lead into additional and larger culverts (3 x 900 mm pipes) placed preferably directly "downstream" of the railway culverts to allow the storm-water to be removed more effectively.

All accumulation of water up-slope of the road must be avoided. In addition, the shoulders must be constructed of approved material (Annex G), and graded, shaped and compacted to ensure that surface water is quickly and efficiently removed from both edges of the pavement after precipitation events.

3.6.3 Erosion of embankment and loss of surfacing during flooding

The failure of the road on a high embankment at about km 22.4 (coordinates 32.870408°E and 24.4131°S) with loss of surfacing and erosion of the slopes on the south side was due to flooding from the north caused by the dam on the Limpopo River to the west reaching its capacity. It was apparent that as the water rose in this area of the road, it flowed beneath the surfacing, which was lifted and washed away. The bituminous surfacing was a double seal on a strongly cemented sand base and it appeared that the bond between the two layers was weak with very little prime penetration, exacerbating the situation by allowing the water to penetrate beneath the seal.

Recommendation:

It is not possible to economically raise the height of the embankment to avoid overtopping but it is suggested that a part of the embankment slopes be flattened slightly 1: 2 (V:H) and maintained in a smooth condition. Deep-rooted grasses (e.g. vetiver sp.) should be established on the slopes. It is also important that the slope on the down-stream side of the embankment is flattened in the same way, vegetated with grass and maintained free of any obstruction that will cause turbulent flow of the water overtopping the embankment.

To improve the adhesion of the seal to the cemented sand layer, a low viscosity prime should be used and allowed to penetrate as deep into the base as possible. One of the current "ecoprimes" consisting of emulsified cutback bitumens should be used although there is little reported experience concerning its use on stabilised sands. It may also be beneficial to place a 150 mm section concrete edge beam alongside the seal to promote adhesion of the seal.

A mono-camber of 3% towards the north would also reduce turbulence of the water flowing southwards as it leaves the edge of the road.

The remainder of the damaged embankment should be re-constructed as planned to be used as a control section.

3.6.4 Undermining of embankment due to flooding

Just before the bridge at coordinates 32.870408°E and 24.4131°S the floodwaters had overtopped a much lower embankment than that in Section 4.3.3 (about 1 m high) and on the downstream slope severe undercutting of the pavement had occurred with a total loss of the embankment supporting the pavement structure (Figure 28). This again was due to turbulent flow of the overtopping water causing erosion of the embankment leading to undercutting of the shoulders and ultimately the pavement structure.

Once the shoulders had been eroded, the unstabilised layers beneath the stabilised base and subbase were easily eroded leading to "undermining" and collapse of the pavement structure (Figure 28).

Figure 28: Erosion of embankment and undercutting of pavement caused by overtopping

Recommendation:

To avoid such erosion, it is essential that the shoulders and the embankment are compacted to as high a density as possible (not only the 95% typically specified for shoulders but preferably 98 or 100% Mod AASHTO). The shoulder materials should comply with those for a gravel wearing course in the Standard Specifications (Annex G) and the camber should be reduced to 2% over the shoulders to reduce water flow velocities. Any obstructions (bushes or trees, etc.) likely to lead to turbulent flow should be removed during routine maintenance and all termite or ant activity must be neutralised (not ecologically ideal but it must be done to protect the embankment!). The establishment of a smooth grass cover using a deep-rooted grass species will also assist in increasing the erosion resistance of the embankment fill.

3.6.5 Summary

The proposed recommendations for climate adaptation are summarised as follows:

Problem	Adaptations
Loss of surfacing on low lying roads during overtopping	Replace current gravel wearing with a 100 mm thick "rollcrete" This should be slightly lower than the existing road to form a drift at natural ground level. Rip and re-compacted the existing (or preferably new material) in the shoulders Construct a V-drain where space allows on the down-stream side of the road. Include some mitre drains off the side drain to reduce water flows,
Pavement failures due to raised moisture contents in sub-layers	Improve the side drains on the upslope side of the road with better shape and grade. Construct additional and larger culverts directly "downstream" of the railway. Avoid all accumulation of water up-slope of the road Construct the shoulders with approved material and grade, shape and compact to ensure surface water is removed from both edges of the pavement.
Erosion of high embankments and loss of surfacing during flooding	Flatten embankment slopes slightly and maintain in a smooth condition. Establish deep-rooted grasses on the slopes. Flatten and vegetate slope on the down-stream side of the embankment Improve the adhesion of the seal to the cemented sand layer (low viscosity prime) Place a 150 mm section concrete edge beam alongside the seal Construct a mono-camber of 3% towards the north to reduce turbulent flow

Undermining of embankment due to flooding	Compact shoulders and embankment to as high a density as possible. Shoulder materials must comply with those for a gravel wearing course Reduce camber to 2% over the shoulders. Eliminate any obstructions likely to cause turbulent flow Establishment of a smooth grass cover using a deep-rooted grass species

5. Climate Resilience Adaptation Recommendations: Ghana

3.7 Contextual information on Ghana

3.7.1 Ghana observed weather-related disaster impacts

Ghana has experienced rapid urbanisation and already the majority of people (54 per cent in 2015) is living in urban built-up areas. Urbanisation is expected to continue and it is estimated that 71 per cent of Ghana's population will be located in cities and towns by 2050 (UN ESA, 2014).

Ghana is vulnerable to the effects of weather related natural hazards such as floods and droughts; 16.3 million people have been affected by weather related disasters over the past four decades. Seventeen recorded flooding events have costs the lives of approximately 450 people and affected an estimated 3.8 million people. Of particular mention is the 'northern' and '2nd northern' floods of 1999 and 2007 that caused large scale devastation affecting more than 650,000 people cumulatively and killing approximately 110 people (CRED EM-DAT, 2016). Flooding is the weather-related natural hazard responsible for killing most people and inflicting the largest economic damages.

Insufficient and erratic rainfall have also been responsible for significant food insecurity that resulted in two large-scale operations in 1997 and 1998 to provide subsidies for food supplies in affected areas (NADMO, 2016). Population growth and unsustainable land-use practices have resulted in significant coastal erosion, deforestation, desertification and soil erosion and, coupled with variability in rainfall and lack of sufficient infrastructure, have resulted in significant flooding events. Figure 29 indicates the extent of flooding hazards in Ghana, depicting the exposure of the northern and south-western (Accra) regions.

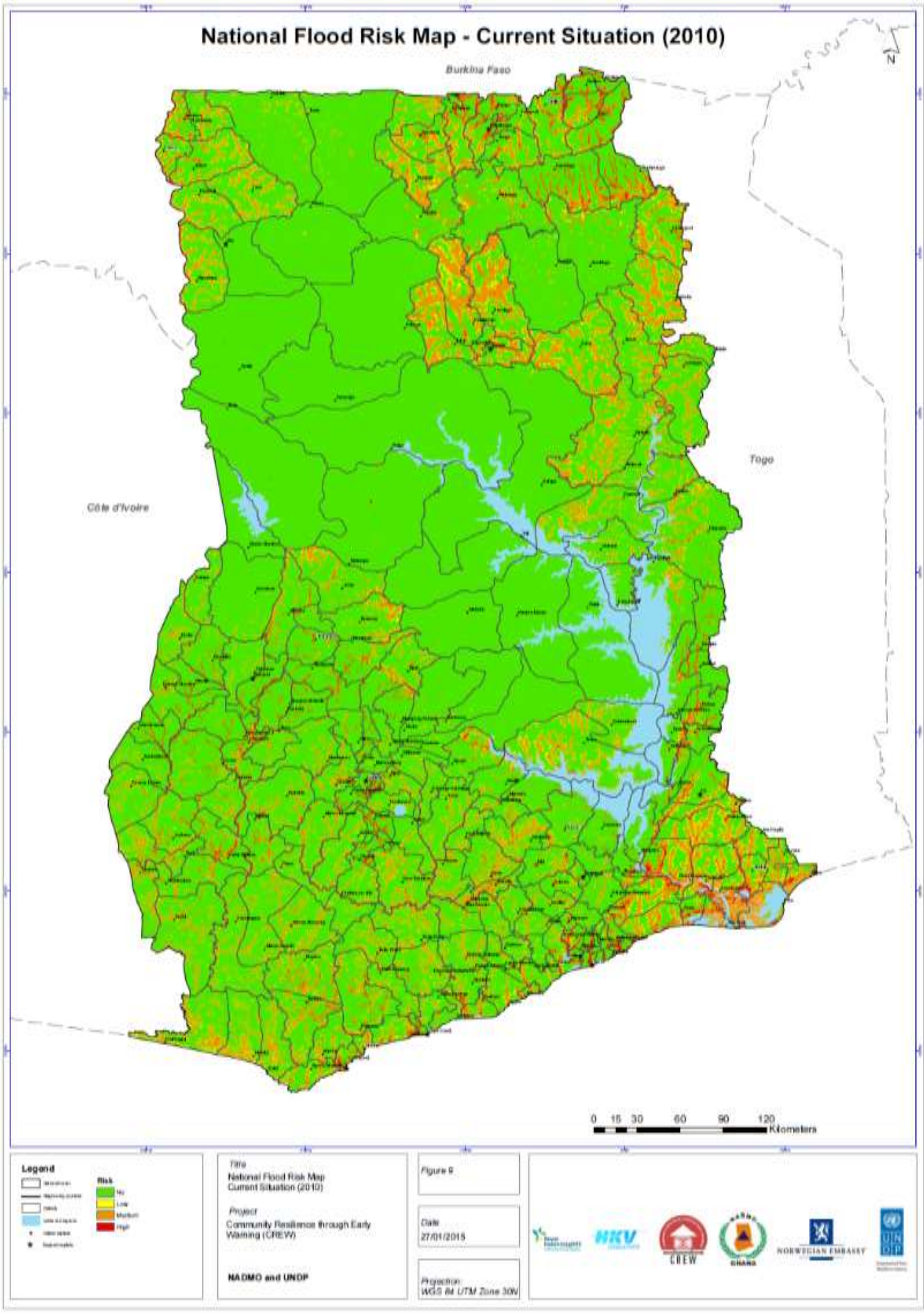


Figure 29: Flood Risk Map, 2010 (https://crewghana.wordpress.com/)

3.7.2 Projections of future climate change over Ghana for the mid and far-future

Located in tropical West Africa, Ghana's climate exhibits relatively small inter-annual variability in temperature. As a consequence of the regional response to global warming over the country, temperature increases under low mitigation may reach values unprecedented in terms of natural variability as early as in the 2030s (Mora et al., 2013; Niang et al., 2014). Under low mitigation the ensemble of CMIP5 GCMs project temperature increases to range between 3 and 4°C over the southern parts of Ghana including the coastal areas, with increases of more than 4°C projected for the northern interior regions. RCM projections are indicative of changes of similar amplitudes (Patricola and Cook, 2011; Mariotti et al., 2011; Vizy et al., 2013).

The CMIP5 GCM projections of future rainfall patterns over Ghana, and in fact the larger West African region, are uncertain. The projections do not only differ significantly in terms of the amplitude of change, but also on the direction of change (i.e. whether it will become drier or wetter) (Niang et al., 2014). This uncertainty may at least be partially attributed to the inability of GCMs to resolve convective rainfall (e.g. Biasutti et al., 2008) – a shortcoming that carries over to the CORDEX RCMs. Another possible cause of this wide uncertainty range are the systematic errors exhibited by most GCMs in the simulation of Atlantic ocean SSTs off the west coast of Africa, with implications for the model simulations of the West African monsoon. There is greater correspondence in GCM and RCM projections that extreme precipitation events over West Africa may increase under climate change (Seneviratne et al., 2012; Haensler et al., 2013), although the confidence in these projections is thought to still range only between low and medium.

The 8 km model simulations of ***present-day climatology (1971-2000)*** over Ghana are displayed in Figure 30. The simulated climatologies for annual average maximum temperatures (°C), very hot days (number of events per grid point per year), annual rainfall totals (mm) and extreme rainfall events (number of events per grid point per year) are shown. Annual average maximum temperatures in the mid- to high twenties (°C) are simulated to occur along the coastline of Ghana, in correspondence with observations. Higher maximum temperatures are simulated to occur over the interior regions to the north. More than 100 very hot days are simulated to occur annually over the far northern interior regions of Ghana, but less than 10 of these days are simulated to occur annually (on the average) along the coastline, due to the moderating effects of the ocean. High average annual rainfall totals of more than 1,200 mm per year are simulated to occur all along the coastline of Ghana. This rainfall pattern exhibits the clear signature of strong sea- breeze circulations and the influence of larger-scale onshore monsoon winds. A strong south-north gradient in rainfall is simulated to occur to the north of the coastal belt, with local rainfall maxima over areas of steep topography and in the vicinity of inland lakes. The simulated pattern in annual average numbers of extreme rainfall events over the area of interest closely follows that of the simulated rainfall totals. More than 12 extreme rainfall events are simulated to occur along the coastline.

For the ***mid-future period of 2021-2050*** relatively small temperature increases of about 1°C are projected to occur over most of Ghana, with increases reaching values up to 2°C in the north (all changes are calculated relative to the baseline period 1971-2000) (Annex I). Both of the downscalings are indicative of rainfall increases over the coastal belt and eastern interior for the mid-future, with rainfall decreases being projected for the western interior. Extreme rainfall event changes are projected to follow a similar pattern than the projections of rainfall totals. An increase of four of these events or more per year are projected to occur at locations all along the coastal belt (and increase of about 30 per cent in the frequency of occurrence of these events), corresponding to the region of maximum increase of rainfall events.

Large temperature increases, of more than 4°C, are projected for southern and central Ghana for the ***far-future period of 2071-2100*** relative to 1971-2000 (Annex I) in the CCAM- ACCESS1-0 downscaling. Somewhat more conservative temperature increases are projected by the CCAM-CNRM-CM5 downscaling. Both downscalings are indicative of drastic increases in the number of very hot days occurring over the area of interest under climate change. These may increases may be as large as 100 days per year over the southern interior regions of the country. Both downscalings are also indicative of rainfall decreases along the coastline of Ghana and the Atlantic Ocean to the south in the far-future. General rainfall increases are projected for the interior regions of Ghana, with the exception of rainfall decreases that are projected for northern Ghana in the ACCESS1-0 downscaling. The projected pattern of changes in extreme rainfall events closely resembles that of the projected changes in annual average rainfall totals. Increases of four or more events per year (an increase of

30 per cent or more) are projected to occur over the coastal belt, extending to the eastern interior regions.

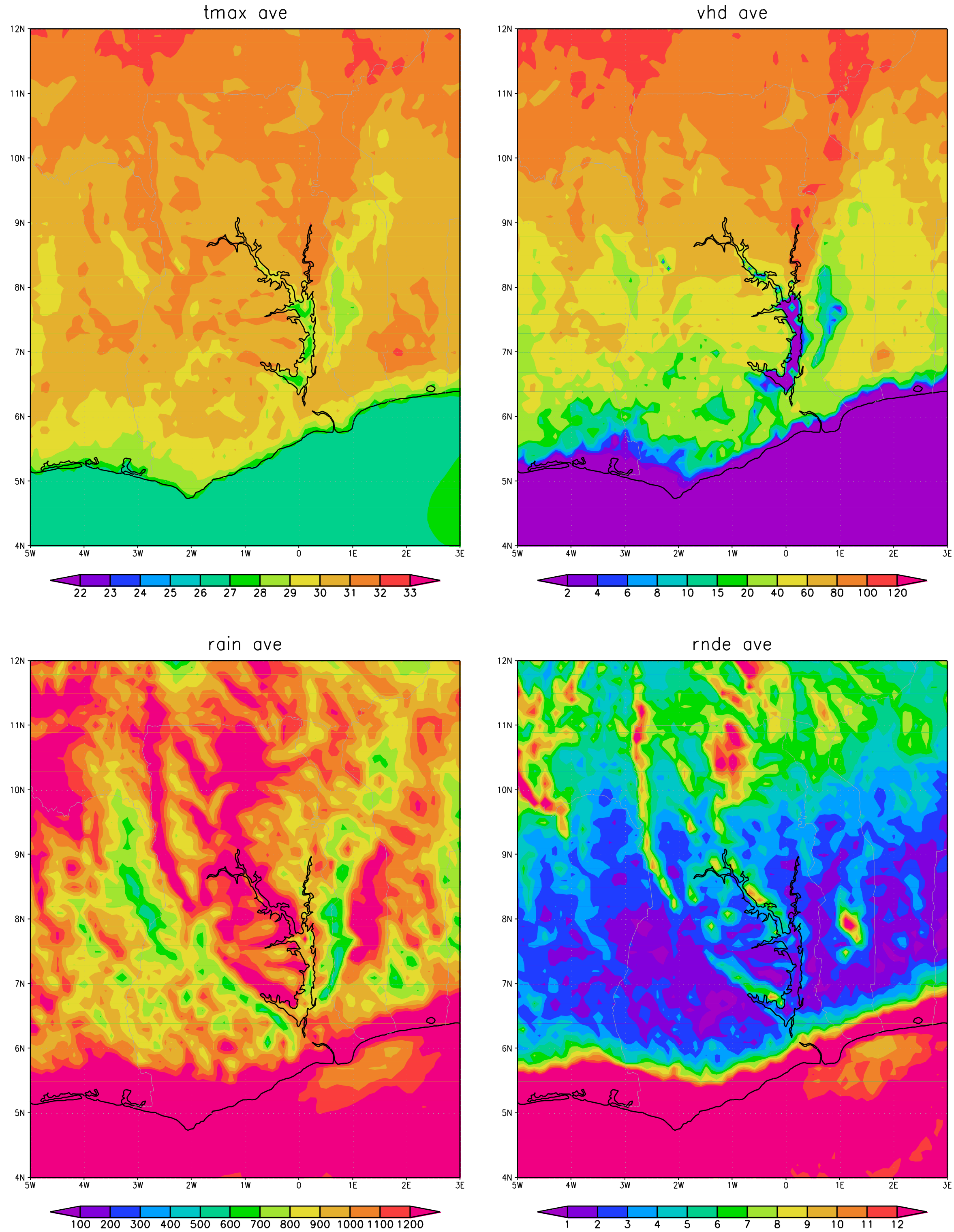


Figure 30: CCAM downscaled climatologies (averaged over the ACCESS1-0 and CNRM-CM5 downscalings) for the period 1971-2000 over the 8 km resolution area of interest over Ghana, for maximum temperature (°C), very hot days (number of events per grid point per year), rainfall (mm) and extreme rainfall days (number of events per grid point per year).

3.8 Contextual information on the project site: Tampion-Tidjo Road

The Tampiong Jimle rural access road (Figure 31) is situated roughly 30km north east of Tamale and is 35 km long. The road is located in the Northern Region of Ghana (Figure 32), and cuts through the Savelugu Nanton and Yendi Districts. The unpaved road is located in the Volta Basin, a trans-boundary basin of nearly 400,000 square kilometres (note: 42 per cent of the basin is located in Ghana).

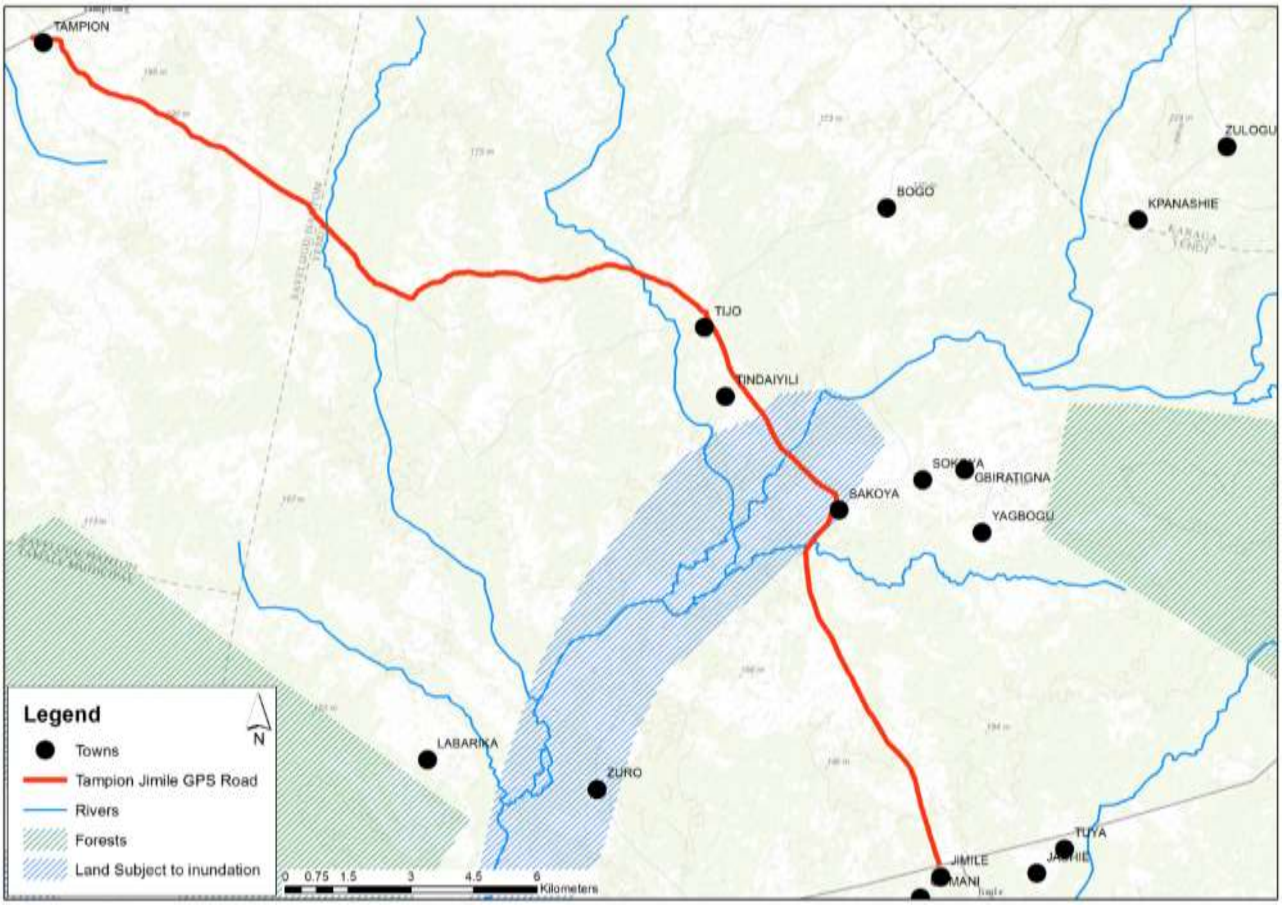


Figure 31: Geographical outline of the Tampiong to Jimle Road in Northern Ghana

The road is located on a flat topography with a minimum altitude of 128m and a maximum altitude of 182m (Figure 33).

The road crosses an area with very low population density and provides the rural town of Tijo and the rural villages of Sakoya and Suri access to the service and market towns of Tampion and Jimle (Figure 34).

Figure 32: Geographical location of the Tampiong to Jimle Road in Ghana

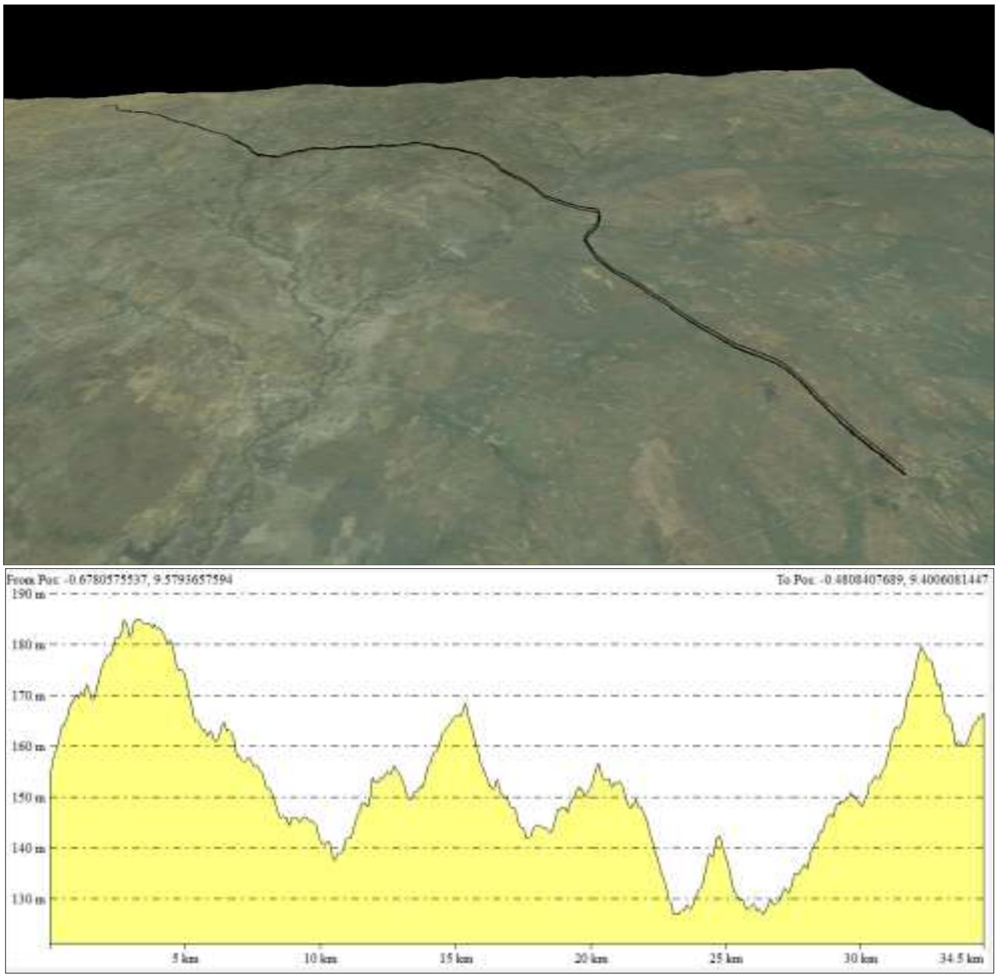


Figure 33: Topographic information on the Tampiong Jimle Road road

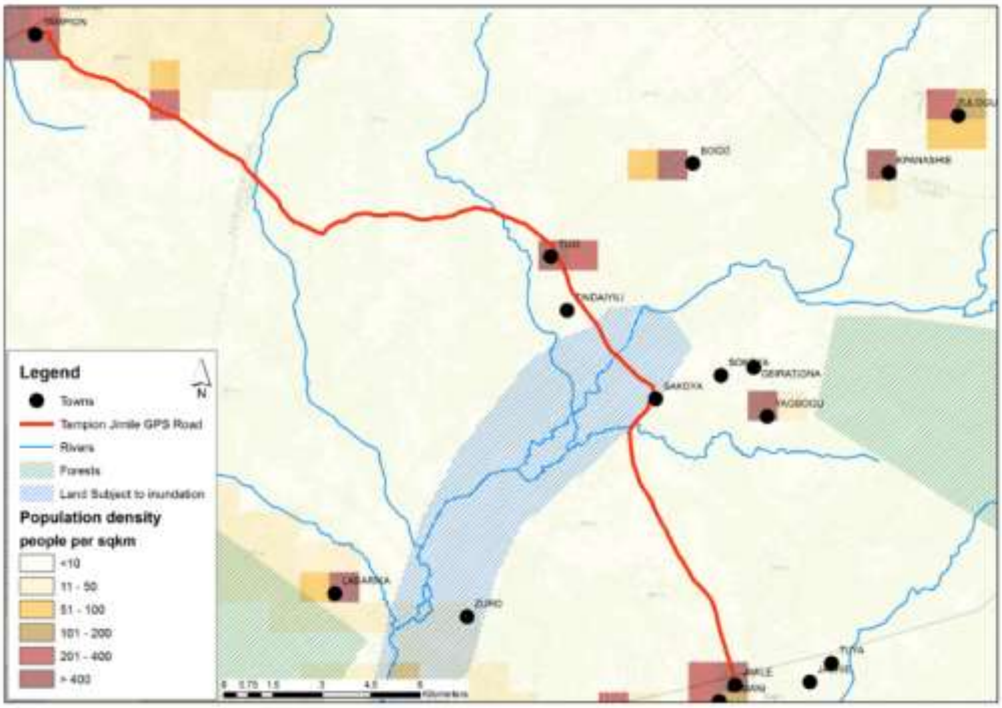


Figure 34: Population density along the Road

Land use in the area (Figure 35) is characterised by subsistence agricultural farming which forms the base of the local economy. Land cover is predominantly characterised by open shrub land with evidence of croplands located in close proximity to the villages and towns.

The road crosses several tributaries of the Mawi River. The Mawi River flows south to meet up with the Benya River becoming the Kalaraki River which eventually drains into Lake Volta. Due to the flat topography of the region the rivers drain slowly leaving large areas subjected to frequent flooding.

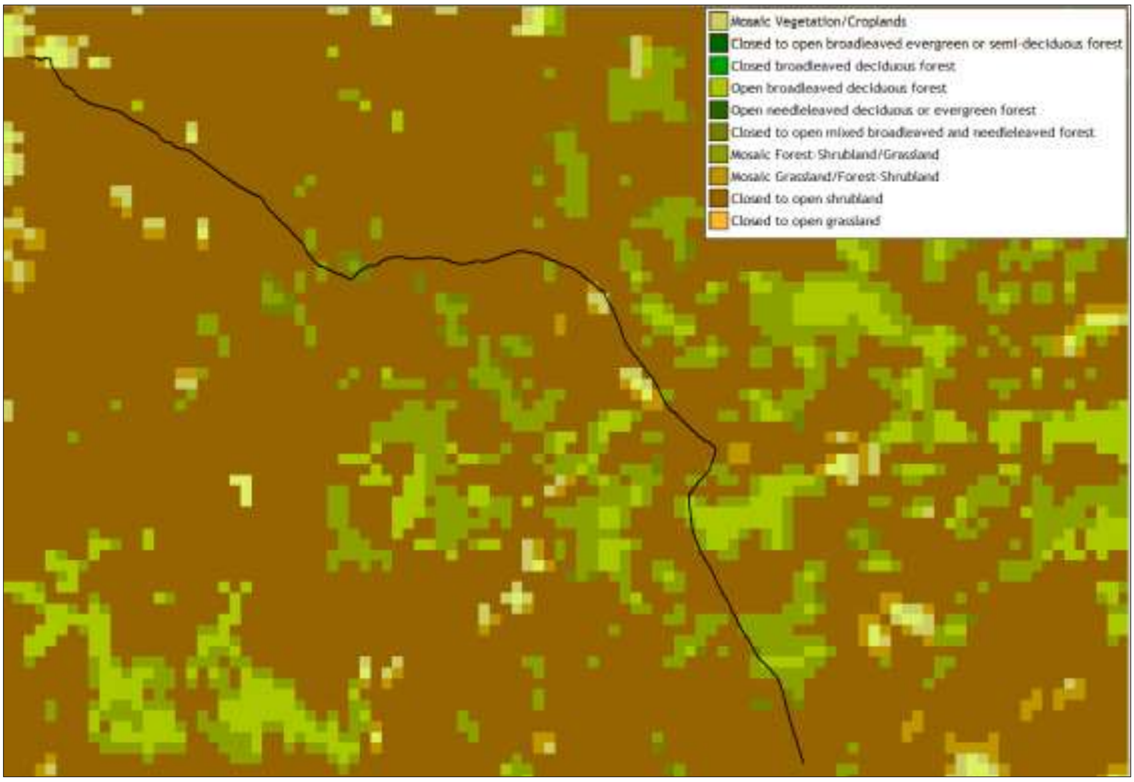


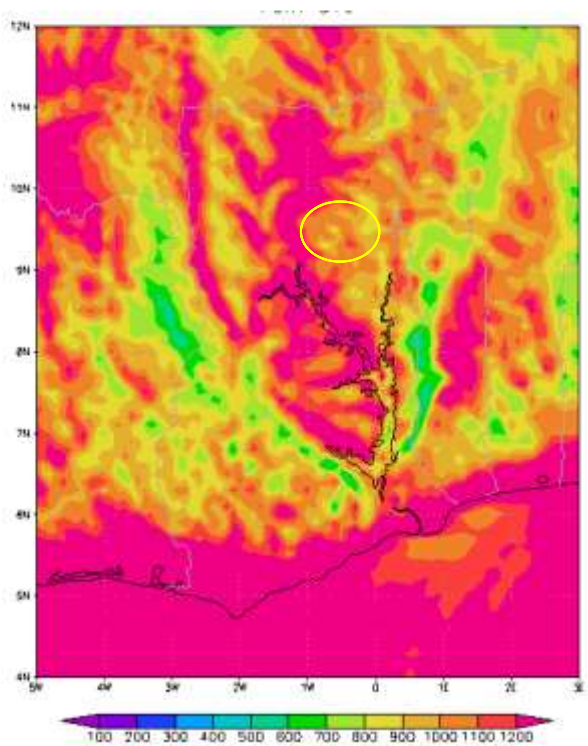
Figure 35: Land cover along the Road

The climate change projections for 2020-2030 and 2070-2100 are shown in the figures below (the yellow ellipses indicate the location of the selected trial road). Both downscaling models, namely ACCESS 1-0 and CNRM-CM5, project a wetter future for the area in which the demonstration section is located. However, as was the case for Mozambique, the catchment area of the Volta River, as well as future projections for rainfall over that area, should be consulted to inform appropriate adaptation designs.

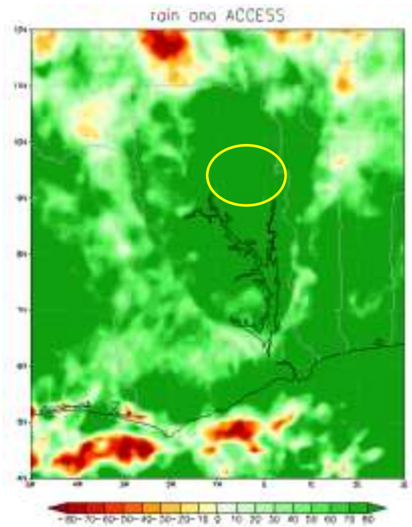
Rainfall Totals

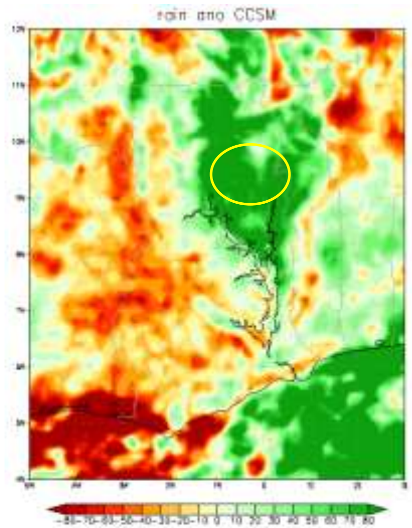
Average 1961-1990

Top: ACCESS1-0
Bottom: CNRM-CM5

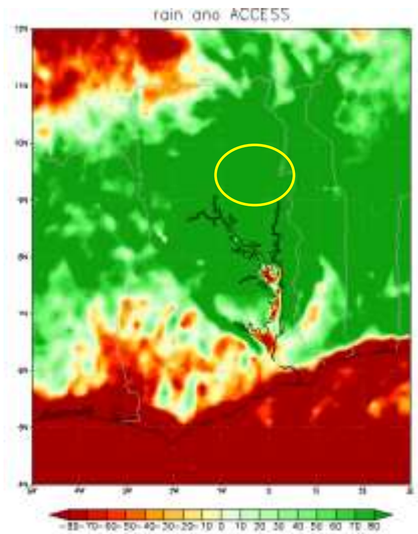


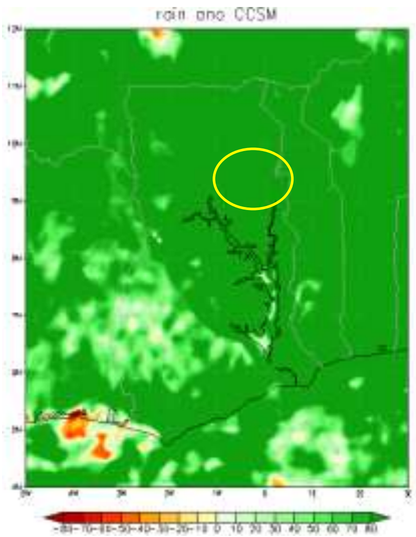
2021-2050





2071-2100

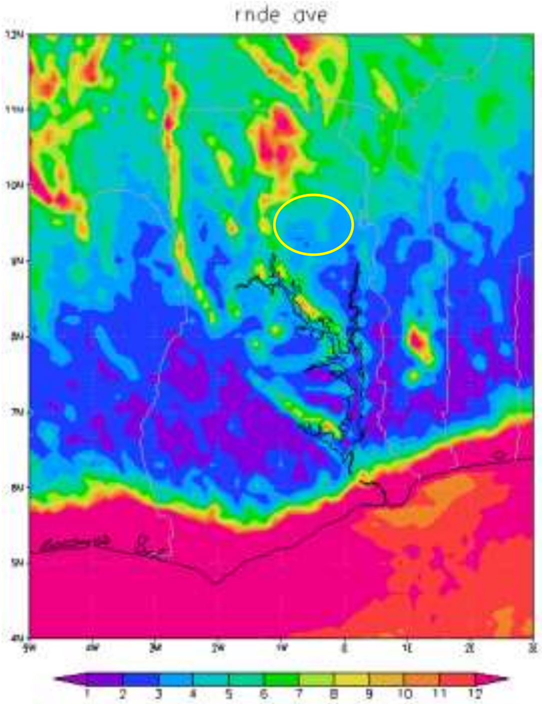




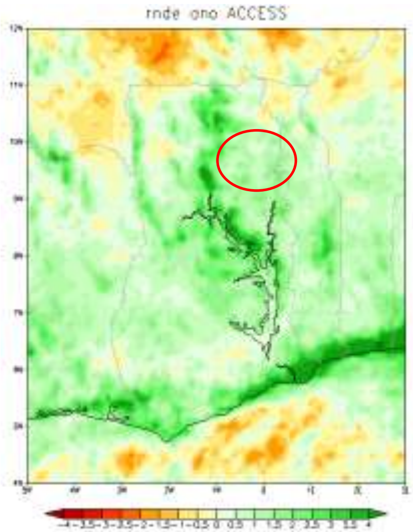
Extreme Rainfall Days

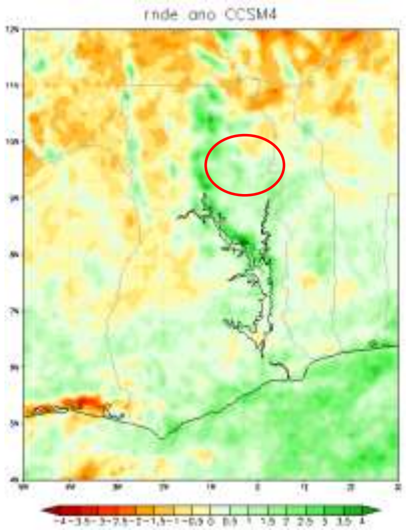
Average 1961-1990

Top: ACCESS1-0
Bottom: CNRM-CM5 Bottom

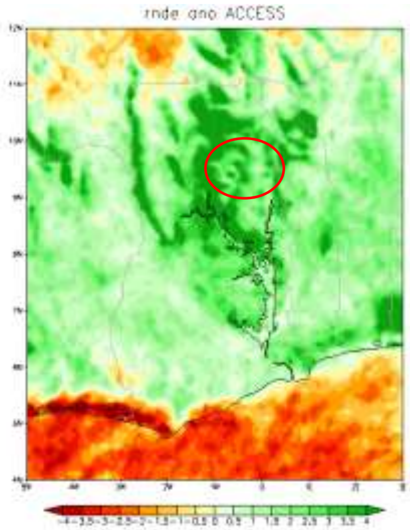


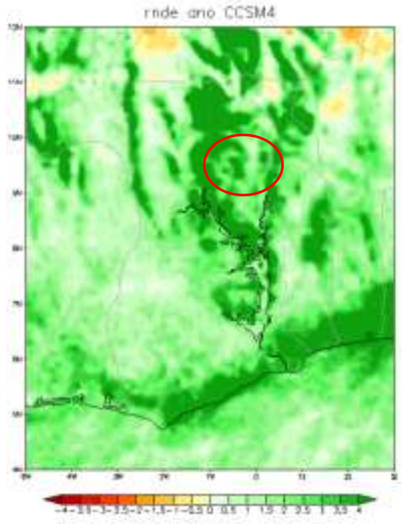
2021-2050





2071-2100





3.9 Climate resilience adaptation recommendations: Tampion-Tidjo Road

Five dominant problems were identified along this road:

1. Erosion of side drains and road surface
2. Impassability due to poor materials and local ponding of water
3. Poor road condition due to unsuitable wearing course gravel
4. Flooding of the road where no drainage or insufficient structures exist
5. Erosion around existing drainage structures

The preliminary line-diagram for the proposed upgrading of this road is provided in Annex J. It is proposed over the first 6 km to reshape the existing road surface, widen it to 7 m and place a 100 mm subbase (wearing course) layer. The strip diagram indicates that there will be 3 No 900 mm pipe culverts in this section with localised stone pitching at the culverts. The remainder of the road is similar, although 150 mm of gravel will be placed on the reshaped surface. A number of areas of raised formation are planned and 11 No 900 mm pipe culverts, 7 No 1200 mm pipe culverts and 2 No 2x2m box culverts will be included.

In general, the proposed upgrade design follows good engineering practice although the number and heights/capacities of some of the drainage structures may be limited. Observations indicate that the formation should be raised over most of the road length, good side- and mitre-drains should be installed, a good road shape should be implemented and the road should be surfaced with an appropriate gravel (Annex G). A typical cross section should be as illustrated in Figure 36.

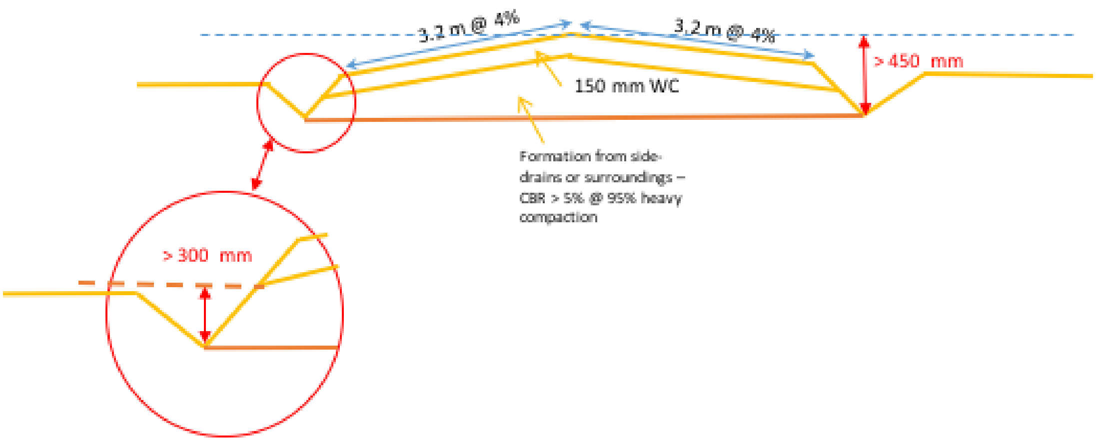


Figure 36: Recommended cross section for unpaved road

It is suggested that the road be upgraded according to conventional standards (and those illustrated on the strip diagram), but that selected areas are constructed in a more climate resilient manner incorporating the recommendations discussed below.

3.9.1 Erosion of side drains and road surface

V-drains as indicated above (Figure 36) are particularly susceptible to erosion when water flows at high velocities or where material has a low cohesion. The existing situation indicates that the local materials are susceptible to erosion and in these cases, adequate provision for removing water from the side drains quickly (before high flow velocities are reached) through appropriately graded and spaced mitre-drains should be made (typically 30 to 50 m apart depending on the grade – the steeper, the closer the mitre drains must be). Check dams can be included where such spacings are impracticable or topography makes the mitre-drains ineffective.

In some areas (e.g. between km 4.7 and 5.1) the current road is below natural ground level (NGL) and this will be almost impossible to achieve. In such areas, the current "channels" need to be filled and the road formation placed above NGL.

Recommendations:

At km 7.1 -7.5, the road should be constructed in accordance with the cross section shown in Figure 36. The existing eroded, poorly drained surface with localised laterite outcrops (Figure 37) must be ripped, shaped and compacted (with heavy high amplitude rolling on exposed laterite hardpan areas attempting to induce fractures and avoid perched water tables), raised where necessary to allow adequate and effective side-and mitre-drains to be installed and then surfaced with a selected gravel wearing course. The gravel wearing course must comply fully with the requirements in the Ghana Standard Specifications for Roads Manual, in terms of Grading Coefficient and Shrinkage Product. The laterites seen on site (borrow pit at about km 2.1) and being used locally, although not tested during this investigation, mostly appear visually to comply with these requirements. In addition, construction must be of the highest quality (as indicated in the Standard Specifications or better), particularly the compaction

Figure 37: Eroded, poorly drained section of road with laterite outcrops

3.9.2 Impassability due to poor materials and local ponding of water

Most of the existing earth roads consist of loose sand/fine gravel, mud or exposed laterite hardpan and are not shaped to remove water through any drainage system (Figure 38). Upgrading and shaping of the road as suggested in Figure 36 will eliminate the impassability and drainage problem provided that the wearing course materials are of the prescribed quality and are placed and compacted according to specification.


Figure 38: Existing muddy and fine gravel earth road with passability problems

Recommendations:

The section of road 200 m before and after coordinates 9.51649°N and 0.58038°W should be constructed with the proposed shape and drainage according to Figure 36 and ensuring that the wearing course complies with the standards required by the National Specification (Annex G).

Where unsuitable materials exist (loose sand and mud (Figure 38)), these should be removed and replaced with a better quality gravel that can be properly compacted. It will be necessary to widen some areas to accommodate drains and in other areas to fill existing depressions below natural ground level so as to ensure that the side-drains can effectively remove water from the vicinity of the road and embankments.

As the existing road is little more than a track in many areas, it is recommended that some re-alignment of sections be carried out to avoid some of the problem areas and improve the geometrics.

3.9.3 Poor road condition due to unsuitable wearing course gravel

The current road is primarily an earth road making use of the existing surficial materials with only limited sections using imported gravel because of “spot regravelling” mostly to improve local passability problems.

Recommendations:

A trial section of 300 m (km 3.0 to 3.3) of the conventional construction following the strip diagram should be constructed with a wearing course material that fully complies with the standards required by the National Specification (Annex G). This should ensure no oversize, good grading and shrinkage properties and very good compaction, irrespective of the materials being used on the conventional construction to compare only the difference between optimum and conventional material selection and construction.

3.9.4 Flooding of the road where no drainage or insufficient structures exist

As long sections of the road are essentially un-engineered earth road, little attention has been paid to water control. The result of this is that during the wet season numerous areas are under water for significant periods, and although not necessarily impassable, may be uncomfortable or even unsafe. Two particularly bad areas of flooding were noted at km 10.65 and 17.60 during the visit and have been highlighted for the installation of box culverts during the upgrade. Normal hydrological surveys should be carried out and appropriate structures installed to handle the expected water. As water crossing structures have been included in the new design, it is expected that this has been done for the upgraded road.

Recommendations:

At points along the road where natural water courses occur, the catchment area must be defined and the expected maximum (or some percentile of these) flows generated within these catchments under predicted future precipitation regimes calculated. These figures can then be used to calculate the required apertures of the drainage structures for comparison with those currently designed. This can be done for selected watercourses in Phase 2 of the project.

However, it is proposed that the section of road between 10.6 and 10.8 km be constructed as follows:

- Construction will need to be carried out in the dry season or when the mud is at least in a dry condition
- The existing subgrade should be removed to a depth below the current "mud" level.
- A stable platform for the construction of the culvert slab and approach fills must be placed using an inert gravelly material with the upper 150 mm compacted to at least 93% MDD (Ghana test method S1).
- The two box culverts and the two 1200 mm pipe culverts should be constructed as planned, although hydrological analyses are still being carried out to confirm that these will have adequate capacity.
- The approach fills must then be constructed using material with a CBR of not less than 8% measured after 4-day soaking on a laboratory mix compacted to a dry density of 95% MDD (GHA S1), a swell of less than 1% and a Plasticity Index of less than 30%.
- The upper 300 mm of the fill shall consist of selected materials with a CBR of not less than 15% at 95% MDD compacted to a dry density of not less than 95% MDD (GHA S1), but preferably to refusal with a minimum of 95% MDD.
- The laterite wearing course complying with Annex G shall be placed on top of this selected layer and compacted to at least 98% MDD. This shall be carefully shaped to ensure that the camber is between 4 and 5% and water flowing off the road leads into appropriate drains as discussed in section 5.3.5 to avoid erosion.

The similar section of road between km 13.30 and 13.50 should be constructed according to the proposed DFR design to compare any differences in performance.

3.9.5 Erosion around existing drainage structures

Although the current alignment has little attention paid to drainage, there are a few structures along the road. The culverts at about km 8.85, although effective show evidence of overtopping and the associated erosion in the areas where mortared stone pitching has not been applied (Figure 39).

Figure 39: Erosion around culvert head-walls

Recommendations:

Careful attention needs to be paid to the areas around head-walls and behind wing-walls to ensure that water does not flow over or on the road in these areas. This requires good side drains on the approaches to culverts as well as protection using mortared stone pitching or rip-rap.

The mortared stone pitching should be continuous behind the wing-walls (Figure 40) and be blocked in at the top and bottom using concrete strips (Figure 41). If necessary, down-chutes can be constructed in the pitching alongside the wing-walls and at intervals in the stone pitching.

Figure 40: Stone pitching to avoid erosion around culvert wing-walls

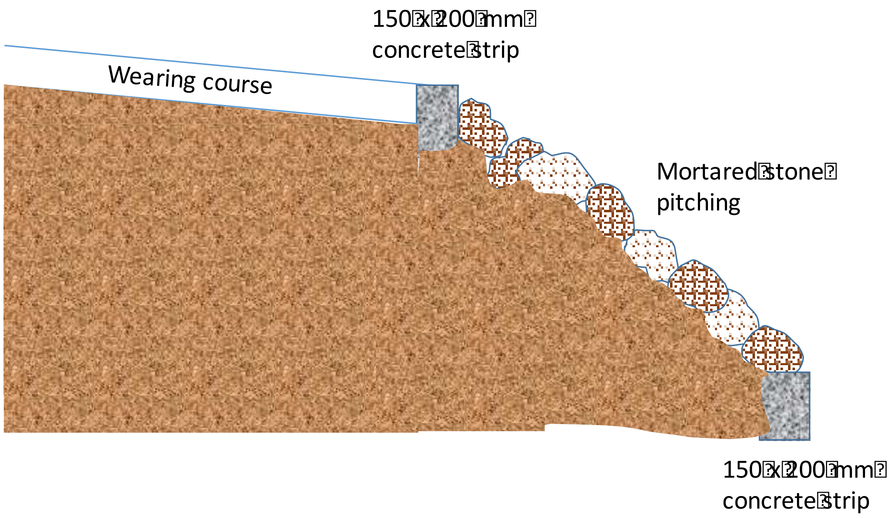


Figure 41: Concrete strips to retain stone pitching

3.9.6 Summary

The proposed adaptation measures are summarised as follows:

Problem	Adaptations
Erosion of side drains and road surface	Constructed with better cross-section Rip, shape and compact existing eroded, poorly drained surface with localised laterite outcrops Raise road where necessary to allow adequate and effective side-and mitre-drains to be installed Surface with a selected gravel wearing course complying with the necessary requirements (local laterites) Construct to the highest quality, particularly the compaction
Impassability due to poor materials and local ponding of water	Construct with the proposed shape and drainage Ensure that the wearing course complies with the standards Remove unsuitable materials (loose sand and mud and replace with a better quality Widen some areas to accommodate drains and to fill existing depressions in other areas that are below natural ground level to ensure that the side-drains are effective Some re-alignment is necessary to improve the geometrics.

Problem	Adaptations
Poor road condition due to unsuitable wearing course gravel	Construct with a wearing course material that fully complies with the standards
Flooding of the road where no drainage or insufficient structures exist	Define the catchment areas and the expected maximum flows. Calculate the required apertures of the drainage structures for comparison with those currently designed. Section of road between 10.6 and 10.8 km should be constructed as follows: • Remove existing subgrade to a depth below the current "mud" level. • Construct a stable platform for the culvert slab and approach fills • Construct the two box culverts and the two 1200 mm pipe culverts as planned - hydrological analyses must confirm that these will have adequate capacity. • Construct the approach fills must then be constructed using material with a CBR of not less than 8% • The upper 300 mm of the fill shall consist of selected materials with a CBR of not less than 15% • The laterite wearing course shall be placed on top of this selected layer , compacted to at least 98% and carefully shaped to ensure that the correct camber and that water flowing off the road leads into appropriate • The similar section of road between km 13.30 and 13.50 should be constructed per the proposed DFR design as a control section
Erosion around existing drainage structures	Pay careful attention to drainage in the areas around head-walls and behind wing-walls Improve side drains on the approaches to culverts as well as protection using mortared stone pitching or rip-rap. Continue mortared stone pitching behind the wing-walls and blocked in at the top and bottom using concrete strips

6. Summary

In this report, preliminary recommendations for the climate adaptation of three roads, one in each of the prioritised AfCAP Partner Countries, are presented. The three prioritised countries and the identified roads for the demonstrations are:

1. In Eastern Africa: Ethiopia –Tullo Bollo to Kela, south of Addis Ababa;
2. In Southern Africa: Mozambique –Chokwe to Macarretane (R448), north-west of Xai Xai; and
3. In Western Africa: Ghana - Tampion-Tidjo Road, north of Tamale.

These roads, which are intended to form the basis of the demonstration programme, are representative of some of the most prevailing hazards that low volume access roads are exposed to in AfCAP Partner Countries.

The roads were selected following site visits undertaken in these three countries. As part of these visits, at least two roads identified by national ministries, departments or agencies were visited and reported on (cf. Annexures A, B and C).

The report also presents preliminary recommendations for Phase 2 of this study, which will focus on:

a) demonstrating appropriate engineering and non-engineering adaptation procedures, and the assessment of the socio-economic impacts of adopting more climate resilient adaptations;
b) sustainable enhancement in the capacity of three AfCAP partner countries;
c) sustainable enhancement in the capacity of additional AfCAP partner countries; and
d) uptake and embedment across AfCAP partner countries.

These preliminary recommendations are presented in Annex E of this report, focussing primarily on the objectives, scope and deliverables for Phase 2. A tentative programme of activities and target dates for deliverables are also provided.

The preliminary recommendations presented in this report, as well as general methodologies and guidance offered in the two previous project reports, namely the *Climate Threats Report* and the *Climate Adaptation Options Report*, will be debated at country workshops to be held in Ethiopia, Mozambique and Ghana in early February 2017.

The outcomes of the above workshops will set the basis for Phase 2 of this AfCAP project on *Climate Adaptation: Risk Management and Resilient Optimisation for Vulnerable Road Access in Africa*.

The main climatic resilience problems and proposed adaptation measures for each of the countries are summarised in the following table.

Problem	Adaptations
ETHIOPIA	
Shear failure due to excessive subgrade moisture	Constructed to minimise both volumetric movements and subgrade shear failures Raise the formation at least 500 mm above natural ground level and flattening the slopes of the embankment to not steeper than 1:4 (V:H). Use material excavated from the side drains to give a better cross-section Side drains to be carefully graded to avoid ponding and feed into appropriately spaced mitre drains. Spacing of mitre-drains selected to minimise erosion (< 40 m)
Erosion of wearing course and side-drains on grades	Constructed according to current design. Shoulders must be constructed using appropriate wearing course material, compacted to 98% and carefully graded to 4% camber, leading into re-shaped side drains. Cross-draining culverts (single 900 mm pipes) to be installed every 40 to 50 m down the hill
Slope instability	Clean/reshape existing failed slope at km 46.0 without removing excess material from the toe Place a series of rock-filled Gabion baskets as a catch-wall. These should be on a stable platform within the current drainage area and should be 3 m at their base and 3 m high, with all the baskets attached to each other. Plant grass on the landslide scar and *eucalyptus sp* trees on the stable slope above the landslide and around the perimeter of the failed area.
Erosion of embankments near structures	Reshape and grade drains (side and catch-water) on the upslope side of the road be with some enlargement. Replace existing pipe and install a second similar one installed next to it. The adjacent access path/road should be reshaped, grassed and the access moved away from the culvert. Anti-erosion measures need to be installed at the outlet of the culvert – stilling pod, or a concrete spillway with flow retarding structures.
Collapse of structures	Remove the collapsed bridge and replace with a slightly larger capacity bridge with the deck at a higher level (1 m higher) The existing river has a direction change at the bridge – this will require stone pitching on the eastern abutment to provide erosion protection

Problem	Adaptations
MOZAMBIQUE	
Loss of surfacing on low lying roads overtopping	Replace current gravel wearing with a 100 mm thick "rollcrete". This should be slightly lower than the existing road to form a drift at natural ground level. Rip and re-compacted the existing (or preferably new material) in the shoulders. Construct a V-drain where space allows on the down-stream side of the road. Include some mitre drains off the side drain to reduce water flows.
Pavement failures due to raised moisture contents in sub-layers	Improve the side drains on the upslope side of the road with better shape and grade. Construct additional and larger culverts directly "downstream" of the railway. Avoid all accumulation of water up-slope of the road Construct the shoulders with approved material and grade, shape and compact to ensure surface water is removed from both edges of the pavement.
Erosion of high embankments and loss of surfacing during flooding	Flatten embankment slopes slightly and maintain in a smooth condition. Establish deep-rooted grasses on the slopes. Flatten and vegetate slope on the down-stream side of the embankment. Improve the adhesion of the seal to the cemented sand layer (low viscosity prime). Place a 150 mm section concrete edge beam alongside the seal. Construct a mono-camber of 3% towards the north to reduce turbulent flow.
Undermining of embankment due to flooding	Compact shoulders and embankment to as high a density as possible. Shoulder materials must comply with those for a gravel wearing course. Reduce camber to 2% over the shoulders. Eliminate any obstructions likely to cause turbulent flow. Establishment of a smooth grass cover using a deep-rooted grass species.

Problem	Adaptations
GHANA	
Erosion of side drains and road surface	Constructed with better cross-section Rip, shape and compact existing eroded, poorly drained surface with localised laterite outcrops Raise road where necessary to allow adequate and effective side-and mitre-drains to be installed Surface with a selected gravel wearing course complying with the necessary requirements (local laterites) Construct to the highest quality, particularly the compaction
Impassability due to poor materials and local ponding of water	Construct with the proposed shape and drainage Ensure that the wearing course complies with the standards Remove unsuitable materials (loose sand and mud and replace with a better quality Widen some areas to accommodate drains and to fill existing depressions in other areas that are below natural ground level to ensure that the side-drains are effective Some re-alignment is necessary to improve the geometrics.
Poor road condition due to unsuitable wearing course gravel	Construct with a wearing course material that fully complies with the standards
Flooding of the road where no drainage or insufficient structures exist	Define the catchment areas and the expected maximum flows. Calculate the required apertures of the drainage structures for comparison with those currently designed. Section of road between 10.6 and 10.8 km should be constructed as follows: • Remove existing subgrade to a depth below the current “mud” level. • Construct a stable platform for the culvert slab and approach fills • Construct the two box culverts and the two 1200 mm pipe culverts as planned -hydrological analyses must confirm that these will have adequate capacity. • Construct the approach fills must then be constructed using material with a CBR of not less than 8% • The upper 300 mm of the fill shall consist of selected materials with a CBR of not less than 15% • The laterite wearing course shall be placed on top of this selected layer, compacted to at least 98% and carefully shaped to ensure that the correct camber and that water flowing off the road leads into appropriate

	• The similar section of road between km 13.30 and 13.50 should be constructed per the proposed DFR design as a control section

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Annex A: Notes on Field Visits undertaken in Ethiopia

A.1 Background

As part of the AfCAP climate vulnerability project, the selection of one roads in each of the three target countries (Ethiopia, Mozambique and Ghana) for implementation of the proposed adaptation measures was required. These roads should preferably be on an improvement/upgrading/ rehabilitation programme with funding already allocated for their work.

The Ethiopian Road Authority (ERA) was requested to identify candidate roads for this purpose. The following roads were identified:

1) Tullu Bollo - Kela – Unpaved road (80.5 km)
2) Butajira - Ziway - paved road - (51.5 km)

Discussions before the first site visit were held with Engs Alemayehu Endale and Deribachew Mezgebu of ERA. Specific interest was indicated in a failed embankment in the Sheshemene area following flooding earlier in 2016 and this site was visited following inspection of the Butajira-Ziway road. The visits were carried out between 7 and 10 November 2016. The CSIR team was accompanied by Eng Deribachew Mezgebu during the visits.

A.2 Observations

A.2.1 Tullo Bollo – Kela Road

The road is an engineered gravel road up to about km 33.0 where a number of surfacing trials have been constructed. For the remainder of the road up to the end in Kela at km 80.5, it consists mostly of an engineered earth road, with localised spot graveling. Despite being passable for the majority of its length, there is very little motorised traffic using the road, with only a few medium buses and motorcycles and many pack-animals, animal drawn carts and bicycles. The first portion of the road overlies expansive clay (black cotton soil) which is replaced by a stronger residual volcanic material subgrade after the experimental surfacing sections. Side and mitre drains and a few small bridges and culverts assist with the drainage of the road.

A general overview of the road is shown in Figure A.1. The reference numbers shown in Figure A.1 refer to GPS Way Point noted along the route. Descriptions of these Way Points are described in Table A.1.

The location of structures are shown in Figures A.2 to A.4 (extracted from the ERA GIS asset management system). It should be noted that in Figures A.2 to A.4, ‘Pipeline’ refers to a ‘culvert’; ‘slab’ refers to a ‘slab bridge’ (i.e. concrete reinforced slab supported on two concrete wing walls); and “ford” refers to ‘a shallow place in a river or stream allowing one to walk or drive across’.

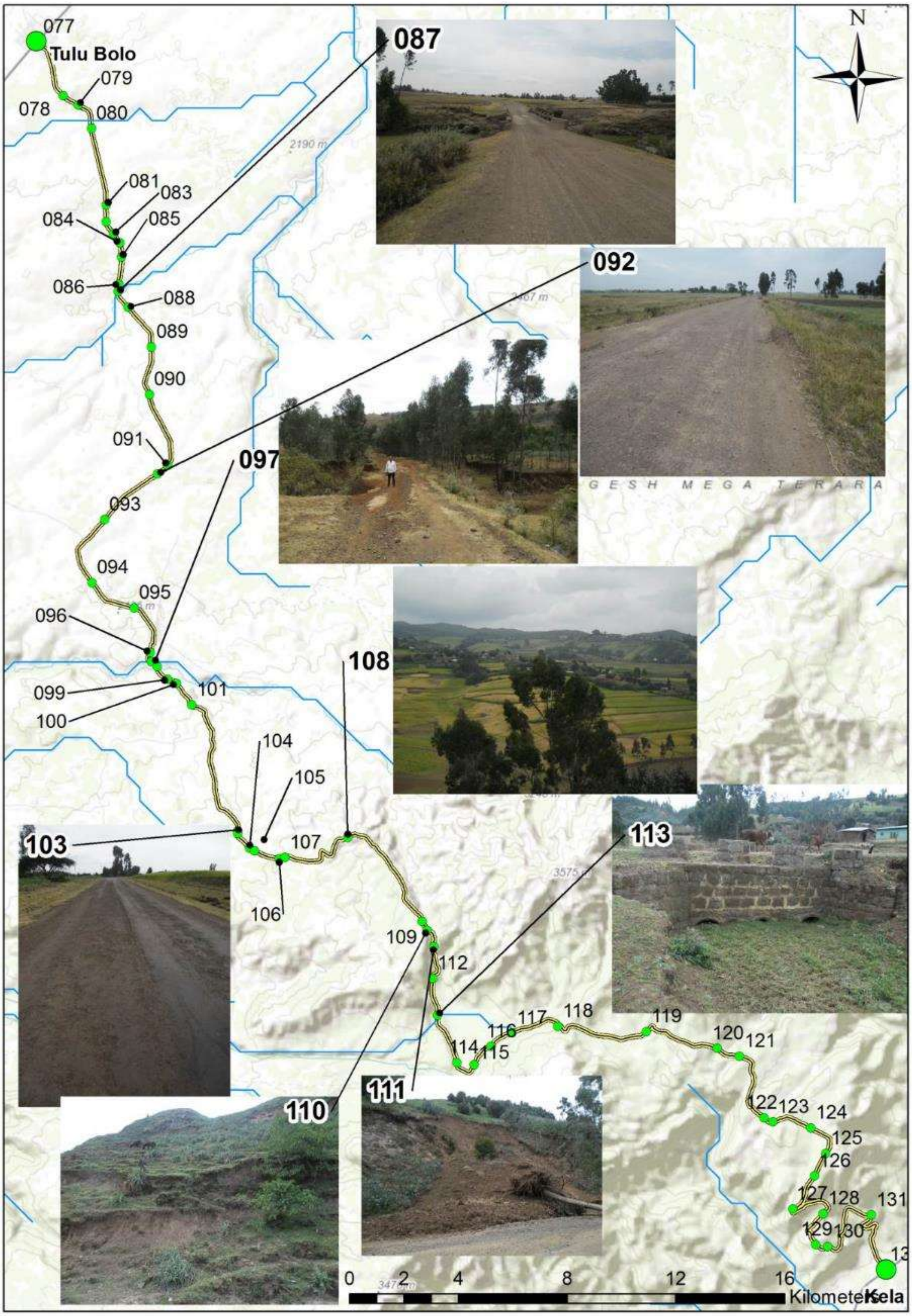


Figure A.1: General overview of the Tullu Bollo to Kela Road (numbers refer to GPS Way Points described in Table A.1)

Table A.1: Description of GPS Way Points

WPT	Description/Notes
77	Start of paved section. Very bad condition. Two years old.
78	Start of gravel section. Odometer zeroed.
79	Culvert
80	Bridge (1.7km). Sinder gravel wearing course. Poor riding quality.
81	Bridge (4.7km)
82	Village
83	Slab bridge (5.8km)
84	Village
85	Slab bridge
86	Stop: inspection of (ravelled) wearing course
87	Bridge (8.1km)
88	Village. Black cotton clay erosion (on left)
89	Village
90	School (Sombo school) in village
91	Cross drain; shear failures in spots.
92	Shear failure, water ponding (black cotton clay)
93	Village
94	Village
95	Enter town - paved road (Harbo Chulule)
96	Exit town (unpaved)
97	Cross drain; erosion
98	Bridge (Wonga river)
99	Quarry
100	Quarry
101	Village. Deep erosion - no black cotton clay, no subgrade failures
102	Start trial section (Otto seal) - 4 years old (trial section ends at WP106)
103	Culvert
104	Village (Cobel) km34.4. Sand seal on Otto seal - eroded on sides of road
105	Watter crossing Otto seal
106	End trial section (km35.9)
107	Slab bridge (37.7km)
108	Erosion on some steep uphills
109	Culvert
110	Line drains, slope instability
111	Landslide
112	Damage to drains + slope instability
113	Collapsed bridge + dysfunctional drainage channel/culverts
114	Town (Acabar), start of paved section (km49.4)
115	Exit town, end of paved section (km50.4)
116	Cross drain
117	No drainage, poor riding quality (km 52.3)
118	Bridge & cross drains
119	Bridge (km57.9)
120	Town (Keshet), start of paved section (km60.8). Drift in town.
121	Exit town, end of paved section (km61.7)
122	Cross drain (km 64.6)
123	Very poor riding quality (km 65.1). Retaining wall.
124	Poor riding quality (drainage problem) [Cross drain (km67.6)]
125	Shear failure (km68)
126	Culvert km68.3 (elevation approx 3,300m)
127	Downhill to valley (poor riding quality)
128	Blocked side drains, road eroded
129	Water retarder
130	Culvert
131	Surface erosion on sharp downhill sections/bends, just passed crossdrain
132	Kela: end of road (km80.5), elevation approx. 1,915m

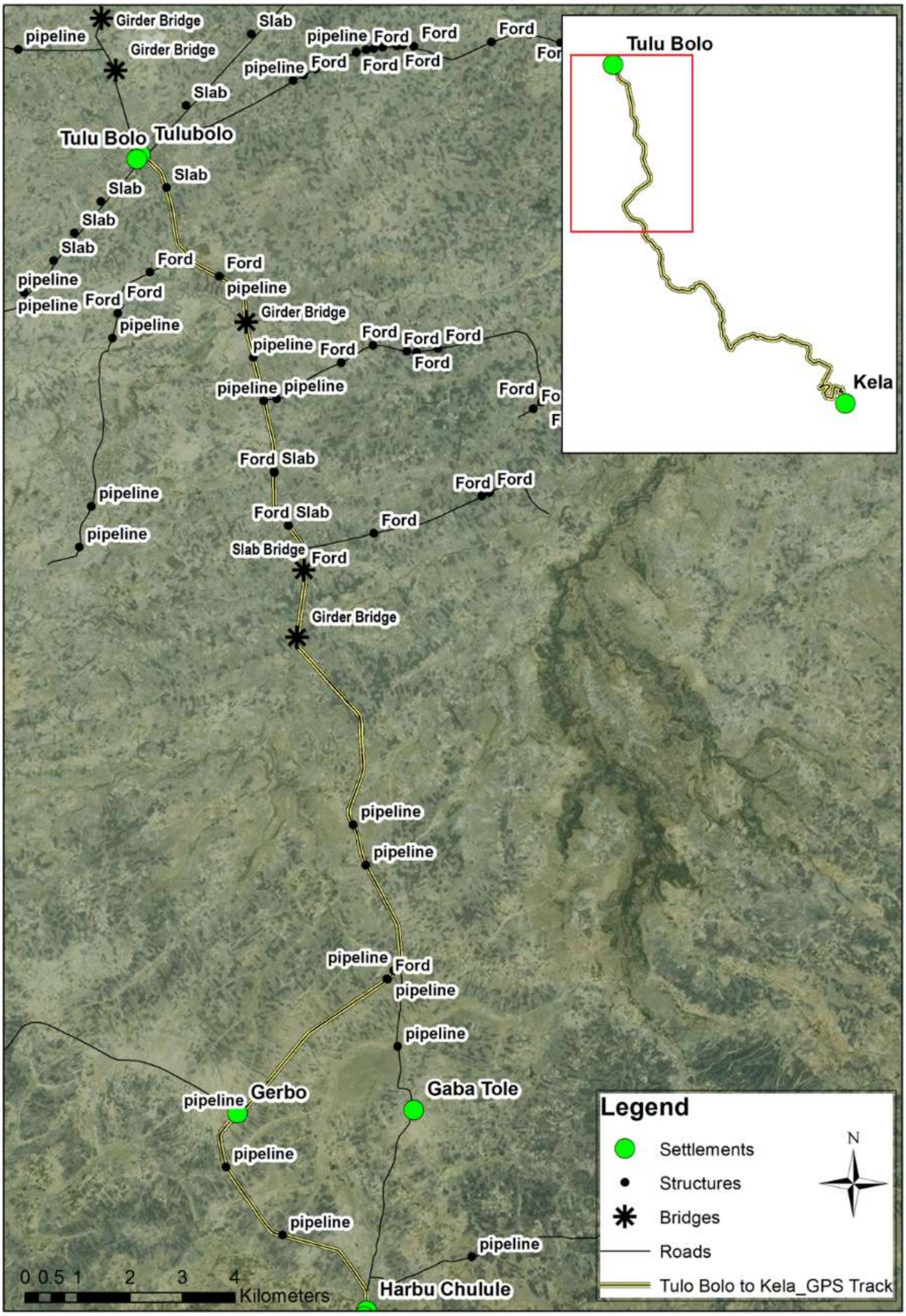


Figure A.2: Location of drainage structures along the northern section of the Tullu Bollo to Kela Road

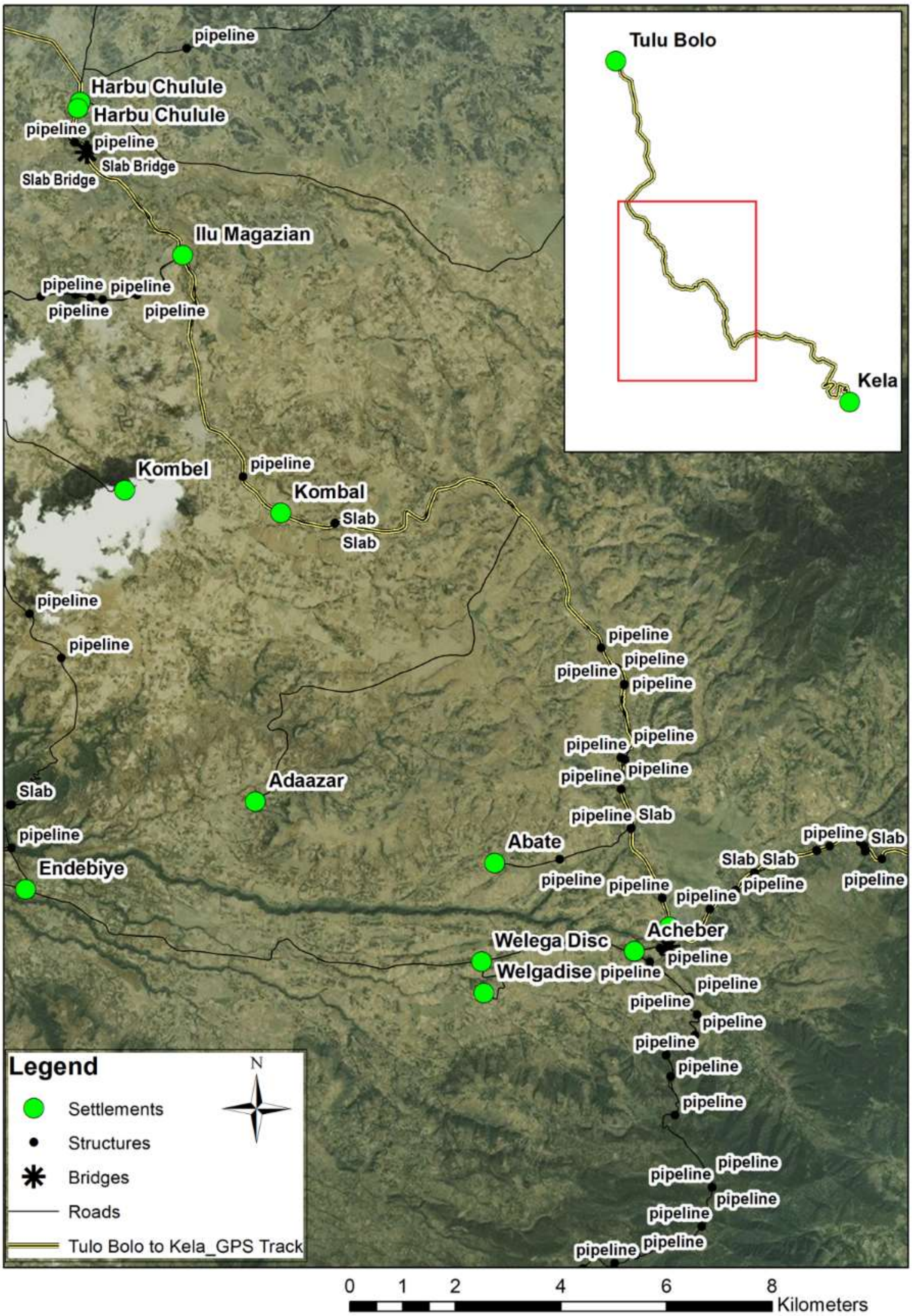


Figure A.3: Location of drainage structures along the central section of the Tullu Bollo to Kela Road

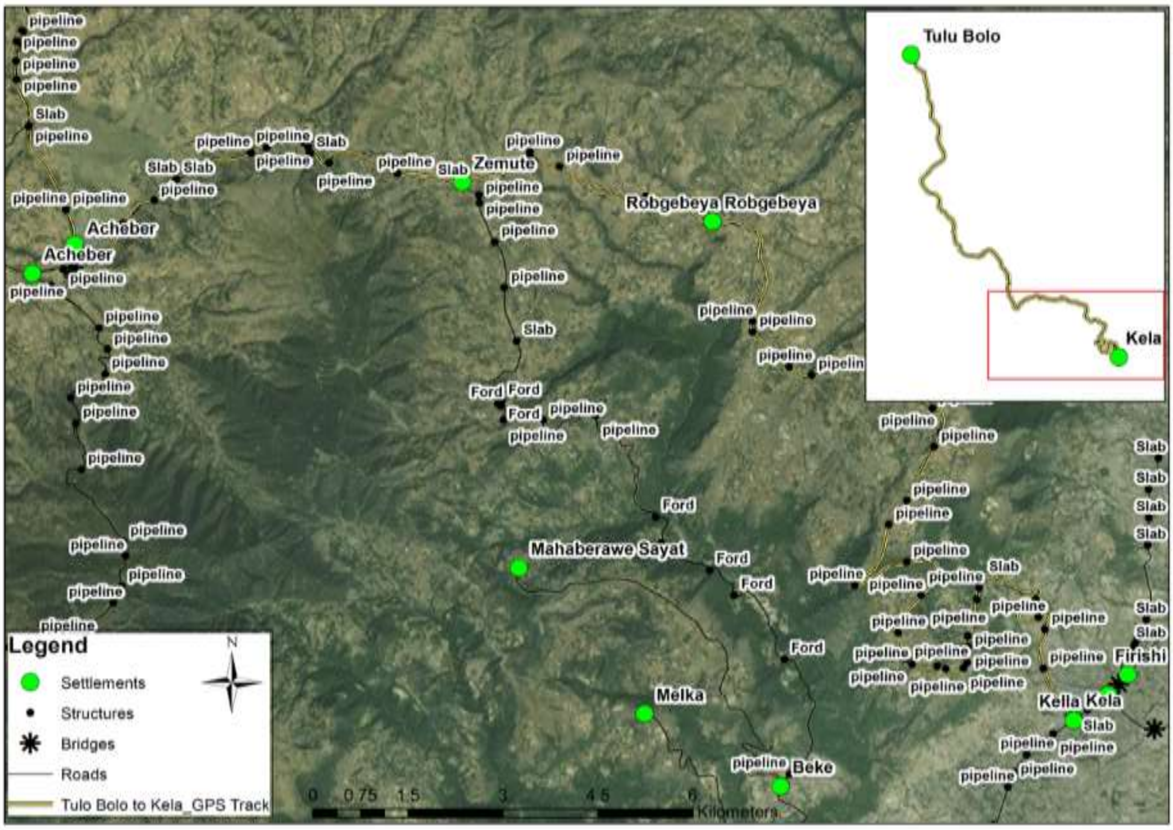


Figure A.4: Location of drainage structures along the southern section of the Tullu Bollo to Kela Road

Between the start of the road and the trial sections at km 33, the road consists of cinder gravel wearing course mostly placed directly on the expansive clay subgrade. The wearing course material contains a large proportion of oversize gravel that results in a poor riding quality in many places. Good side-drainage is evident in many places, although there has been significant erosion in some of these drains (Figure A.5).

Figure A.5: Cinder gravelled road with erosion of side drains

However, where side drainage is impeded and water appears to accumulate, large shear failures are seen (Figure A.6), which are not present over the majority of the road. This is clear evidence that the expansive clay, when unsoaked (or at least at lower moisture contents) is sufficiently strong to support the wearing course without shearing. A CBR strength of 5% has been shown to be adequate for the subgrade of unpaved roads with light traffic. Where the material becomes saturated (the CBR of the clay is about 1%), failure occurs.

Figure A.6: Shear failure of subgrade at point of water accumulation

A large and old bridge at km 8.1 (Figure A.7) shows no evidence of deterioration or damage due to flooding. The only damage is the loss of a mortared parapet wall that has probably been knocked into the river by a vehicle.

Figure A.7: Bridge at km 8.1

Between km 25.6 and 26, the road descends a steep grade alongside which there is severe erosion (Figure A.8). No cross-drains occur in this section of road and all storm-water on the left side is channelled down the side of the road to the river at the bottom of the hill.

Figure A.8: Erosion alongside the road on a steep grade

Trial sections using various surfacing types carried out by TRL start at km 33.0 and end at km 35.5. These include different surfacing types, aggregates and binder contents and in general all show good performance after about 4 years in service. These sections are, however, not discussed in this report other than to indicate that the base was a crushed basalt and almost only where there is oversize in the base do potholes and surfacing loss occur.

After the trial sections, the road continues mostly with a crushed basalt wearing course, although this has been lost in places. On some of the grades, even with side-drains, significant erosion of the wearing course gas occurred, indicating that the shape of the road is inadequate (Figure A.9). Although the crushed basalt makes a strong wearing course structurally, it is poor in terms of the lack of cohesion (low plasticity) and is susceptible to ravelling and erosion. The addition of some clay binder to the material would produce a significantly better wearing course gravel.

Figure A.9: Section of road with lined side-drain but showing excessive longitudinal (becoming transverse) erosion

The road then passes into a section of cut slopes with some small fills between km 44.6 and 46.0 km. Some landslides have occurred (Figure A.10) and there are definite signs of other instability issues in the area (Figure A.11). At one of the culverts in a small fill downhill from the landslide in Figure A.12, sever erosion of the side of the fill has occurred, mostly associated with the presence of a track/road leading off to the side. This has undercut a portion of the road and resulted in damage to the adjacent culvert, where the head and wing-walls have moved and deprived the pipe of support, which has resulted in separation of the pipe from the headwall (Figure A.12).

Figure A.10: Landslide at km 44.6

Figure A.11: Landslide scar on hill with erosion of embankment in foreground

Figure A.12: Damage to head and wing-walls and pipe in culvert caused by adjacent erosion of the embankment

At km 47.4 a small concrete bridge has collapsed. It is not sure whether this was the result of overloading or flooding, but inspection indicated that the western abutment had appeared to have tilted (Figure A.13). The collapsed section of the bridge had been restored to road level using local gravel. The evidence suggests that the collapse was water related as a diversion channel with another drainage structure had been constructed to confine the stream to a straight path. This, however, did not appear to be too effective (Figure A.14) as the south side (downstream) was totally silted up and the northern side (upstream) had only a small area of the pipes open.

Figure A.13: Collapsed bridge at km 47.4

Figure A.14: Diversion channel and culverts

At km 54.2, a small concrete bridge with little headwall but more than 1 m of soil cover occurs. The approach channels to this culvert from various sides are highly eroded and undercutting in the channels is leading to unstable soil conditions in the slope above the channel (Figure A.15). Drainage problems a little further along the road (km 68.0) have led to the accumulation of water adjacent to the road and localised shear failures in the road (Figure A.16). It also evident at this site that there is a loss of wearing course gravel exposing significant subgrade material, some of the crushed stone having punched into the softer underlying subgrade and other material probably eroded from the road during overtopping in the area.

Figure A.15: Small concrete bridge with eroded inlet channels

Figure A.16: Shear failures resulting from localised drainage problems

A.2.2 Butajira - Ziway

This is a paved road about 51.5 km long which was constructed 7 years ago. As it was described as being susceptible to storm damage, the road was inspected over its full length and in general was performing well, apart from some isolated problems as discussed below. The road was constructed with a cinder subbase and a crushed stone base and surfaced with a double seal (19 and 6.7 mm) on the carriageway and a single seal on the shoulder. The road was generally raised above natural ground level and had effective side drains. Of particular interest was the high number of "donkey carts" with steel wheels (the road described above in section A.2.1 carried almost totally pneumatic-tyred carts), which were heavily loaded with local crops (Figure A.17).

Figure A.17: Heavily loaded donkey cart with steel wheels

Over long sections of the road, severe edge break was evident and was inspected at a number of places along the road. Without any maintenance, this edge break was progressing beyond the yellow line markings into the carriage-way and in some cases was almost the full depth of the base layer (Figure A.18).

Figure A.18: Large truck noted alongside road during site visit

After many observations, the cause of the edge-break was attributed to a combination of vehicle spilling off the road and loosening the single sealed shoulder and then the high stresses of the steel wheels of the donkey-carts (steel marks were visible on many sections of the road) causing breakage of the edges of the edge-break. It was noted that the steel wheels are, in fact, not flat but curved, and only the central 50 per cent or so of the wheel width is in contact with the road, increasing the point loads on the surfacing and edges of failures (Figure A.19).

Figure A.19: Close-up of steel wheel on a donkey cart showing curved profile

The double seal appeared to be very “streaky” over large lengths of the road (Figure A.20). This was a construction problem related to blocked nozzles on the binder distributor as well as poor overlap of the binder and stone spreading passes. This was particularly evident along the centre-line of the road. Problems with the surfacing were apparently encountered during construction due to the inexperience of the contractor with chip seals.

The areas on the road with low binder and stone application rates were prone to the formation of potholes (Figure A.21) and closer inspection of these areas indicated the top of the primed base, with some initial cracking, ultimately leading to the formation of the pothole, under traffic and particularly in wet weather.

Figure A.20: Streaky nature of the double seal

Figure A.21: Centre-line pothole and close up of new pothole forming on right (exposed primed base

The effects of heavy rainfall were evident at km 24.2 where a mortared stone-pitched side-drain had been severely damaged by rainwater. This has led to introduction of the water into the pavement structure with edge-break and failure of the shoulders (Figure A.22).

Following this, the road descends down an escarpment into the rift valley. Of particular note here was the lack of cross-drains over long distances during descent into the valley, resulting in erosion of the side-drains and the necessity for water to flow across the road.

Figure A.22: Damage to mortared stone pitched side drain and continued edge-break problems

At the bottom of the escarpment the road crosses a flat floodplain on a high embankment. Despite this there are potholes and localised edge-break along the embankment. Many of the large and deep potholes (Figure A.23) could have been avoided by timely maintenance.

Figure A.23: Potholes on embankment over flood-plain

A.2.3 Sheshemene

An interesting problem was inspected about 5 km outside Sheshemene on the road to Sodo. What was apparently a flat stable area suddenly developed a large opening that was subject to extreme erosion in May 2016, washing the entire road away. The most recent GoogleEarth image

(Figure A.24) shows the presence of a water body, which had been there since at least January 2014 (Figure A.25) but is not clear in poor-quality earlier images (Figure A.26) although there appears to be some water accumulation in the same area.

Figure A.24: Google Earth image of problem area near Sheshemene (23/2/2016)

Figure A.25: Google Earth image of problem area near Sheshemene (11/1/2014)

Figure A.26: Google Earth image of problem area near Sheshemene (31/10/2004)

The road lies in an area of late Tertiary volcanism with the predominant materials being volcanic ash and pumiceous material (tephra). These materials by their mode of formation are highly variable and may range from loose unconsolidated or weakly consolidated materials to highly porous hard rocks, often occurring in layers and channels. Although no detailed investigation was carried out during the visit, it is suspected that the subsidence in the area was caused by storm-water breaking into a channel of weak or unconsolidated tephra, which was easily washed out and led to the formation of deep channels. Once water began flowing and the volume (and velocity) increased, erosion would be fast and severe in the weak ash material.

The large "valley" caused by the erosion has been repaired using about 10 m of cinder aggregate as a rock fill (compacted using vibratory rollers) overlaid with up to 5 m of local soil with a CBR greater than 5%. This has been allowed to consolidate with apparently 60 to 80 cm of settlement occurring (supporting the hypothesis that the material is poorly consolidated ash) and will have the conventional pavement structure placed on top. The stream that caused the initial problem has been diverted into a larger river at the floor of the rift escarpment.

The embankment is 31 m wide with side slopes of 1: 1.5 and has a wide drain at the surface alongside and parallel to the road which will remove water some distance away from the embankment. The top of the embankment will be sealed between the edge of the bituminous carriageway and the drain with a mono-camber leading towards the drain. No precautionary measures are being taken on the opposite side of the embankment, although both embankment faces will be covered with soil and vegetated.

Careful monitoring of the surrounding area will need to be carried out, as, if the water has managed to break into a weak channel previously, the possibility of a similar channel or channels being in the area is probably quite high.

A.3 Problems identified during site visits

A.3.1 Erosion of side-drains and road surface

Although the cinder gravel placed on the unpaved road was of fairly good quality, there were strong signs of erosion and material loss on the grades. This was primarily due to the poor shape of the roads, resulting from minimal maintenance that caused a loss of camber, but is also probably exacerbated by low compaction levels. Similarly, the lack of regular mitre drains resulted in a build-up of water volumes and flow velocities in many of the side drains, leading to bad erosion and ponding at the bottom of inclines.

A.3.2 Damage to structures

A number of the culverts and small concrete “bridges” showed significant damage due to excessive water flows as well as that caused by vehicles. However, the structures appear to have generally coped with the local precipitation.

A.3.3 Flooding of road

Only localised flooding of the roads was identified with little damage to the roads in these areas. Adjustment to drainage capacities and slight raising of embankments in areas of known flooding would probably avoid such recurrences.

A.3.4 Road condition

The unpaved road that was surfaced with cinders was generally adequate, although excessive oversize material resulted in some roughness in a number of places. It was also clear that the expansive subgrade clays become unacceptably weak when inundated by water – in their normal conditions, they have sufficient strength but when soaked are subjected to shear failure under traffic. Articular attention needs to be paid to drainage in such areas or else higher formations with better quality materials are necessary.

A.4 Solutions

The paved road inspected did not appear to be particularly troublesome in terms of climate adaptation. The application of good design and construction standards would result in it becoming climate resilient, due to the generally rolling to hilly nature of the topography in the areas inspected and the generally good properties of the crushed stone materials used for construction. Localised problems only require normal engineering solutions.

The unpaved road, however, shows signs of potential deficiencies and this is reinforced by the low numbers of motorised vehicles currently using it. Certain areas along the road could be greatly improved in terms of current condition as well as climate resilience.

A.5 Recommendations

Based on the observations during the site visits it is proposed that the road to be selected for adaptation measures should be the Tullo Bollo – Kela road. This has number of areas that are probably not adequately climate resilient at the moment and include slope stability, poor subgrades and drainage problems. It is considered that these would be strongly affected by particularly increases in extreme precipitation events.

The road is also currently on an upgrading programme and thus would be suitable for continued assessment.

Annex B: Notes on Field Visits undertaken in Mozambique

B.1 Background

As part of the AfCAP climate vulnerability project, the selection of one roads in each of the three target countries (Ethiopia, Mozambique and Ghana) for implementation of the proposed adaptation measures was required. These roads should preferably be on an improvement/upgrading/ rehabilitation programme with funding already allocated for their work.

The Administração Nacional de Estradas (ANE) was requested to identify candidate roads for this purpose. The following roads were identified (in red in Figure B.1):

1) Non classified: Mohambe- Maqueze
2) R441: Chinhacanine- Nalazi
3) N221: Chibuto- Guijá
4) N220: Chissano- Chibuto

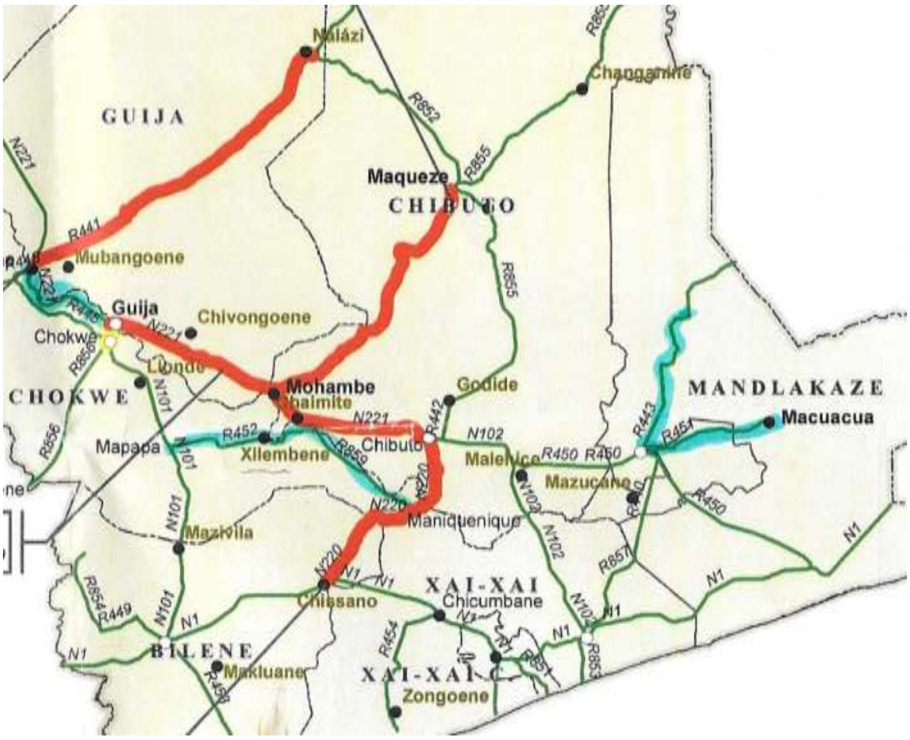


Figure B.1: Roads inspected during visit to Gaza Province – roads in red are those initially suggested by ANE and those in blue are the additional roads inspected during the visit

However, it was determined that the first two roads above had been identified by Mott Macdonald for a similar exercise funded by the World Bank. The other two roads are national roads carrying more than “low volume traffic”, although they are currently in various states of disrepair and are probably not carrying the actual traffic that will use them once they are upgraded.

Despite this, all of the roads except the third road listed above were visited and inspected as well as a number of other roads identified by the ANE counterpart staff accompanying the visit.

The visits were carried out in Gaza Province between 12 and 15 September 2016. The CSIR team was accompanied by Ms Raquel Langa (ANE, Maputo), Mr Rogerio Simione (ANE Provincial Delegation, Nampula Province) and Mr Nelson Horacio (ANE Provincial delegation, Gaza Province).

The maintenance history for the above roads is provided in Table B1. The comments made in the last column should be noted.

Table B.1: Maintenance History of the Inspected Roads

ROAD	TYPE OF INTERVENTION / ACTIVITIES PER YEAR					
	2011	2012	2013	2014	2015	2016
N220, Chissano - Chibuto	Routine Maintenance (Grass cutting, refilling of unpaved shoulders, repair of potholes, cleaning of aqueducts, trenches and drainage channels)	Routine Maintenance (Grass cutting, refilling of unpaved shoulders, repair of potholes, cleaning of aqueducts, trenches and drainage channels)	The road was partially destroyed by the rains of the year 2013. Emergency work was carried out, consisting of the opening of deviations and improvements of some sections to re-establish transitability	Routine Maintenance including diversion (repair of potholes, cleaning of aqueducts, trenches and drainage channels)	Routine Maintenance including diversion (repair of potholes, cleaning of aqueducts, trenches and drainage channels)	No work Planned because the road is included in phase 2 of the World Bank-funded emergency project. A public tender was launched to hire Contractor to design the project and rehabilitate it. The evaluation process has already been completed and the report sent for approval by the Funder.
N221, Chibuto - Guija	Routine Maintenance (Grass cutting, refilling of unpaved shoulders, repair of potholes, cleaning of aqueducts, trenches and drainage channels)	Routine Maintenance (Grass cutting, refilling of unpaved shoulders, repair of potholes, cleaning of aqueducts, trenches and drainage channels)	The road destroyed by the floods of the year 2013. The emergency work was carried out to re-establish the road's transiability, including the construction of the new Mohambe to Guija diversion for a length of 34km.	Road N221, Chibuto - Mohambe: Routine Maintenance (Tapping of holes, cutting of grass and shrubs, cleaning of aqueducts, ditches and drainage channels, landfills in the accesses of the bridge of Mobeira in km 7) Road N221, Mohambe -Guija : On the main road no work was done. Only the routine maintenance of the diversion (grass cutting, leveling of the platform, repair of the platform, opening of ditches and drainage channels)	Road N221, Chibuto - Mohambe: Routine Maintenance (repair of potholes, cutting of grass and shrubs, cleaning of aqueducts, trenches and drainage channels) Road N221, Mohambe -Guija : On the main road no work was done. Only the routine maintenance of the diversion (grass cutting, grading, repair of the platform, construction of the aqueduct, cleaning of ditches and drainage channels)	No work Planned because the road is included in phase 2 of the World Bank-funded emergency project. A public tender was launched to hire Contractor to design the project and rehabilitate it. The evaluation process has already been completed and the report sent for approval to the Funder.
N/C Mohambe - Maquez	Routine Maintenance: - (cutting grass and shrubs, repairing the platform, grading, construction of aqueducts, opening of new pits, laying of vertical signs)	Routine Maintenance: - (cutting grass and shrubs, repairing the platform, grading, construction of aqueducts, opening of new pits, laying of vertical signs)	The road destroyed by the floods of the year 2013, made detours to ensure the transitability.	**Emergency Work:**-(Construction / repair of drifts, Construction of landfill layer to raise the height of the road, Sealing, construction of aqueducts, construction of box culverts, opening of new drainage channels, protection in mortar) **Routine Maintenance** :- (Cutting of grass and shrubs, repairing the platform, grading, construction of aqueducts, opening of new pits, laying of vertical signs)	**Emergency Work:** - No work was done **Routine Maintenance:** - (repair of platform, grading, opening of new pits). Contract terminated because of poor performance)	**Emergency work:** - Longitudinal protection of drifts in mortar stone and gabions with hand-laid stone. These works are already completed. **Routine Maintenance: -** Planned the following work; Cutting of grass and shrubs, repair of the platform, construction of aqueducts, passage of the leveler, opening of new pits, soil base, placement of horizontal signs
48, Chokwe - Macarreta	Routine Maintenance (Grass cutting, refilling of unpaved shoulders, repair of potholes, cleaning of aqueducts, trenches and drainage channels)	Routine Maintenance (Grass cutting, refilling of unpaved shoulders, repair of potholes, cleaning of aqueducts, trenches and drainage channels)	The road destroyed by the floods of the year 2013, made landfills in critical sections to ensure the transitability	Routine maintenance (covering of holes, refilling of unpaved shoulders, filling, regularization and compacting of damaged platform between km 19 -24, landfill at points that are cut between 20-24 kms, placement of veritical signaling, cleaning of aqueducts, ditches and drainage channels)	Routine maintenance (covering of holes, refilling of unpaved shoulders, filling, regularization and compacting of damaged platform between km 19 -24, placement of veritical signaling, cleaning of bridges, aqueducts, ditches and drainage channels)	No work Planned because the road is included in phase 2 of the World Bank-funded emergency project. A public tender was launched to hire Contractor to design the project and rehabilitate it. The evaluation process has already been completed and the report sent for approval to the Funder.
452, Mapapa - Chilember	Routine Maintenance (Grass cutting, refilling of unpaved shoulders, repair of potholes, cleaning of aqueducts, trenches and drainage channels)	Routine Maintenance (Grass cutting, refilling of unpaved shoulders, repair of potholes, cleaning of aqueducts, trenches and drainage channels)	The road destroyed by the floods of the year 2013, made landfills in critical sections to ensure the transitability.	Routine maintenance (cutting of grass and shrubs, plugging of holes, refilling of unpaved shoulders, cutting of grass and shrubs, laying of vertical signaling, cleaning of bridges, aqueducts, ditches and drainage channels)	Routine maintenance (cutting of grass and shrubs, plugging of holes, refilling of unpaved shoulders, filling, regularization and compacting of damaged platform between km 0 - 5, placement of veritical signs, cleaning of bridges, aqueducts, ditches and drainage channels)	No work Planned because the road is included in phase 2 of the World Bank-funded emergency project. A public tender was launched to hire Contractor to design the project and rehabilitate it. The evaluation process has already been completed and the report sent for approval to the Funder.
R859, Chilembene - Crz N220/Maniquenique	Routine Maintenance (Grass cutting, refilling of unpaved shoulders, repair of potholes, cleaning of aqueducts, trenches and drainage channels)	Routine Maintenance (Grass cutting, refilling of unpaved shoulders, repair of potholes, cleaning of aqueducts, trenches and drainage channels)	The road destroyed by the floods of the year 2013, made landfills in critical sections to ensure the transitability	Routine Maintenance (cutting of grass and shrub cover holes, refilling of unpaved shoulders, filling, regularization and compacting of damaged platform between kilometers 19 - 23, landfills at points that suffer cuts between km 19 -23, placement of vertical signaling, Cleaning of aqueducts, ditches and drainage channels)	Routine maintenance (cutting of grass and shrubs, plugging of holes, refilling of unpaved shoulders, filling, regularization and compacting of damaged platform between km 19 -23, placement of veritical signaling, cleaning of aqueducts, ditches and drainage channels)	No work Planned because the road is included in phase 2 of the World Bank-funded emergency project. A public tender was launched to hire Contractor to design the project and rehabilitate it. The evaluation process has already been completed and the report sent for approval to the Funder.
R451, Mandlakazi - Chibonzane	No work done	No work done	No work done	No work done	Routine Maintenance: Construction of aqueducts, opening of ditches and drainage channels, platform repair, erosion repairs, soil base, cutting of grass and shrubs, cleaning of aqueducts, trenches and drainage channels	Routine Maintenance: Construction of aqueducts, opening of ditches and drainage channels, platform repair, erosion repairs, soil base, cutting of grass and shrubs, cleaning of aqueducts, trenches and drainage channels

B.2 Observations

B.2.1 N220 – Chissano – Chibuto

This road is 10 years old and was originally constructed with a cement stabilized sand base (6% cement) and over the initial portion, apart from a few potholes and stabilization cracks (both filled and unfilled) was in a relatively good condition. The design was completed in 2000 and construction started shortly afterwards. The design traffic was for just over 1 million ESALs over a 15-year period. The design report indicates that a base course of emulsion treated sand over a cement treated sand subbase was proposed. However, the cement treated base option given in the report resulted in a total saving of 15 per cent, which appears to have been accepted.

The flooding of 2012 caused significant damage to the road and drainage structures along the road. In some areas, only the surfacing had been badly affected (Figure B.2). In others, the subbase had been eroded during overtopping and the entire road had collapsed (Figure B.3) and various pipe culverts had been washed completely away (Figure B.4). The rainfall at the time of the 2012 flooding was in excess of 300 mm derived from two tropical storms (Dando and Funso) just a week apart.

Figure B.2: loss of surfacing from cement stabilised sand base

Figure B.3: Undercutting and collapse of pavement due to erosion of embankment during overtopping

Figure B.4: Site of embankment and culvert removed by flooding with deviation on the left

A large 7-span concrete bridge (at 24°49'15.28"S and 33°29'16.93"E) had been badly damaged as well, with the loss of the approach fills to both abutments as well as the collapse of one of the piers, probably due to scouring of the foundation (Figure B.5).

Figure B.5: Loss of bridge approach fills and collapse of one pier during 2012 flooding

Erosion of the downstream slopes of a number of embankments was observed, with this being exacerbated when vehicle or foot paths had removed the vegetation (Figure B.6). In addition steeper slopes appeared to be more prone to erosion and undercutting of the pavement (Figure B.7). It was also apparent that erosion of the downstream embankment slopes was increased when turbulent flow was initiated by trees and termite mounds. Termite mounds in particular appeared to be a problem, as the mounds caused turbulent flow conditions, which then eroded the site of the mound and the network of tunnels in the termite nest beneath the surface (Figure B.7).

Figure B.6: Erosion of track caused by vehicle movements

Figure B.7: Localised loss of road and embankment caused by turbulent flow around termite mounds

It was also noted that damage to the road and embankments was concentrated in low areas of the road where the water moved across the road more rapidly (Figure B.8). This appears to be caused by local turbulent conditions (no culvert was installed at the bottom of the sag) and it is proposed that this could be reduced or eliminated by ensuring that the road is at the same level at these points and the flow of water over the road is not concentrated in certain areas. This section of the road was closed for three days while the water subsided and emergency repairs were made to the road.

Figure B.8: Damage to embankment and loss of road at lowest point

The section of road after the failed bridge had collapse entirely with the overtopping of the embankment causing undercutting of the road. It was clear that the strong cemented base course was supported by a much weaker (also cemented) subbase, which was eroded and led to undermining of the base course (Figure B.9).

Figure B.9: Total loss of road and embankment caused by overtopping and undermining from the downstream side

B.2.2 N221 Chibuto – Guija

This is also a national road, normally carrying traffic higher than a conventional low trafficked road, although the condition of the road and the loss of some bridges at the time of the visit had reduced the present traffic to very low counts. In areas where the road was on high embankments (4 to 6 m) little damage had occurred. Numerous small bridges showing little or no damage were crossed although there was significant settlement at the approaches to many of them, indicating relatively thick alluvial material beneath the approach fills. The bridges seemed to be mainly founded on piles. A number of their approach fills, however, had been badly eroded while being overtopped during the flooding. The Mobeira Bridge in particular had undergone some emergency repairs to the approach fill, using sandbags and wooden stakes.

Figure B.10: Emergency repairs to approach fill on the Mobeira Bridge using sandbags and wooden stakes

Just before arriving in Mohambe, a large floodplain area where the embankment had been totally washed away was inspected (Figure B.11). The area approaching this showed extensive erosion damage (Figure B.12) due to overtopping from the river to the south-west (this area apparently had a number of pipe culverts, but they could not cope with the flooding from the river and were washed away). This is also an interesting scenario, as the flood waters rose from the river in the south west and did not come down the “valley” from the north-east as would be expected at first glance (Figure B.13). Adaptation measures will need to include such possibilities as this, where typically the damage occurs downstream of the water. In this case, the potential for water from both sides is possible depending on whether the source is flooding of the river or local precipitation.

Figure B.11: Total loss of embankment due to flooding

Figure B.12: Damage to embankment due to overtopping on approach to site in photograph above

Figure B.13: Google Earth image of the damaged area shown in the previous figures – note complete loss of embankment along part of the road alignment (photographed in 2013)

B.2.3 Non-classified road from Mohambe- Maqueze

This is an unpaved (mostly earth) road, which is about 50 km long and is currently on an upgrading programme partly funded by the World Bank. It is also part of a climate adaptation programme currently being carried out by Mott Macdonald under a World Bank Project.

Significant damage was done to this road during the 2012 flooding and a number of drifts (emergency repairs) have been installed to improve passability and various short sections have been spot re-gravelled with a blend of sand and calcrete. The road appears to be particularly troublesome as it weaves among and along the edge of various large natural lakes with the altitude varying between only 11 and 30 m above sea level along the entire 50 km of road. Although no traffic counts were available during the visit, it is estimated that the road carries about 25 vehicles per day, with very few heavy vehicles.

The road was driven over initially from south to north and various points were inspected. These included mostly the emergency concrete drifts, which took various forms. They were all raised above the surrounding natural ground level and most had erosion protection measures on their eastern sides. These varied from “stepped gabion baskets” (Figure B.14) to concrete walls enclosing gabion lined stilling ponds (Figure B.15). In general, they appear to be effective, although relatively costly to construct, especially in view of the lack of aggregate in the area to fill the gabion baskets (aggregate was apparently hauled from Maputo). A suggestion to reduce the costs would be to construct the drifts at natural ground level. This would also reduce likely erosion - it would mean that the road would be closed for a slightly longer duration while the flood water subsides.

Figure B.14: Concrete drift with stepped gabion basket

Figure B.15: Concrete drift with gabion lined stilling pond to minimise water velocities and erosion

The road is a mostly un-engineered earth road with minimal side drainage and makes use of the in situ sandy material as the wearing course. The road generally had only two wheel tracks and had very few corrugations, which is indicative of the low traffic volumes. The local sandy materials (reddish and grey) appear to be suitable for the light traffic on this road, and have been compacted into a hard durable wearing course, probably mostly by traffic.

At the northern end of the road, numerous culverts have been constructed as part of the upgrading project. These are spaced at various intervals, but with the flat grades prevailing in the area, many of them appear (visually, although no water was present during the visit) to be unable to actually move the water away from the road effectively (Figure B.16).

Figure B.16: Newly constructed culvert in flat terrain

B.2.4 N221 – Mohambe-Guija

Although not on the list of projects for consideration, a stop was made at one area along this road where the approach fills of three bridges had been washed away during the 2013 floods. In all cases, overtopping of the wing-walls had led to the erosion of the approach fills behind the abutments and damage to the bridges (Figure B.17).

Figure B.17: Loss of approach fills on three consecutive bridges

B.2.5 R452 Guija-Mazivilla road to Xilembene

This road was identified as a potential candidate for the project as a result of a number of the other roads being unsuitable.

The road was paved and had suffered some damage during the 2012 flooding. The first 5.8 km of the road from the west end had suffered extensive loss of surfacing and thick reeds were growing on each side of the road. In these areas the shoulders were relatively flat but the water could drain away from the road. The following section of road up to km 8.1 was in relatively good condition with some potholes and patches. The topography was very flat with only a 9 m variation in altitude along the entire length (about 17 km) of the road.

It was interesting to note the high number of termite mounds on the embankments along the road compared to their relative abundance away from the road reserve – it appears that either the termites under the roadbed were not exterminated during construction and continued to construct their nests, or else the termites tend to migrate towards the newly compacted fills after construction.

In a number of places along the road, the shoulders had been built up with grass and soil to be higher than the adjacent bituminous surfacing, causing water to pond on the pavement during rain.

B.2.6 R859 Xilembene to Maniquenique

This road was about 35 km in length and had a number of problems along it. The terrain was also very flat with a maximum variation in altitude of about 8 m along the road, ending at about 11 m above sea level at the eastern end. The area is a highly cultivated one, with a number of large commercial farms, being fed by a number of irrigation canals, some of which run parallel and adjacent to the road.

The road consisted dominantly of a “concrete” filled Geocell pavement (apparently 22 per cent cement was used) overlying the local natural soil, generally on a 2 to 3 m fill with an irrigation canal along much of the western portion of the road (Figure B.18). The total thickness of the Geocell was 75-80 mm, resulting in a thin, essentially concrete road (Figure B.19). Although there were localised failures and potholes along the road, the biggest problem was the loss of adhesion between the seal and the "concrete" base (Figure B.20). There was no evidence of a prime having been applied.

Figure B.18: Good section of Road R859 showing embankment and irrigation canal (empty)

Figure B.19: Area of road showing Geocells and in situ material exposed by erosion of embankment next to road

Figure B.20: Area of Geocells with total loss of seal and development of pothole in central part of photograph

This road is currently on the rehabilitation programme with a design and build contract out to tender. The proposed design should be an interesting one as the road, although structurally sound over most of its length, is very thin (shallow structure) and will be difficult to rehabilitate with the Geocells in place. It would probably be best to break them up using an impact roller for use as a new subbase, and then place a cemented sand base over the top.

B.2.7 R448 Chokwe to Macarretane

During the site inspections it was proposed that this road be visited as it was also susceptible to numerous problems and was on the programme for upgrading and repairs. The road carries less than 250 vehicles per day and will certainly carry less than 1 million standard axles. Although it is a national road, it would qualify for inclusion in the adaptation project.

As the road leaves Chokwe (km 3.8 to 4.1, taking the traffic light in town as 0), it shows severe loss of surfacing and damage due to flooding (Figure B.21). This apparently occurred in 2012, when water came from south-west of the road, over the road towards the Limpopo River to the north-east. The damage was repaired with local gravel and the seal has not been replaced. The direction of flooding indicates that it was due to local precipitation and not rising of the level of the Limpopo River. No cross-drainage was evident near this section of road.

Figure B.21: Damage to and loss of surfacing caused by 2012 flooding

At about km 8.0, there are significant outer wheel path failures in the right hand side lane (Figure B.22), typically indicative of weakening of the structural or support layers due to moisture ingress. It was clear that the shoulders were not well-shaped to move water away from the edge of the carriageway.

Figure B.22: Patches of outer wheel path failures in east-bound lane

Although there were culverts along the road that were in good condition generally (Figure B.23), they were fairly widely spaced in this area, which appeared to be flatter and more arid. The culverts were nearly all 600 mm diameter pipes, which was surprising as the railway running parallel to the road had culverts in the same locations but these generally consisted of 3 x 1 m square box culverts next to each other.

Figure B.23: Single 600 mm pipe culvert in flat terrain

A number of small bridges and one larger one were also inspected. They all showed signs of flood-water damage to varying degrees. This was mostly loss of surfacing near the bridge approaches, damage to erosion protection measures and localised loss of embankment material (Figure B.24).

Figure B.24: Damage to small bridge approach fill, erosion protection and surfacing

Overtopping and loss of surfacing had occurred at a number of other places along the road, one of the worst areas being at about km 22.3, despite the embankment in this area being about 4 m high (Figure B.25). The overtopping apparently occurred both in 2000 and in 2012. The damage was mostly initiated in 2000 and the road was repaired only with local gravel and not resealed. Damage in 2012 required additional repairs. According to local residents, the flooding was from the north indicating that it was due to local precipitation and not rising of the level of the Limpopo River. Google Earth images of the area in 2000 and 2010 (Figure B.26 and Figure B.27), however, show that the water appears to have approached from the east in 2000, where the Limpopo River is dammed.

Figure B.25: Loss of seal and damage to embankment

Figure B.26: Google Earth image of the area approaching Chirrunduo taken on 26/3/2000

Figure B.27: Google Earth image of the area approaching Chirrunduo taken on 26/9/2010

B.2.8 Road R443 – from Mazucane – Inhambane Province

This road was visited purely to inspect the local upgrading methods for a typical rural low volume road. The road is a 30 km section of currently un-engineered earth road that is being upgraded to sealed standard (cost of 387 million MT). Currently the road is depressed below the surrounding natural ground level and has very poor drainage (Figure B.28). The design is to raise the formation between 400 and 600 mm, place a 300 mm natural sand subbase over this with a 150 mm cement (5%) stabilised sand base course and a single seal.

The contractor had new high quality equipment on site and appeared to be doing a good job. The construction of the formation included moving the existing sand on the road (including widening) and importing a yellow brown sand as the formation (Figure B.29). This resulted in large quantities of red sand spoil along the edge of the road that had to be removed before any appropriate drainage measures could be installed – inspection of this material indicated that it would probably have been perfectly adequate for the formation material and only the subbase and base material would need to have been imported from the borrow pit at about km 6.0. This material was a slightly cohesive red sand, typical of those materials that have given good performance as base courses in even untreated states on low volume roads in the SADC region.

Figure B.28: Typical example of road prior to upgrading

Figure B.29: Placement and compaction of subgrade material on Road R443 showing spoil piled at road edges

B.2.9 Manjacaze-Chibonzane

This road was visited as this was evidently a typical rural access road, leading solely to a small village with houses scattered along the route. The total length inspected was about 22 km and the road was a mostly un-engineered earth road, about 5 m wide and showing 2 wheel tracks, indicative of less than about 25 vehicles per day. A maintenance contract valued at 6.3 million MT (about US$83 000) was in progress, although there was little evidence of any work being carried out at the time of the visit – some spot regravelling and a couple of new culverts were observed.

The road was constructed of a red-brown sand that compacted quite well to provide an appropriate surfacing for the standard of road required. However, the road crossed a large flood-plain between two shallow marshy areas (dry during the visit) with cross-drainage provided only by two double-pipe 600 mm culverts (shown in red on Figure B.30).

Figure B.30: Road R451 crossing between two marshy areas with only two culverts. The closely spaced mitre drains on the left have been installed after 2013

It is interesting to note that there is only 3 m variation in altitude along the road from the left to the right of the image above, over a distance of 800 m. Figure B.31 shows one of the culverts, somewhat damaged, which acts an equalisation pipe between the two sides of the road. This road is apparently never overtopped.

Figure B.31: Typical example of road prior to upgrading

B.3 Problems identified during site visits

B.3.1 Erosion and undercutting

This is a ubiquitous problem seen on a number of roads affecting the edges of the roads as well as embankments and takes different forms related to different problems.

- Oversteep slopes result in rapid flow of water and erosion down the slopes when they are overtopped. This is particularly prevalent on the downstream sides of embankments and is exacerbated by turbulent water flow, which may be caused by the location of the road, shape of the embankment and presence of trees and obstructions (e.g. termite mounds).
- Weak support layers under the strongly cemented base course
- Foot and vehicle tracks leading off the road and down slopes result in a loss of grass growth, which soon causes erosion and material loss in these areas when rained on.

B.3.2 Damage to structures

Numerous structures that had been severely damaged by flooding were observed. Many of these were irreparable and the structures would need to be destroyed and reconstructed. The main areas affected are:

- Approach fills that are washed away during flooding
- Protection works that are washed away
- Damage to piers caused by debris in the flooding river
- Scour of foundations
- Entire bridges that are washed away

B.3.3 Damage to road surface

The damage to the road surface was seen at a number of locations resulting from different causes:

- Hydrostatic pressures under the seal due to high water levels
- Water entering from the edge of the surface beneath the seal and disrupting the bond between the base and the seal (Figure B.32). This may have been due to various factors:
  - Poor bond at the edge of the seal near the shoulder allowing water to enter
  - Cracks in the surfacing allowing water to enter
  - Possible block cracking in the heavily stabilised sands allowing water to penetrate the base.
  - The use of non-durable single seals (they should be more durable than those observed) adjacent to the good double seal on the carriage way allowing water into the shoulder materials and then into the base (Figure B.33).
- The Geocell section of road indicated open cracks above the cell part of the road (Figure B.34), which allowed water below the seal resulting in loss of the seal, exacerbated by the absence of a prime.

Figure B.32: Loss of seal due to water penetrating at edge of seal

Figure B.33: Example of failure of non-durable single seal on shoulder

Figure B.34: Open cracks reflecting through from actual Geocell grids

B.4 Solutions

B.4.1 Erosion and undercutting

B.4.1.1 Embankments

A lot of the damage to the embankments was considered to be due to turbulence caused by concentrations of water flowing across the road at slightly lower points. This is exemplified in Figure B.35 taken during the 2012 flooding where such turbulence is clearly visible along the road. There was also evidence to suggest that the presence of trees and termite nests exacerbates the problem, with trees affecting the laminar flow of water while termite nests initially cause some turbulence and then provide weakness in the embankment (tunnels and voids) leading to erosion and undermining of the road. It is also suggested that the embankment slopes on the downstream side should be flattened to reduce the velocity of water flowing down it and prevent undercutting and erosion.

Figure B.35: Photo of 2012 flooding showing localised turbulent flow at low points in embankment

As the flooding in the areas visited can often come from either side of the road, it is recommended that the embankments on both sides of the road are flattened, covered with a layer (150 mm thick) of suitable clayey material, compacted and then grassed over with a deep-rooting indigenous grass. It is preferable that both rhizomous and bunch-rooted grasses are used to ensure surface strengthening for erosion protection and deeper anchoring to avoid surface sloughing. Flattening should be to a maximum slope of 1 vertical to 3 or 4 horizontal to reduce the velocity of flow of water down the embankment slope, as well as minimising "wave" action on upstream slopes during the approaching flood.

B.4.1.2 Roads

Even on low formations, damage to the road formations by water flowing over the road was observed (Figure B.36). This should be eliminated by keeping the road at natural ground level as far as possible where the water flows across the road.

Figure B.36: Undercutting of downstream part of road due to water flowing across it

B.4.2 Side drainage

It is obviously not possible to design entire lengths of road that will not be overtopped during extraordinary flood events in such flat and low-lying areas. However, for normal rainfall, it is imperative that the side and mitre drains are capable of removing water from the road effectively. On nearly all of the roads inspected, the side drains were usually effective where they existed but most mitre drains were ineffective (Figure B.37). While it is acknowledged that in flat areas, the removal of water from mitre drains is difficult, their general configuration observed made drainage almost impossible. Most of these did not extend more than a few metres away from the road and effectively acted as small sumps. Maintenance usually resulted in the silt and materials from the drains being mounded along the side of the drains and at the end of the drain, reducing their capacity for removing water from the road environment even further. The ends of the mitre drains must be opened up to allow water to flow out of them, even if a larger "sump" is excavated to hold water while it evaporates. Building up of the drain on the downhill side is acceptable, as this will minimise overtopping of water which could then flow back onto the road.

Figure B.37: Short mitre drain built up on both sides and at end during maintenance

It is also important that the access to the drains is not blocked by windrows formed during grader blading of gravel roads. Similarly, grassing of shoulders on sealed roads should not result in the shoulders becoming higher than the edge of the surfacing and thus trapping water on the paved portion of the road.

B.4.3 Cross drainage

It is essential that cross-drains have the capacity to move water from one side of the road to the other without erosion, excessive siltation or permitting the water to enter the pavement structure. Where the terrain is so flat that removal of the water is almost impossible, the water should be removed as far from the road as practically possible and the allowed to flow into a sump or drain-away areas. It should not be allowed to accumulate close to the road (Figure B.38).

Figure B.38: Photo of 2012 flooding showing localised turbulent flow at low points in embankment

Culverts should be kept in good condition without breakages and certainly without cracks in their structure (Figure B.39). Such cracking will allow the penetration of water into the pavement layers and induce failure of the road.

Figure B.39: Culvert allowing equalisation of water where road has severed floodplain area – note damage and potential for further damage when soaked

B.4.4 Structures

Apart from one bridge and a number of culverts that were totally removed from their supports or location during flooding, the dominant mode of damage affecting structures was erosion of the approach fills and erosion protection measures (Figure B.40). Depending on the degree of flooding (i.e. the return period of the storms that have occurred), it may not be possible to design all structures to withstand them. However, the improvement of the materials, construction and protection measures of the approach fills should be carried out as a matter of course. This will mostly involve:

- Better materials for the fill (possibly blending in some coarser gravel)
- Higher compaction efforts
- Higher wind walls with better water diversion characteristics
- Better erosion protection measures (gabions, grouted rock, concrete slabs, etc.)

Figure B.40: Erosion of fill around abutments during flooding

It is also important, certainly for new road developments, to try and remove the impact of flooded rivers attempting to change direction n near the structures. Figure B.41 shows a river approaching the bridge at an angle and then being sharply diverted to cross under the bridge perpendicularly. The damage to the approach fill and pavement clearly indicates that the folded river could/did not change direction and overtopped the embankment causing the damage to the approach fill and the road.

Figure B.41: Damaged road and fill caused by change in direction of river

B.5 Recommendations

Based on the observations during the site visits it is proposed that the two roads to be selected for adaptation measures should be the non-classified road from Mohambe to Maqueze and Road R448 from Chokwe to Chirrunduo.

Work on the non-classified road is already in progress, with the construction of various drifts/fords, a number of culverts and some localised spot regravelling being observed during the visit. However, no activity or plant was noted anywhere on the road during the visit. It is anticipated that some additional adaptations can be incorporated on this road, even at this stage.

No work appears to have been started on Road R448 yet. This road requires a number of adaptations and these should be proposed for incorporation into the proposed rehabilitation project.

Annex C: Notes on Field Visits undertaken in Ghana

C.1 Background

As part of the AfCAP climate vulnerability project, the selection of one roads in each of the three target countries (Ethiopia, Mozambique and Ghana) for implementation of the proposed adaptation measures was required. These roads should preferably be on an improvement/upgrading/ rehabilitation programme with funding already allocated for their work.

The Department of Feeder Roads (DFR) was requested to identify candidate roads for this purpose. The following roads were identified:

1) Kusawgu Junction - Tuluwe - Adape - bitumen surfacing/rehabilitation of (77.5km)
2) Fazhini Junction - Janjorikukuo Junction -rehabilitation - (9.0km)

A brief discussion before the first site visit was held with various officials from the Northern Region (Tamale), including the Regional manager, Eng Don Kuubetersie. It was suggested that a third road close to Tamale also be inspected during the visit. The visits were carried out between the 17th and 19th October 2016. The CSIR team was accompanied by Engs Don Kuubetersie, Efua Akwetea-Mensah, Edmond Balika and Abdul Hamidu.

C.2 Observations

C.2.1 Fazhini Junction - Janjorikukuo Junction

This mostly earth road is 9.3 km long and is currently almost impassable to the point that there are no vehicles using it. Various structures and parts of the road were washed away prior to 2009 and have not yet been replaced. The road is mostly an un-engineered earth road with localised areas of spot gravelling, some rudimentary side and mitre drains and a few remaining culverts (Figure C.1).

The rehabilitation has been designed and a Contractor is currently on site replacing missing drainage structures and constructing some larger new ones, before carrying out a full rehabilitation of the road. This is planned to include improved raised formations and side drains, improved drainage and the application of a 100 to 150 mm thick laterite gravel wearing course.

It is envisaged that the road will become a connector between the R90 and N10 roads, avoiding the need to pass through Tamale. A number of potential problems with this proposal were noted during the site visit. Because of the current lack of passability along the road, the only traffic on the road consisted of motor cycles and pedestrians. Improvement of the road such that it becomes a through-route will lead to rapid deterioration of the gravel wearing course and significantly increased maintenance costs, higher traffic speeds and increased dangers to pedestrians.

Figure C.1: Track of road between Fazhini Junction in South East and Janjorikukuo Junction in North West

The road starts northwest of Giana with a raised culvert immediately at the beginning where water can pass beneath the upgraded road parallel to the existing R90 road. The road then drops to a low point, which will be raised with imported gravel and then surfaced with a 100 mm thick subbase (wearing course). This will be a local laterite from a nearby borrow pit. The quality of the gravel appears to be good, with a good riding quality over the short initial section using the gravel (Figure C.2). This section still needs to be raised before final gravelling.

Figure C.2: Laterite wearing course with rudimentary drains – section still to be raised

The proposed rehabilitation works include widening of the carriageway (gravel surface and shoulders) to 7 m (it is currently less than 3 m in places), the provision of side- and mitre drains and the construction of new drainage structures. There are currently five areas with drainage problems, which are being addresses with the addition of a number of pipe culverts (mostly 900 or 1,200 mm diameter) as well as two double 2 x 2m box culverts (Figure C.3).

Figure C.3: Construction of standard double 2 x 2 m reinforced concrete box culvert

At about km 4+800, the culvert had been destroyed during flooding some years ago (Figure C.4) and only parts of the concrete walls remain. This is to be replaced with a new double 2x2 m box culvert as well as a 900 mm pipe culvert.

Figure C.4: Site of culvert washed away and due to be replaced

In general, the road can be handled using good engineering decisions and the proposed rehabilitation design appears to be adequate for the road. Care will, however, need to be taken to ensure that water is removed from the side of the road as effectively as possible. Some of the local materials are particularly prone to erosion (Figure C.5) and side drains will need to have adequate mitre drains (turnouts) to ensure that water velocities do not build up to speeds that will result in excessive erosion.

Figure C.5: Erodible materials that will require careful drainage design

C.2.2 Tampion-Tibognaayili-Tidjo

This road is similar to the previous one, currently being impassable but potentially becoming a through-route between two national roads, the final portion between Tijo and the N9 at Jimle.

The road inspected is 19.2 km long (Figure C.6) and is currently on the programme for rehabilitation. A rehabilitation design has been completed (Annex J) but the project has not yet gone out to tender. The current start of the road on Tampion is likely to be moved 500 or 600 m towards the north east to make use of a better aligned haul road currently being used to haul material to the rehabilitation of the adjacent R90.

An existing subbase quality material borrow pit (residual sandstone/laterite) has been opened at km 1.7 and a better quality laterite borrow pit just beyond this at km 2.1.

Between km 4.7 and 5.1 is a section of poor drainage with a silty fine material occurring at the surface. This is very weak and has resulted in significant churning and deformation, apparently becoming impassable when wet (Figure C.7).

Figure C.6: Approximate trace of Tampion-Tijo road on Google Earth

Figure C.7: Poorly drained area with weak silty material

Just past this is an area of outcropping laterite and shale, with the laterite forming a "perched water table`" resulting in significant drainage problems (Figure C.8). The water drains through the layer where it has been fractured. This is a common problem on calcrete hardpan. Where a similar situation exists, a heavy vibrating or impact roller could be used to fracture the hardpan and avoid the perched water table condition.

Figure C.8: Perched water table on hardpan laterite outcrops

It is interesting that there are two distinctly different laterites in the area. One has strong cemented iron pisoliths in a grey weak clayey matrix, while the second one has the pisoliths strongly cemented by iron oxides (Figure C.9).

Figure C.9: Laterite with clay matrix (grey part on left) and with iron oxide matrix (right)

At about km 8.85, a series of box and pipe culverts allow a river to cross the road with standing water occurring on both sides of the road. There was evidence of overtopping of the embankment with some erosion on the downstream side of the fill in places, particularly next to the wing-walls. The embankment was on a 1:1.5 slope but still had evidence of erosion, except where grouted stone-pitching was placed, which was highly successful in protecting the slopes (Figure C.10).

Figure C.10: Grouted stone pitched embankment protection

Next to the head-wall of the culvert, an area of tunnelling associated with a new ant nest was observed (Figure C.11). Overtopping of the embankment would result in water entering this "nest" and collapse of the road in this area. Despite the deleterious ecological effects, such ants should be exterminated in order to avoid damage to the embankment.

Figure C.11: Initiation of ant nest in embankment

In the area of km 10.4, the road was totally flooded (Figure C.12). Although it was possible to drive through it (four-wheel drive was utilised), the road cannot be considered accessible for all vehicles beyond this point.

Figure C.12: Flooded area at about km 10.5

The proposed design in this area is to install two 2x2m box culverts and two 1200 mm pipe culverts and raise the road onto an appropriate embankment.

From about km 11.3 onwards the road decreases in width to no more than a track in places (Figure C.13) with localised drainage problems and loose material requiring 4-wheel drive (Figure C.14).

Figure C.13: Road decreases in width to a track in many places

Figure C.14: Localised drainage and passability problems

The section of road ends at Tidjo village after about 19.0 km and joins an access road that extends for another 15 km or so to the N9 at Jimle. Although upgraded only a few years ago, this road requires significant maintenance and some localised upgrading.

C.2.3 Kusawgu Junction - Tuluwe - Adape

This is an unpaved (mostly earth) road, which is about 77 km long leading to Lake Volta and is currently on an upgrading programme. The road is passable for most of the first 70 km or so, although a number of flooded streams had to be crossed during the visit. During the trip, however, it was not possible to ford the streams after this and the village at the end of the road (Adape) could not be reached.

Recent logging activity in the area has led to large vehicles using the road (Figure C.15) and a number of concrete box culverts had collapsed and been repaired using logging off-cuts (Figure C.16).

Where the road formation has been raised adequately, the general performance is good. In other areas, poor drainage and the presence of hard laterite outcrops has affected the road performance severely. From about km 35, the road is mostly an earth rack and riding quality and passability deteriorate significantly.

Figure C.15: Large truck noted alongside road during site visit

Figure C.16: Collapsed culvert repaired using logging off-cuts

The first section of the road is surfaced with a good laterite material, which appears to be self-stabilising resulting in a hard wearing course layer, although where the road passes through the villages poor drainage has led to erosion and potholes.

At about km 6.5, ineffective pipe culverts and perched water tables on the laterite hardpan have resulted in drainage problems (Figure.C.17). Further down the road a number of culverts have become exposed and there are various problems where side roads and accesses join the main road – primarily the introduction of water collected on these roads onto the main road and concomitant erosion and damage to the road.

Figure C.17: Poor drainage due to perched water tables and ineffective pipe culverts

At about km 14.7 there is a Bailey Bridge replacing a concrete one that was washed away some time ago. This is effective but shows some evidence of erosion of the bank protection beneath the bridge (Figure C.18).

Figure C.18: Erosion of bank protection beneath Bailey Bridge

The two collapsed "bridges" (Figure C.16 and Figure C.19) between km 45 and 47.4 have been made "passable" by the placement of logging off-cuts but appear to be somewhat precarious for larger vehicles.

Figure C.19: Collapsed concrete bridge showing severe damage to deck, abutments and wing-walls.

From this area onward the mostly un-engineered earth road with minimal side drainage continues and is of poor quality. At km 63.7, the road was flooded as a result of an earth dam being built by the community adjacent to the road (Figure C.20). Although this was passable at the time of the visit, it is unlikely that it would be passable after severe rains when the dam fills up. The road continues as a more or less 4 x 4 track with numerous other areas where flooding had to be traversed until a local resident suggested that the flooding became too severe for even a 4x4 vehicle and the continuation of the trip along the road was abandoned (Figure C.21).

Figure C.20: Newly constructed culvert in flat terrain

Figure C.21: Flooded road at which point the trip was ended

C.3 Problems identified during site visits

C.3.1 Erosion of side-drains and road surface

Although the laterite gravel placed on the road was of fairly good quality, there were strong signs of erosion and material loss (Figure C.22). This was primarily due to the poor shape of the roads, resulting from minimal maintenance that caused a loss of camber, but is also probably exacerbated by low compaction levels. Similarly, the infrequent presence of mitre drains resulted in a build-up of water volumes and flow velocities in many of the side drains, leading to bad erosion and ponding at the bottom of inclines.

Figure C.22: Erosion of road surface and side drains

C.3.2 Damage to structures

Apart from the bridge that had been replaced by the Bailey bridge, the structures generally coped with the local precipitation. Damage to the structures was mostly traffic related, although erosion of the embankment protection beneath the Bailey bridge should be repaired before additional erosion leads to damage of the abutments and approach fills.

C.3.3 Flooding of road

The flooding of the roads is typical of that seen on un-engineered roads where no specific attention is paid to the control of water. In most of the cases, the flooding was not particularly severe and would be avoided by raising the road and constructing traditional pipe culverts to cater for the expected water flows.

C.3.4 Road condition

The laterite surfaced portion of the roads was generally in a reasonable condition and would perform well with a little additional surface maintenance and attention to maintaining a good cross-sectional shape. The earth sections of the road varied from poor to impassable for normal traffic, resulting in nearly all of the roads being abandoned by most through traffic and limited to motorcycles and bicycles.

C.4 Solutions

None of the engineered section of the roads inspected appeared to be particularly troublesome in terms of climate adaptation. The application of good design and construction standards would result in their becoming climate resilient, due to the generally rolling nature of the topography in the areas inspected and the generally good properties of the laterite gravels available.

C.5 Recommendations

Based on the observations during the site visits it is proposed that the road to be selected for adaptation measures should be Tampion – Tidjo road. This has number of areas of drainage and flooding problems and suffers from a number of problems that would be exacerbated by climate change, particularly increases in extreme precipitation events.

The road is also currently on an upgrading programme and thus would be suitable for continued assessment.

Annex D: Preliminary Bills of Quantity for Demonstration Sections

<<< To be completed >>>

Annex E: Proposed Objectives and Scope for Phase 2 of Study

E.1 Aims and Objectives

The overall project aim is to move forward from previous AfCAP research and deliver *sustainable enhancement in the capacity of AfCAP partner countries* to reduce current and future climate impacts on vulnerable rural infrastructure. This is to be achieved through research, and consequent uptake and embedment, at both policy and practical levels, of pragmatic, cost-beneficial engineering and non-engineering procedures based on the recognition of locally-specific current and future climate threats.

- The fundamental ***Research Objective*** of this project is for the AfCAP Service Provider to identify, characterise and demonstrate appropriate engineering and non-engineering adaptation procedures that may be implemented to strengthen the long-term resilience of rural access.
- With respect to ***Capacity Building and Knowledge Exchange***, the appointed AfCAP Service Provider must engage meaningfully, from project inception onwards, with relevant partner-country Road and Transport Ministries, Departments and Agencies/Authorities in a knowledge dissemination and capacity building programme based on the outputs from the research. Capacity building should include a wide range of targets from central government agencies to village groups.
- ***Uptake and Embedment*** are integral elements of this project. The appointed AfCAP Service Provider must ensure that there is focus on uptake and subsequent embedment of outcomes. This must be aimed at a range of levels from informing national policies, through regional and district planning, down to practical guidance on adaptation delivery at rural road level.

The overall programme objectives are:

- To identify, characterise and demonstrate appropriate engineering and non-engineering adaptation procedures that may be implemented to strengthen the long-term resilience of rural access, and
- To build capacity and disseminate knowledge.

E.2 Comments on the Terms of Reference for Phase 2

E.2.1 Scope of work for Phase 2

The following sets out the scope of work as per the original Terms of Reference (in italics) and provides commentary based on experience gained during the execution of Phase 1:

1. *In association with the identified programmes or projects in partner countries, undertake demonstrations of engineering and non-engineering options in the three regions of differing topographic/climatic environments.*
   - Phase 1 focused on vulnerability from a rural access perspective resulting from historical and recent impacts of climate, whilst also mapping out projected climate impacts for the periods 2020-2050 and 2070-2100 for three countries in particular (Ethiopia, Ghana and Mozambique). Generic engineering and non-engineering adaptation solutions were recommended, some of which have already born fruit, particularly in Mozambique (e.g., process for embedment of climate-related aspects in technical guidelines and specifications

has been initiated, and the Administração Nacional de Estradas (ANE) has established a new Directorate of Emergencies within the structures of the organisation). In Phase 2, such actions will have to be intensified for the other two countries (Ethiopia and Ghana), whilst also supporting other AfCAP partner countries.

- Phase 1 also provided several technical recommendations for the implementation of demonstration projects as outlined in Chapters 3, 4 and 5 of this report, based on the field visits described in Annexures A, B and C. The technical recommendations for the demonstration sections, when accepted, will have to be mapped out (i.e. detailed designs), resource-defined, costed, programmed and implemented in Phase 2. At the same time, a detailed monitoring and evaluation plan will have to be drafted, defining the desired outcomes and working back from these to define the necessary actions to achieve these (e.g., setting up of baseline data for the demonstration sections and monitoring programmes). This plan should be drafted in the Inception Phase of Phase 2.

2. *Research the lessons to be learned from demonstrations.*

   It may take several years to validate the technical, social and/or economic benefits of the climate adaptation interventions recommended for implementation at the demonstration sites in the three targeted countries (assuming that the actions are appropriate). Nevertheless, several lessons can be learned from the implementation of these interventions in the short term. These lessons could include aspects such as:

   - Contractual proficiency to implement climate adaptation solutions from an infrastructure delivery perspective (i.e. quality of construction), particularly in those cases where innovative (i.e. out-of-norm) technologies are to be applied;
   - Challenges associated with construction material availability (e.g. gravels in Mozambique) and with construction (e.g., availability of compaction water in Ghana during the construction season);
   - Deviations from current norms and standards; highlighting areas in need of improvement at a national/sectorial level;
   - Comparisons between initial costs for standard designs and more climate-resilient designs;
   - Estimation of life-cycle costs for the purpose of cost-benefit analyses;
   - Capturing of qualitative and quantitative benefits to communities resulting from the provision of improved accessibility to markets and essential services (i.e. schools, clinics, hospitals), based on surveys conducted before and after the interventions (and after the occurrence of seasonal weather events), inclusive of traffic surveys.

3. *Work with partners to disseminate lessons learned and identify the means for appropriate uptake and embedment.*

   One of the focal points of Phase 2 will be to assist stakeholders to apply detailed resilience solutions in a cost-effective (economic) manner, to assist them to investigate, detail and implement appropriate engineering and non-engineering options, and to train/mentor those directly involved (cf. Item 4 below).

   In addition to 'lessons learned', it is also of key importance to disseminate the 'outputs' produced to date, inclusive of 'best practices' for a particular situation.

   A substantial dissemination and communication programme will be required that will cascade across all stakeholders at national, regional and local levels.

4. *Work with partners to develop capacity in appropriate government and private sector institutions in climate adaptation options.*

   The prime focus will be to cascade training/mentoring in three demonstration countries, although additional programmes of capacity building in other AfCAP member countries should also be established and implemented.

5. *Develop a knowledge transfer programme for the broader ReCAP community of practice and relevant stakeholders based on the outcomes of the project. This could include workshops and the presentation of peer reviewed papers in conferences and journals.*

   Full scoping consultations would be required, with country workshops being the main communication and training platform. It is also proposed that a Project Implementation Team (PIT) meeting/workshop on Climate Adaptation be convened, and that all AfCAP (and possibly also AsCAP) Partner Countries be invited to participate in this event. As in the case of the most recent PIT meeting on Asset Management (November 2016), the invitation for attendance could be extended to the members of the African Road and Transport Research Forum (ARTReF).

   In order to enhance the visibility of the Climate Adaptation project, and particularly of its outputs, it is recommended that papers be presented at regional conferences on a regular basis. Ideally, these should be linked to workshops either incorporated in the conference itself, or held in parallel or attached to the conferences.

   It will also be important that articles be published in accredited and peer-reviewed Journals to subject the project's activities and outputs to scientific scrutiny.

E.2.2 Deliverables

According to the original Terms of Reference, the following technical and contractual **reports** will be required:

1) Inception Report
2) Demonstration Site Reports
3) Workshop Summary Reports
4) Way Forward for Project Post Phase 2
5) Final Overview Report
6) Short Monthly Progress Reports
7) Scientific Paper.

The following comments are made on the deliverables (note: text in italics has been extracted from the original Terms of Reference):

1. *Individual reports on each of the three demonstration areas that focuses on the lessons to be learnt and that include costed recommendations for implementing climate resilience programmes in each area.*

   The *Demonstration Site Reports* will provide a comprehensive overview of the three demonstration sites (one report for each site), inclusive of detailed information on, inter alia, the design, project specifications, scheduling of activities (programme), bill of quantities, and measures to ascertain quality (quality control). It will also include a monitoring and evaluation plan for each site, in which 'lessons to be learnt' will need to be incorporated. Non-engineering climate resilience adaptation options appropriate to each site should also be included in the reports.

It is recommended that *Post-Construction Site Reports* be included as additional deliverables. These reports (one per site) will contain all as-built data and information (inclusive of minutes of site meetings), setting the benchmark for all future monitoring activities. The AfCAP Service Provider will have to ensure that all data and information contained in this report are properly referenced and checked for quality and completeness. Lessons learned prior to and during construction should also be captured in these reports. All information and data that are impractical to be included in report format should be kept electronically in a secure environment (e.g., regularly backed-up). Electronic files and their content should be clearly labelled and well structured (i.e. enabling other users to understand their content), and all electronic files (inclusive of their location) should be listed and referenced in annexures to the reports.

2. *Training materials drafted and delivered at three separate training workshops in locations associated with the demonstration areas. These workshops to be open to other AfCAP countries and relevant non-AfCAP organisations.*

   In addition to the training material, Workshop Summary Reports will be drafted (one per workshop). Ideally, these workshops should be held at an appropriate venue in close proximity to the demonstration sites, enabling the workshop delegates to visit the sites during the workshops. The workshops should be held towards the middle of the construction window, exposing the delegates to conditions prior to and after implementation of adaptation actions.

3. *Recommendations on further work, including longer term monitoring that should be undertaken in the demonstration areas.*

   Based on experience of other projects, it is recommended that a 'train-the-trainer' programme be initiated with a suitable national institute during Phase 2 or as part of Phase 3 to ensure continuity beyond the completion of the AfCAP project. Training should be provided on an annual basis, also to cater for loss of previously trained personnel in state-owned entities. It is also recommended that a continuous mentoring programme be implemented, possibly with secondments to organisations such as the CSIR.

   Assuming that the climate resiliency measures put into place at the demonstration sites are effective for dealing with at least present climate variability, it may take several years to demonstrate their effectiveness of dealing with extreme weather event. Hence, a long-term monitoring programme will need to be put into place that will stretch well beyond the 70-week Phase 2 programme. Recommendations for a long-term monitoring and evaluation programme will be incorporated in the Monitoring and Evaluation Plan that will be drafted during the Inception Phase of Phase 2. This Plan will have to be updated on a regular basis during Phase 2, and will form the basis for a continuation programme in Phase 3.

4. *An overview document that includes any necessary updates of deliverables 1 and 2 from Phase 1*

   The *Climate Threats Report* and the *Climate Adaptation Options Report* produced in Phase 1 will have to be updated on a continuous basis to include new information considered relevant to stakeholders as well as to augment current information based on feedback obtained from the demonstration sections.

   It is recommended that both reports be combined to produce guidelines for the management and resilience optimisation for vulnerable road access.

5. *A bench-mark scientific paper based on project outcomes be submitted to a recognised scientific/engineering journal.*

   As noted in Section E.2.1, it is recommended that papers be prepared and presented at regional conferences on a regular basis and that articles be published in accredited and peer-reviewed Journals to subject the project's activities and outputs to scientific scrutiny.

E.3 Proposed Scope of Phase 2

It is proposed to adopt the following six distinct parts for Phase 2, reflecting the programme aims and objectives:

- *PART 1: Demonstrate appropriate engineering and non-engineering adaptation procedures*

  Identify, characterise and demonstrate appropriate costed engineering and non-engineering adaptation procedures that may be implemented to strengthen the long-term resilience of rural access. Assess the socio-economic impacts of adopting more climate resilient adaptations.

- *PART 2: Sustainable enhancement in the capacity of three AFCAP partner countries*

  Engage meaningfully, from project inception onwards, with relevant partner-country Road and Transport Ministries, Departments and Agencies/Authorities in a knowledge dissemination and capacity building programme based on the outputs from the research. Capacity building should include a wide range of targets from central government agencies to village groups.

- *PART 3: Sustainable enhancement in the capacity of additional AFCAP partner countries*

  Carry out situational analysis and initiate capacity building programme in additional countries.

- *PART 4: Uptake and embedment across AFCAP partner countries*

  Uptake and embedment will assume the format of informing national policies, through regional and district planning, down to practical guidance on adaptation delivery at rural road level.

- *PART 5: Phase 3 recommendations*

  Set out costed long-term monitoring and evaluation proposals, as well as any future actions that may be required to strengthen uptake and embedment.

E.3.1 Scope and outputs

E.3.1.1 PART 1: Demonstration of appropriate engineering and non-engineering adaptation procedures

Phase 1 has confirmed the selection of three pilot AfCAP Partner countries, comprising Ethiopia, Ghana and Mozambique, for climate adaptation demonstration purposes. These were chosen in order to incorporate diverse geographical and climatological factors. Phase 2 will further the development of adaptation plans and also broaden the scope to cover additional countries.

Phase 1 also focussed on the identification of sub-regions and road networks that are currently experiencing various degrees of climate phenomena/effects and that also have a relevant programme of adaptation measures about to be implemented. Field trip reports have been compiled for each country that documents damage effects and causes, with commentary on adaptive measures considered appropriate (cf. Annexures A, B and C). These are predominantly engineering adaptive measures to address current challenges resulting from inappropriate designs and/or maintenance defects or changing climate effects.

Recommendations have been provided for the implementation of adaptation measures on three demonstration sites (one road per country). These are contained in Chapters 3, 4 and 5 of this report.

One of the main objectives of Phase 2 is to establish demonstration sections in the three targeted countries. This will entail, inter alia:

1) Revisit the road sections identified in Phase 1, and conduct rigorous site investigations with the objective of gathering sufficient data to produce detailed designs and plans for the implementation of engineering and non-engineering adaptation options;
2) Support the road authority (and its appointed consulting engineering team), where appropriate, with:
    a. Drafting of project specifications for the demonstration sites;
    b. Producing bills of quantities, inclusive of an indicative costs, based on item costs derived from projects completed in close vicinity of the planned demonstrations;
    c. Preparing tender documentation or amendments to current tender documentation;
    d. Appointment of contractors (if applicable).
3) Provision of support during construction, including:
    a. Induction of the delivery team (road authority, consulting engineer, contractor, material suppliers) on all aspects related to the design, construction and quality assurance of the demonstrations;
    b. Ensuring that site meetings are held on a regular basis, and that proceedings are recorded;
    c. Implementation of rigorous quality control and data capturing mechanisms to set a robust baseline that will be used as a reference for future monitoring;
    d. Setting a regime of quality control testing, augmented by quality assurance testing witnessed by the AfCAP Service Provider;
    e. Technical support to the contractor, consultant and road authority if and when required.
4) Setting of specific monitoring and evaluation plans for the three demonstration sites, and implementation of these plans;
5) Interaction with local authorities rural communities prior, during and after the interventions to capture relevant data on the impact of these interventions on their socio-economic well-being, inclusive of changes in traffic patterns (by volume and type);
6) Production of appropriate AfCAP reports (pre and post-construction) for each demonstration site, inclusive of lessons learnt prior to and during the execution of the demonstration sections, and, where appropriate, production of peer-reviewed papers for conferences.

Milestone deliverables will be as follows (cf. Section E.2.2):

- Demonstration Site Reports (one report per site)
- Post-Construction Site Reports (one report per site)

In addition to the above, reports on the performance of the demonstration sections will be drafted on completion of the periodic condition assessments. The frequency of the condition assessments will be specified in the overall Monitoring and Evaluation Plan for Phase 2. This Plan will be drafted during the Inception Phase and will be included in the Inception Report. It will be used as a basis for monitoring progress and achievement of objectives.

E.3.1.2 PART 2: Sustainable enhancement in the capacity of three priority countries

It is proposed to broaden the scope of the demonstration sites in Phase 2 to sub-regions in order to support the application of strategic options and non-engineering adaptation measures in more of a regional way, to incorporate national policies and strategies and to address rural access issues for local communities and their economic/social development. This will culminate in Local Infrastructure Action Programmes, involving regional government, local government, local communities and the commercial sector. Model documents and training programmes will be devised to provide guidelines to help develop more resilient communities.

Meaningful engagements, from project inception onwards, will be held with relevant partner-country Road and Transport Ministries, Departments and Agencies/Authorities in a **knowledge dissemination and capacity building programme** based on the outputs from the research. National capacity will need to be developed across all relevant stakeholders. This includes road and transport ministries, departments and agencies/authorities, and will include a wide range of participants from central government agencies cascading all the way through to village groups (e.g. those in close proximity of the demonstration sections). Specific attention will be needed for national road fund boards, scientific ministries and environmental agencies, with the cooperation and buy-in of the road authorities.

The capacity building programme should include the following elements:

- Creating *understanding* of the challenges associated with current and future climate variability and their impact on rural accessibility, as well as engineering and non-engineering adaptation options and resilience strategies that could be implemented to address these challenges (i.e. awareness and knowledge building programmes);
- Further *establishment of a knowledge-exchange network* (e.g. web-based) between organs of state, the private sector and academia; innovative aspects could include how to assess and manage current maintenance backlogs already caused by current (extreme) climate effects;
- *Training Workshops* to be held near the Demonstration Sites (cf. Section E.2.2, Item 2);
- *Dissemination Workshops* to be held at a central location in each of the three countries (i.e. Addis Ababa, Maputo and Accra) near the end of the contract period.

The following is a five-step process that will be used for systematic capacity building. It will focus on the three pilot countries initially:

1. Engage stakeholders on capacity development

An effective capacity building process must encourage participation by all those involved. Engaging stakeholders who are directly affected allows for more effective decision-making, it also makes development work more transparent.

2. Assess capacity needs and assets

Assessing pre-existing capacities through engagement with stakeholders informs what areas require additional training, what areas should be prioritised, and in what ways capacity building can be incorporated into local and institutional development strategies.

3. Formulate a capacity development response

The capacity building response could be based on:

- *Institutional arrangements* – policies, procedures, resource management, organisation, leadership, frameworks, and communication;
- *Leadership* – high level involvement will help priority setting, communication and strategic planning;
- *Knowledge* – knowledge is the foundation of capacity;
- *Accountability* – the implementation of accountability measures facilitates better performance and efficiency.

4. Implement a capacity development response

Implementing a capacity building program should involve the inclusion of multiple systems: national, local and institutional. It should involve continual reassessment and expect change depending on changing situations. It should include evaluative indicators to measure the effective of initiated programs.

5. Evaluate capacity development

Evaluation of capacity building promotes accountability and feeds into a programme of continuous improvement.

Milestone deliverables will consist of Workshop Summary Reports (cf. Section E.2.2), while progress on all aspects of knowledge dissemination and capacity building will be reported in Monthly Progress Reports and summarised in the Final Overview Report (Milestone deliverable).

In addition to the above, the *Climate Threats Report* and the *Climate Adaptation Options Report* will be updated/upgraded and combined to produce AfCAP Guidelines on *Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa*. This guideline document will be produced as a separate document but linked to the *Final Overview Report* (Milestone deliverable). A draft version of this guideline document will be produced prior to the Dissemination Workshops that will be held at a central location in each of the three countries (i.e. Addis Ababa, Maputo and Accra) near the end of the contract period. Feedback received from these workshops will be used to finalise the AfCAP Guidelines.

E.3.1.3 PART 3: Sustainable enhancement in the capacity of additional countries

Capacity building programmes will be initiated in additional African countries, ideally AfCAP Partner Countries. The primary focus will be on knowledge dissemination; where appropriate through workshops will be held within these countries.

It is recommended that a PIT meeting/workshop dedicated to the theme of this project be held in one of the AfCAP Partner Countries, to which representatives of all AfCAP Partner Countries should be invited, as well as (potentially) representatives of ARTReF member countries. The purpose of this meeting/workshop would be to disseminate information and knowledge; share information between countries on challenges they have experienced (and how these were addressed); and create a platform for deliberation on actions that should be undertaken to strengthen capacity within countries and lead to more effective dissemination of knowledge and experiences.

It is recommended that papers be prepared and submitted to peer-reviewed regional conference with the objective to promulgate best practices regionally. Where feasible, workshops dealing with the theme of this project should be organised either in association with or in parallel to these conferences.

Deliverables will include minutes of meetings/workshops as well as conference papers. Progress will be reported in the Monthly Progress Reports and summarised in the Final Overview Report (Milestone deliverable).

E.3.1.4 PART 4: Uptake and embedment across AfCAP partner countries

Uptake and embedment will assume the format of informing national policies, through regional and district planning, down to practical guidance on adaptation delivery at rural road level.

For the three Phase 1 priority countries (Ethiopia, Mozambique and Ghana), focus areas could include:

- Investigate and document existing policies/strategies/plans and identify the necessary mechanisms by which these could be influenced;
- Review of institutional arrangements;
- Document other Development Partner programmes; identify areas of overlap and potential for synergies; and liaise with relevant Development Partners to coordinate policy responses;
- Hold Stakeholder Workshops (i.e. with members of the AfCAP National Steering Committees);
- Identify the need for additional guidance documents;
- Development and support the implementation of Action Plans and programmes;
- Dissemination of outputs.

The above activities/focus areas need to be incorporated in the overall Monitoring and Evaluation Plan in order to be able to track progress in the achievement of the project objectives and envisaged outcomes.

The following processes will be used to achieve uptake and embedment:

1. Policies and planning objectives

Encouraging integrating adaptation at policy and planning levels will achieve clear recognition of climate risks and the need for adaptation within relevant national policies. Briefing will be applied to strengthen cross-sector cooperation between Ministries. Harmonisation between national and regional road network development activities requires coordination at this level.

The development of a land-use map/database, developed on a number of catchment principles and zones will be explored to identify a range of criteria that should be used in the event of further wide scale transport network disruption due to a climate impact. The following is a list of potential parameters that can be inputted into the GIS database:

- Catchment Area
- Population demographics
- Agricultural or Industrial outputs (timber, maize, live-stock, vegetables, etc.)
  - Scale
  - Monetary Value
  - Seasonal or yearly production/harvesting
  - Time sensitive for market delivery
- Alternate routings to urban centres or markets
- Access to schools, doctors, hospitals, work, etc.
- Hot Spots (Vulnerability / Reoccurrences)

By establishing such a database on land-use, developed in conjunction with the roads network, it is possible to better analyse and prepare for future events. It also allows for the overlay of hydraulic data and this too can be used as part of the asset management package to address maintenance and emergency requirements and funding requirements/budgets.

2. Sector policies and plans

The Organisation for Economic Co-operation and Development (OECD, 2009) identifies the national and sector levels as policy entry points that may be useful for adaptation mainstreaming. National policies and plans include national visions, poverty reduction strategies, multiyear development plans, and national budgets. Sector development plans, such as transport master plans and their budgets, often flow from national plans and policies. Projects support sector plans and in some cases also national plans, particularly those that are cross-sector, regional and of extremely high priority. Therefore, influencing these overarching frameworks can affect which projects are prioritised and the criteria they must meet in order to be financed.

The AfCAP Service Provider should aim to assist road and transport ministries to incorporate the following measures into their implementation plans:

- Introduce climate change vulnerability and adaptation considerations to criteria used for selecting projects for implementation and financing;
- Develop sector-specific and country-specific screening tools to identify projects at risk;
- Incorporate contingency budgets for specific adaptation interventions as the need arises;
- Adjust zoning regulations for transport infrastructure (for example, to avoid flood zones);
- Introduce policies and decision matrices on land use practices;
- Design flexible transport infrastructure that can accommodate incremental changes over time;
- Incorporate climate change indicators into budgeting frameworks to ensure accountability.

3. Emergency planning, maintenance operational budgets and early warning

The AfCAP Service Provider should also assist road and transport sector ministries to coordinate more effectively with other line ministries in dealing with climate change issues. Options for doing this include:

- Establish or enhance cross-ministerial committees for managing adaptation to climate change, including for transport;
- Strengthen departments of disaster risk management and meteorology to improve information on which to make decisions;
- Introduce early warning and response systems for transport ministries to improve maintenance schedules and to respond quickly to post-disaster recovery needs;
- Promote low-risk adaptation strategies that will have development benefits regardless of the nature of climate changes that may take place. This is a useful approach where uncertainty is high regarding climate change and capital investments cannot be justified for large-scale infrastructural changes;
- Incorporate climate change adaptation into environmental impact assessments and strategic environmental assessment guidelines. This can take place specifically in the transport sector or, preferably, as part of the national standards. Road and transport ministries can test tools and adaptation approaches by applying strategic environmental assessments with climate change to their sector policies and plans.

For infrastructure that is already in place, increasing maintenance contingency budgets in areas where climate change impacts are acute will be encouraged to allow for more intensive supervision and monitoring of the most vulnerable areas.

4. Augmenting standards and design guides

Operational responses are geared to addressing near-term impacts of climate change. To make decisions today about rehabilitating or retrofitting transportation facilities, especially those with long design lives, transport planners and engineers must consider how climate changes will affect these facilities in future years. Adapting to climate change will also require re-evaluation, development, and regular updating of design standards that guide infrastructure design.

Recommendations will be made for updating design requirements, including technical standards and specifications, to provide additional capacity/functionality for adaptation and to reduce vulnerability. These updated requirements could apply to designs for new structures or new roads, as well as to designs for maintenance, renewal and improvement works.

Recommendations will also be made for implementation efforts to develop and validate these new design rules, standards and specifications.

5. Road Safety

Most of the direct risks can be dealt with proactively by improving the functional and structural characteristics of the road pavement and the road environment. Others will require emergency response, such as network restrictions or even road closures to uphold safety.

In addition to the direct risks, there are indirect risks that also need to be considered, such as, for instance, the inability to access disaster areas and emergency facilities as a consequence of road closures. Indirect risks would require a different set of emergency responses such as the provision of alternative access (e.g. alternative roads and air rescue).

Progress on Part 4 will be reported in the Monthly Progress Reports and summarised in the Final Overview Report (Milestone deliverable).

E.3.1.5 PART 5: Recommendations for Phase 3

As noted in Section E.2.2:

> *Based on experience of other projects, it is recommended that a 'train-the-trainer' programme be initiated with a suitable national institute during Phase 2 or as part of Phase 3 to ensure continuity beyond the completion of the AfCAP project. Training should be provided on an annual basis, also to cater for loss of previously trained personnel in state-owned entities. It is also recommended that a continuous mentoring programme be implemented, possibly with secondments to organisations such as the CSIR.*
>
> *Assuming that the climate resiliency measures put into place at the demonstration sites are effective for dealing with at least present climate variability, it may take several years to demonstrate their effectiveness of dealing with extreme weather event. Hence, a long-term monitoring programme will need to be put in place that will stretch well beyond the 70-week Phase 2 programme. Recommendations for a long-term monitoring and evaluation programme will be incorporated in the Monitoring and Evaluation Plan that will be drafted during the Inception Phase of Phase 2. This Plan will have to be updated on a regular basis during Phase 2, and will form the basis for a continuation programme in Phase 3.*

In addition to the above, activities related to particularly non-engineering adaptation options, such as those outlined in Sections E.3.1.2 to E.3.1.4, may require further actions beyond Phase 2 in order to ensure that, ultimately, optimal uptake and embedment is achieved.

Recommendations for Phase 3 will be submitted to AfCAP as a Milestone Report. The recommendations will be based on an appraisal of progress achieved within the 70-week programme, additional needs identified by stakeholders (e.g. need to update policies and strategic plans through regular iterations, and capacity building requirements), and long-term monitoring requirements for the demonstrations, among others.

E.4 Draft Schedule of Activities

Although indicative resource allocations and budgets have been developed on the basis of the proposed scope and activities outlined above, agreement will have to be reached on the proposed scope and activities before these can be properly resourced and costed.

In the interim, and based on the scope and activities outlined above, a preliminary timeline of activities is provided on the next page.

WORK PLAN FOR PHASE 2: Consultancy Services for Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa		PRELIMINARY PROGRAMME																
ID	**Result Area / Activity**	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July
0	**Inception Phase** (inclusive of overall Monitoring and Evaluation Plan for project)																	
1	**Demonstrate appropriate engineering and non-engineering adaptation procedures**																	
1.1	Site investigation and detailed designs																	
1.2	Assistance to road authorities in setting up demonstrations																	
1.3	Construction of demonstration sections																	
1.4	Interaction with local authorities and rural communities (before & after implementation)																	
1.5	Devise and implement long term M&E Plan																	
2	**Sustainable enhancement in the capacity of three priority countries**																	
2.1	Consultation with stakeholders																	
2.2	Needs analysis																	
2.3	Formulate and implement capacity development programme (inclusive of workshops)																	
2.4	Implementation support																	
3	**Sustainable enhancement in the capacity of additional AfCAP countries**																	
3.1	PIT meeting/workshop																	
3.2	Situational/needs analysis of additional AfCAP Partners																	
3.3	Preparation of papers and organisation of workshops associated / in parallel with conferences																	
3.4	Education and capacity programme																	
4	**Uptake and embedment across three priority countries**																	
4.1	Existing national policies/strategies/plans																	
4.2	Workshops to incorporate climate adaption																	
4.3	Communication with DP's on programmes																	
4.4	Emergency planning and operational budgets																	
4.5	Implementation Plans																	
5	**Phase 3 recommendations**																	
5.1	Recommendations for monitoring & evaluation																	
5.2	Recommendations for capacity building																	
5.3	Recommendations for uptake & embedment																	
5.4	Recommendations for train-the trainer programme																	
R	**REPORTS**																	
R1	Inception Report	★																
PR	Progress Reports (monthly)																	
R2	Demonstration Site Reports				★													
R3	As Built Reports (demonstrations)												★					
R3	Workshop Summary Reports					★	★		★	★						★	★	
R4	Way Forward Post Phase 2														★			
R6	Scientific Papers and Conference Papers																	
R7	Draft Final Guidelines															★		
R8	Final Report (and Final Guidelines)																	★

Annex F: Projections of Future Climate Change in Ethiopia

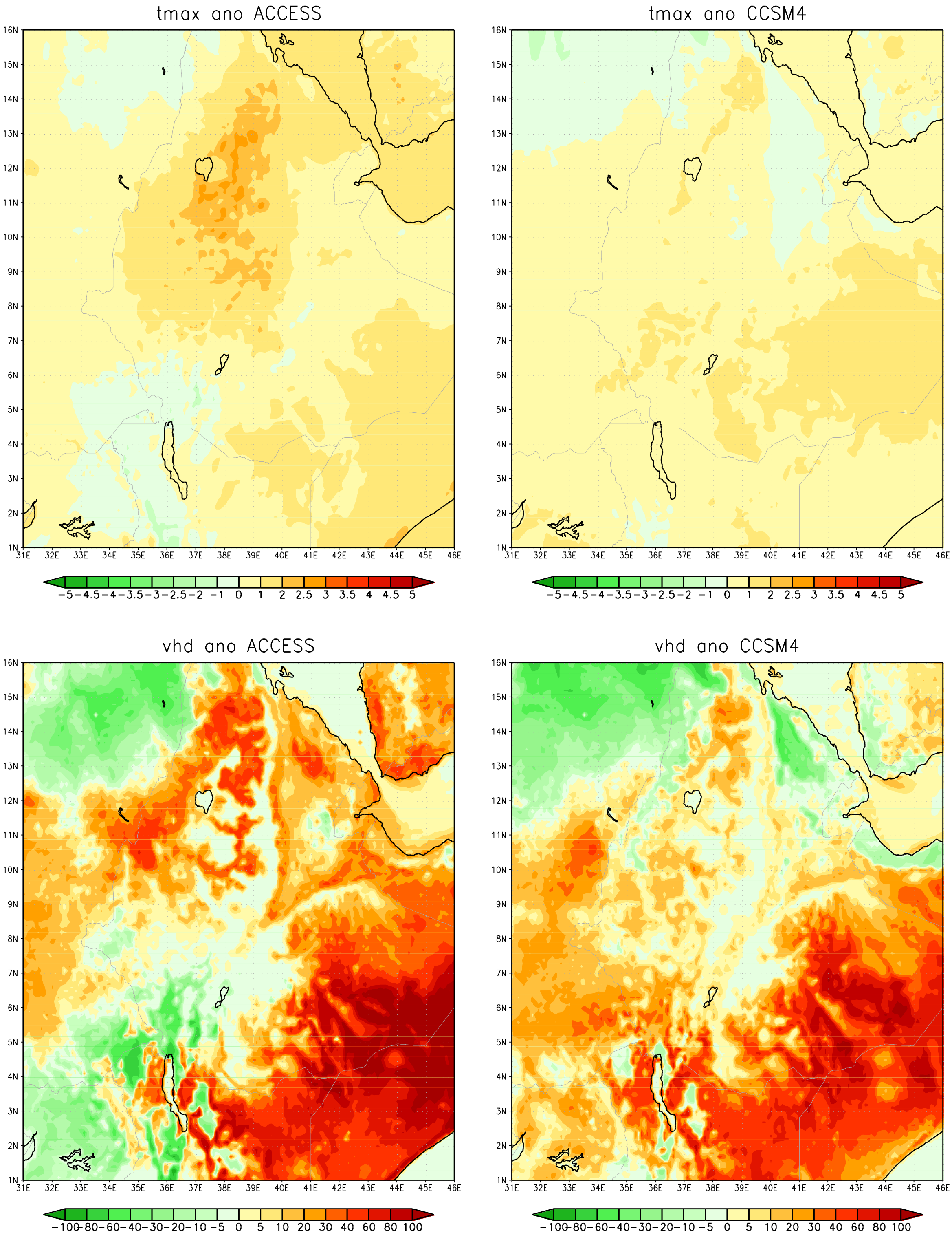


Figure F.1: CCAM projected changes in annual average maximum temperatures (°C, top) and the annual number of very hot days (number of events per grid point per year, bottom) over Ethiopia, for the ACCESS1-0 (left) and CNRM-CM5 (right) downscalings. The projections are for the period 2021-2050 relative to 1971-2000 under low mitigation (RCP8.5).

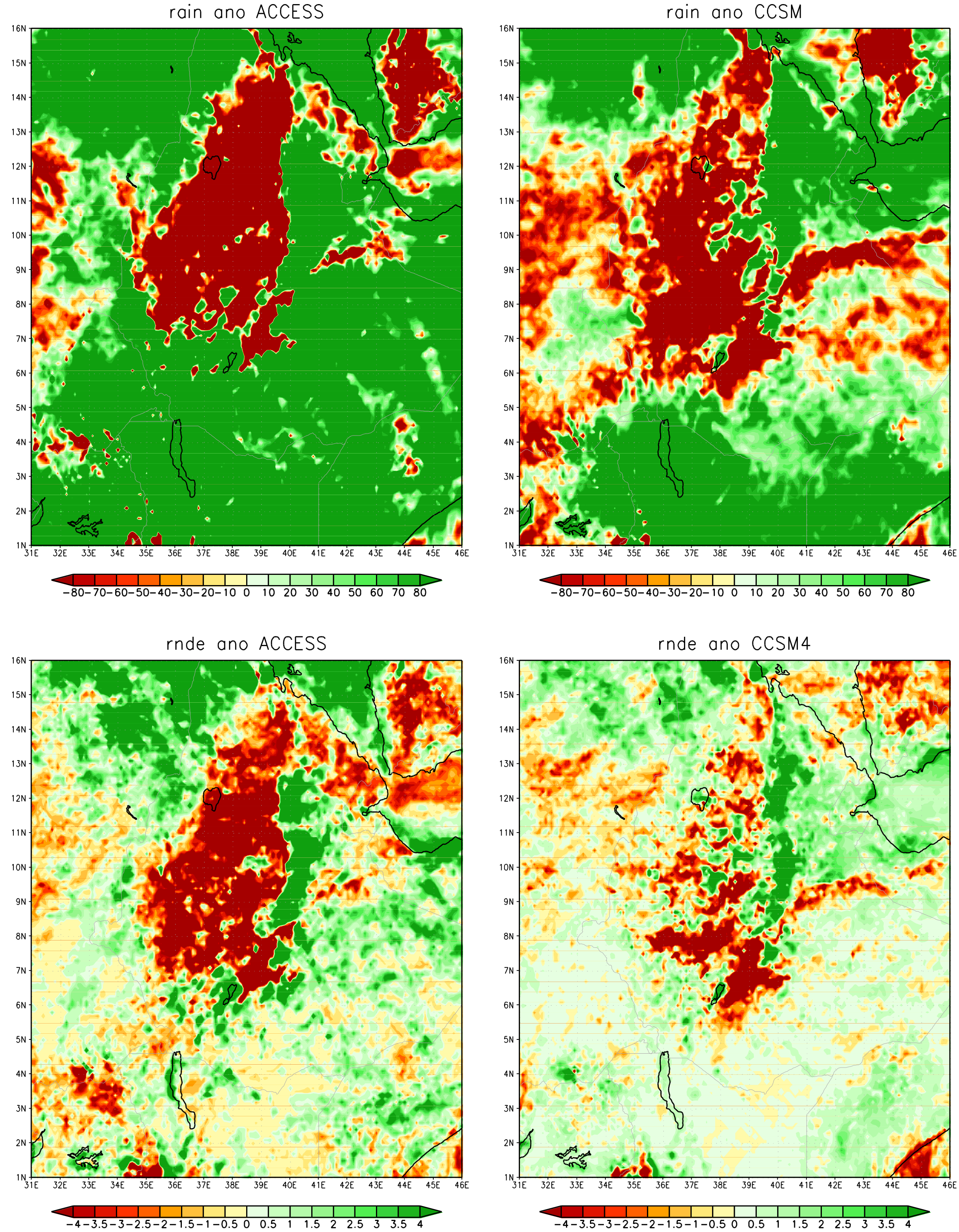


Figure F.2: CCAM projected changes in annual average rainfall totals (mm, top) and the annual number of extreme rainfall days (number of events per grid point per year, bottom) over Ethiopia, for the ACCESS1-0 (left) and CNRM-CM5 (right) downscalings. The projections are for the period 2021-2050 relative to 1971-2000 under low mitigation (RCP8.5).

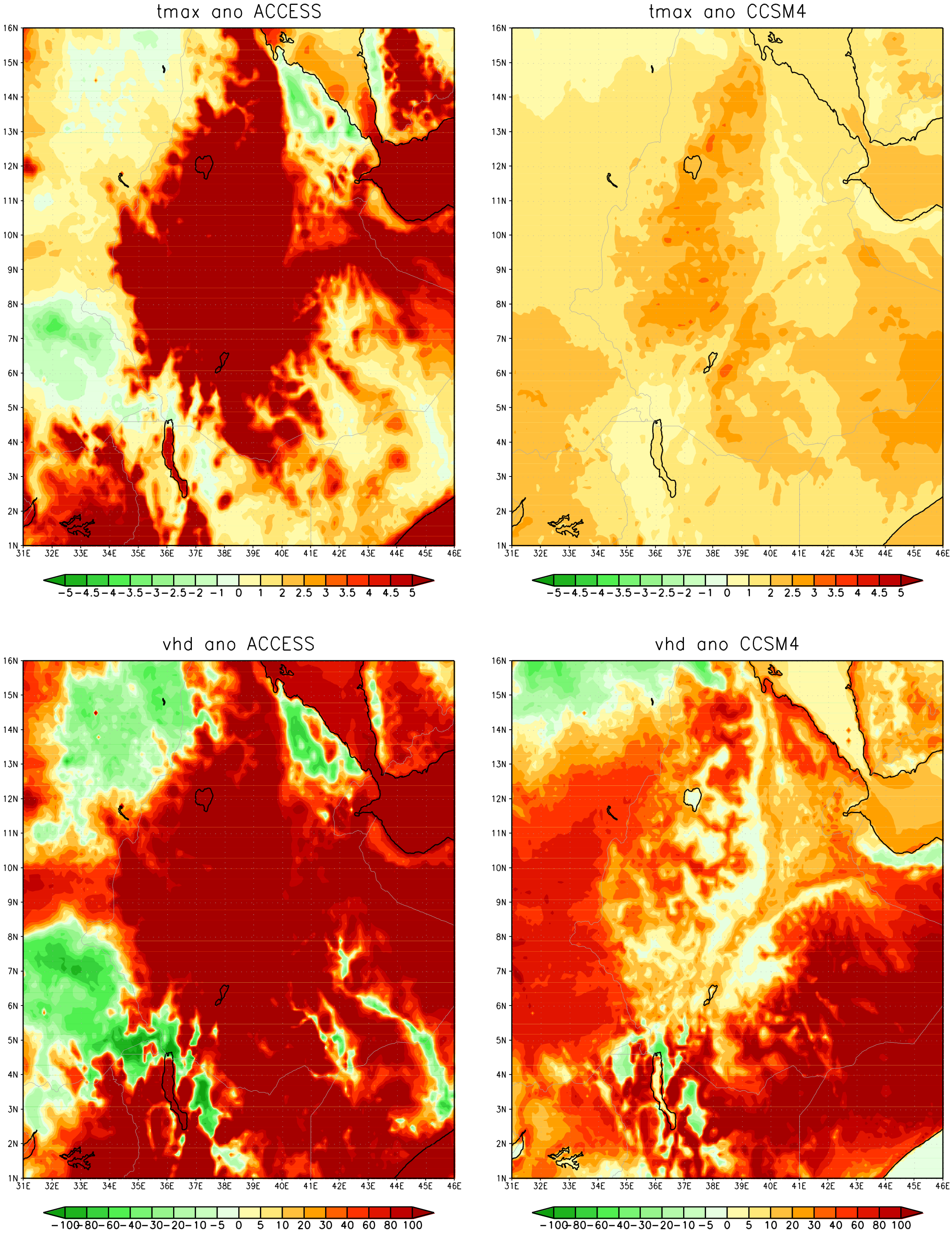


Figure F.3: CCAM projected changes in annual average maximum temperatures (°C, top) and the annual number of very hot days (number of events per grid point per year, bottom) over Ethiopia, for the ACCESS1-0 (left) and CNRM-CM5 (right) downscalings. The projections are for the period 2071-2100 relative to 1971-2000 under low mitigation (RCP8.5).

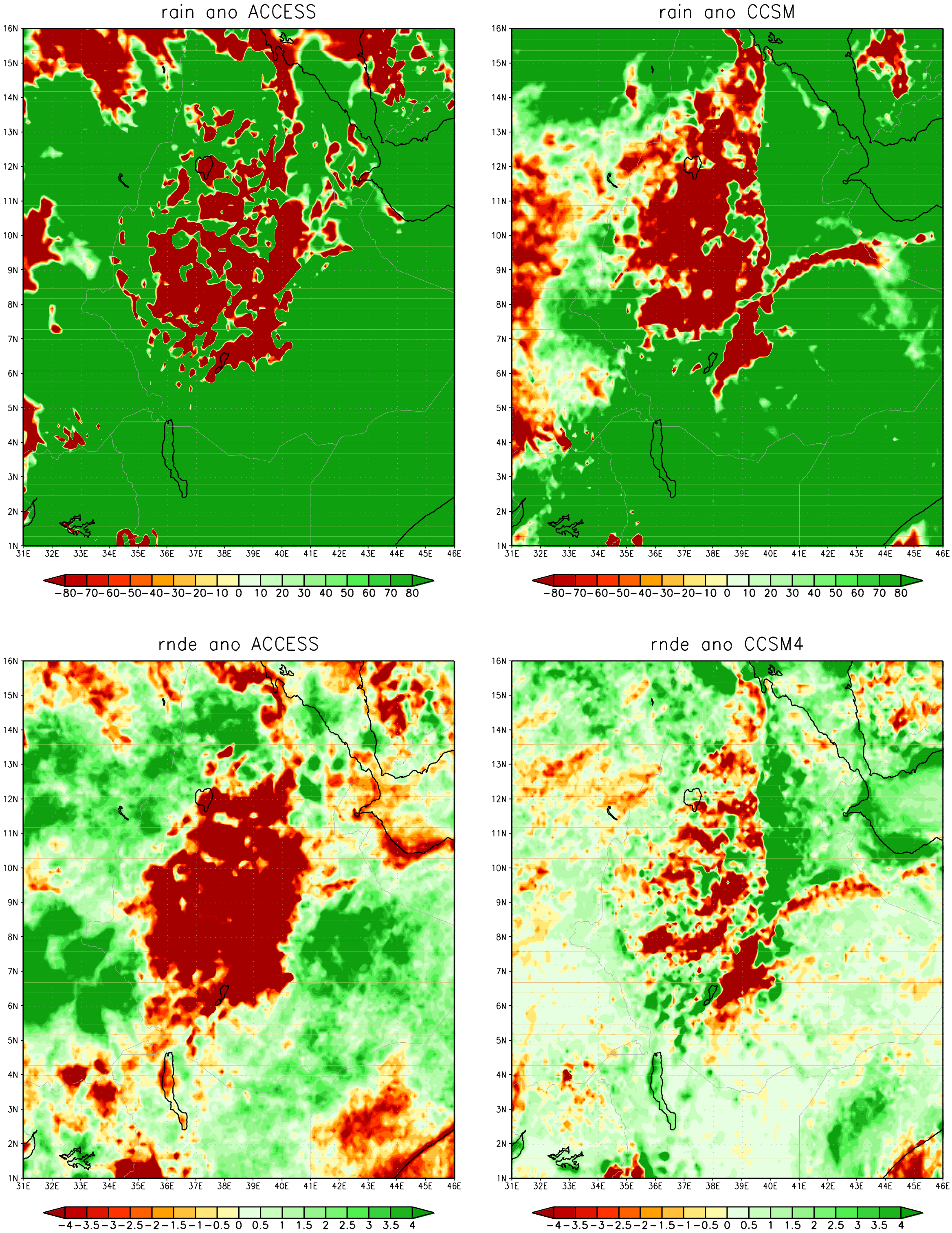


Figure F.4: CCAM projected changes in annual average rainfall totals (mm, top) and the annual number of extreme rainfall days (number of events per grid point per year, bottom) over Ethiopia, for the ACCESS1-0 (left) and CNRM-CM5 (right) downscalings. The projections are for the period 2071-2100 relative to 1971-2000 under low mitigation (RCP8.5).

Annex G: Wearing Course Material Selection

In order to ensure that the gravel roads are climate resilient (or as climate resilient as gravel wearing course can be) it is essential that the wearing course materials comply with the standard specifications as closely as possible.

The standard specifications will depend on whether the testing laboratory uses ASTM/AASHTO/TMH1 or British Standard test methods (see Figures G.1 and G.2 below).

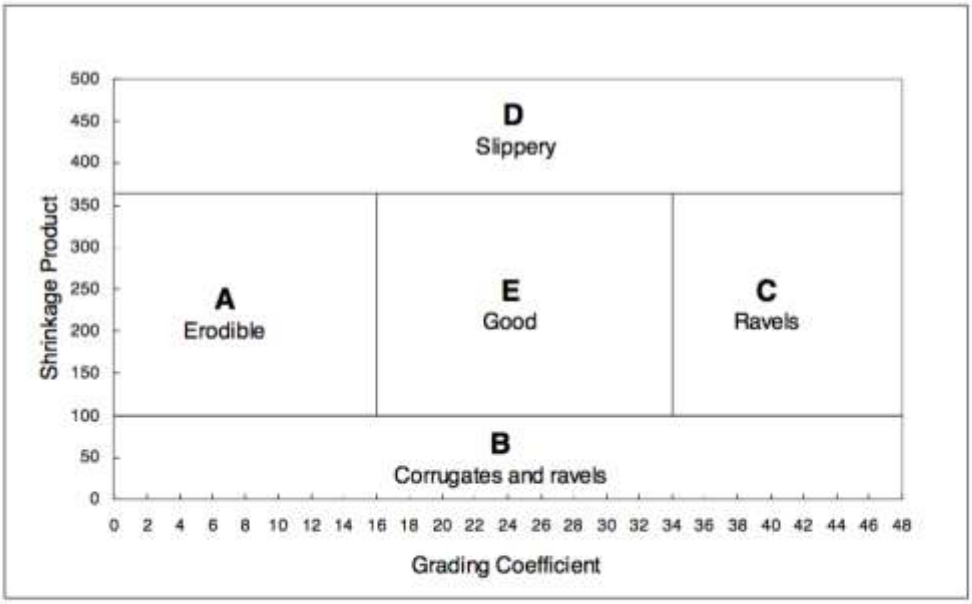


Figure G.1: Wearing course gravel selection chart using ASTM/AASHTO/TMH test methods

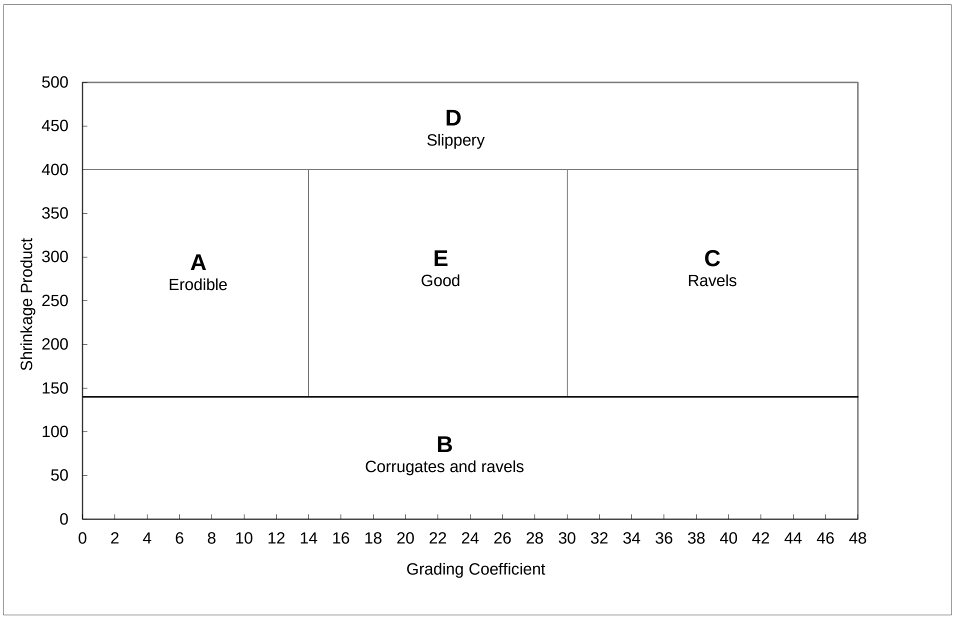


Figure G.2: Wearing course gravel selection chart using BS test methods

Suitable wearing course materials will fall into Zone E of the two charts. Materials outside these limits, particularly those with Grading Coefficients of less than 14 and to a lesser extent greater than 34 (or 14 and 30 using BS tests) will be prone to erosion. In order to promote a good riding quality, the percentage of particles in the wearing course larger than 37.5 mm must be restricted to 5.

In addition, the wearing course must be compacted to as high a density as practically possible, but never less than 95% of BS heavy or Modified AASHTO compaction effort.

Preparation of such materials from natural gravels has been proven to add not more than 10% to the total construction cost, but has yielded rates of return of more than 15% in all cases.

Annex H: Projections of Future Climate Change in Mozambique

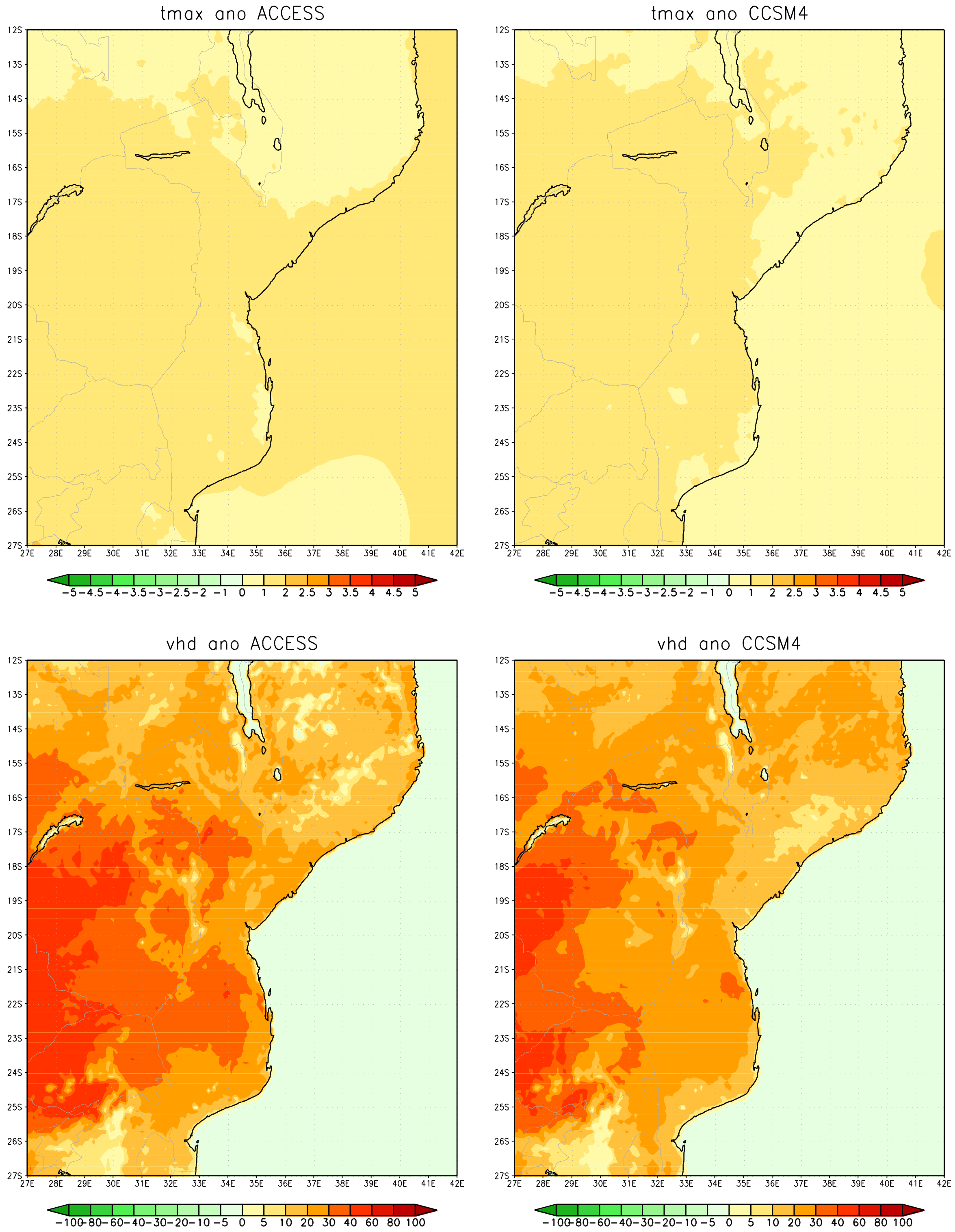


Figure H.1: CCAM projected changes in annual average maximum temperatures (°C, top) and the annual number of very hot days (number of events per grid point per year, bottom) over Mozambique, for the ACCESS1-0 (left) and CNRM-CM5 (right) downscalings. The projections are for the period 2021-2050 relative to 1971-2000 under low mitigation (RCP8.5).

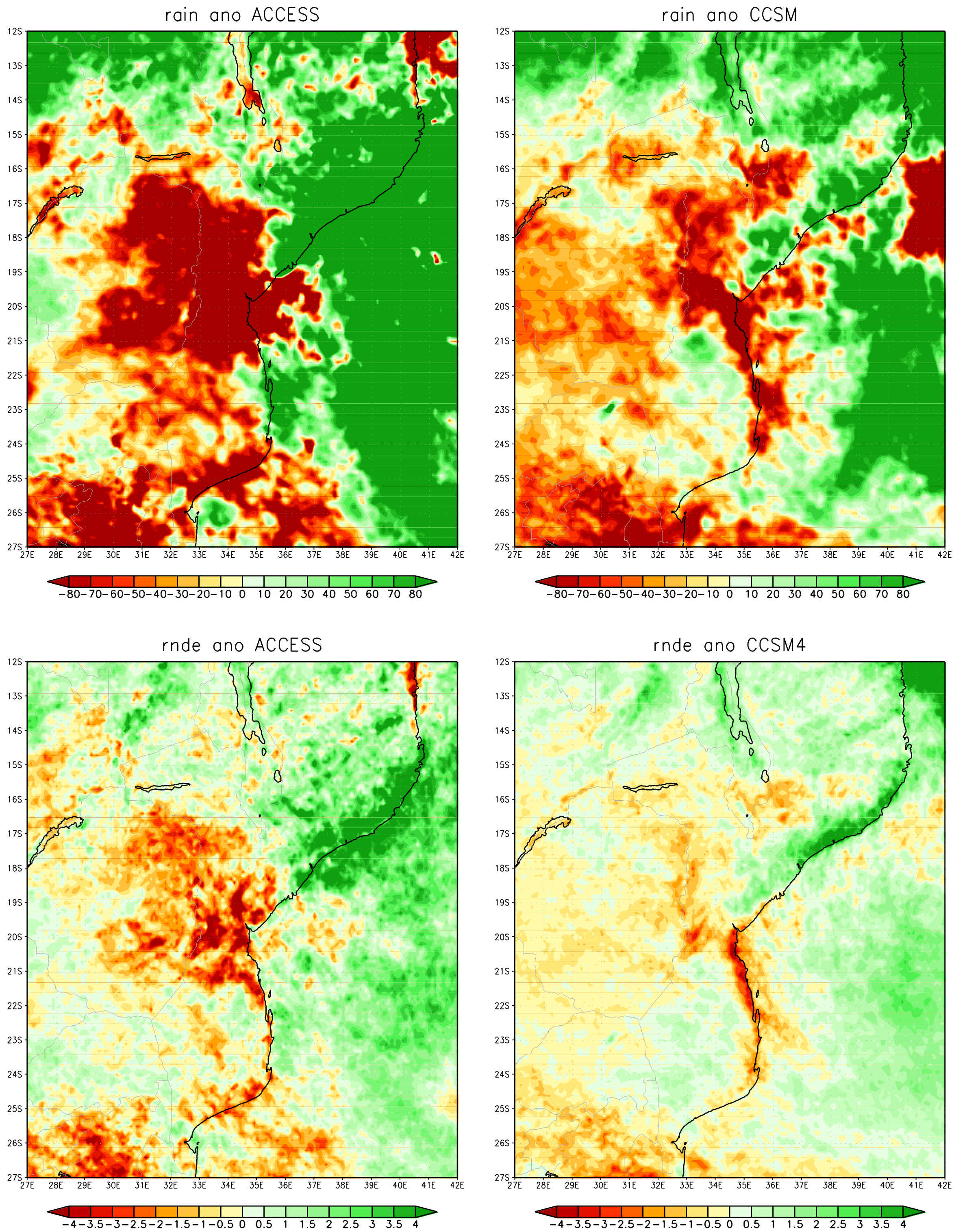


Figure H.2: CCAM projected changes in annual average rainfall totals (mm, top) and the annual number of extreme rainfall days (number of events per grid point per year, bottom) over Mozambique, for the ACCESS1-0 (left) and CNRM-CM5 (right) downscalings. The projections are for the period 2021-2050 relative to 1971-2000 under low mitigation (RCP8.5).

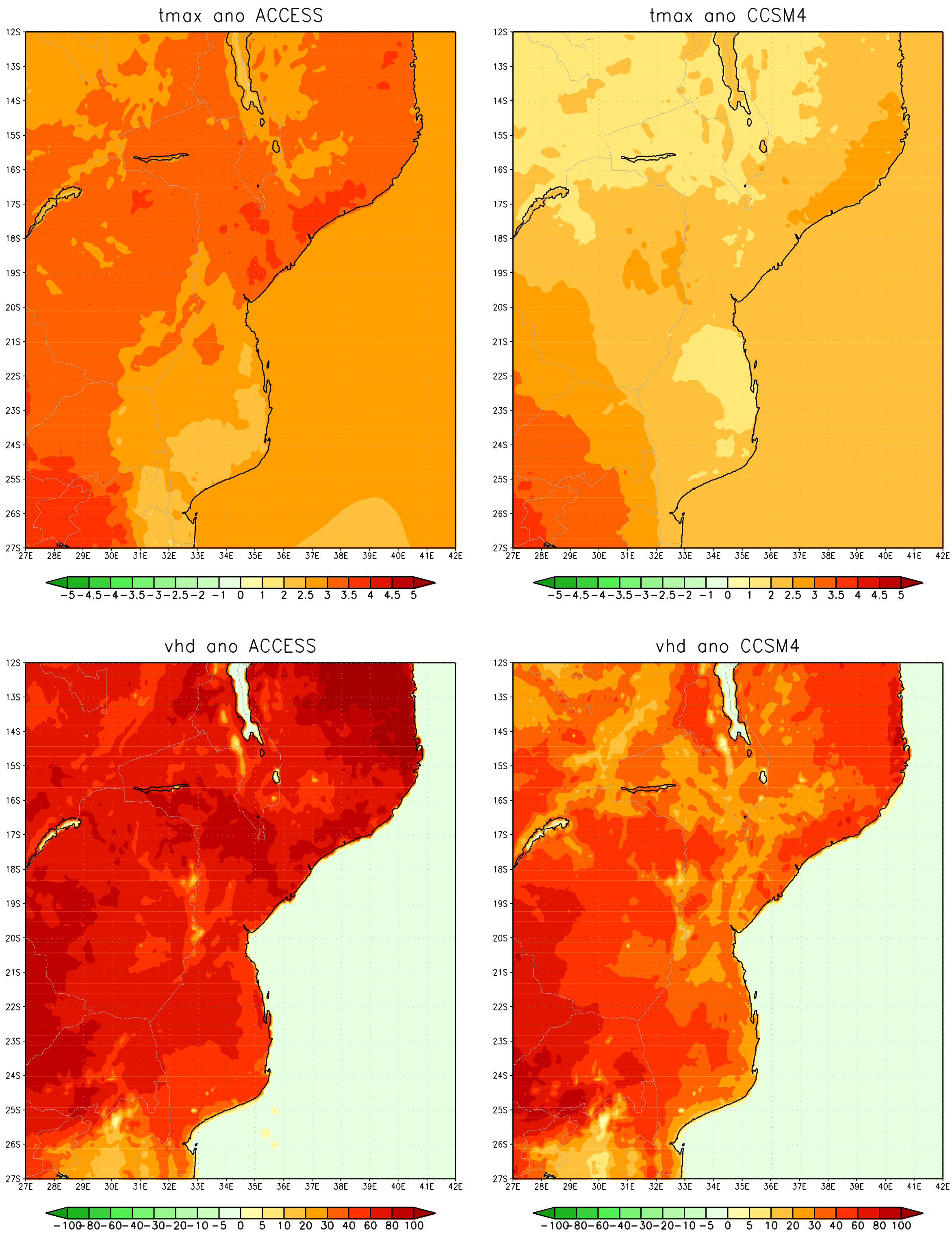


Figure H.3: CCAM projected changes in annual average maximum temperatures (°C, top) and the annual number of very hot days (number of events per grid point per year, bottom) over Mozambique, for the ACCESS1-0 (left) and CNRM-CM5 (right) downscalings. The projections are for the period 2071-2100 relative to 1971-2000 under low mitigation (RCP8.5).

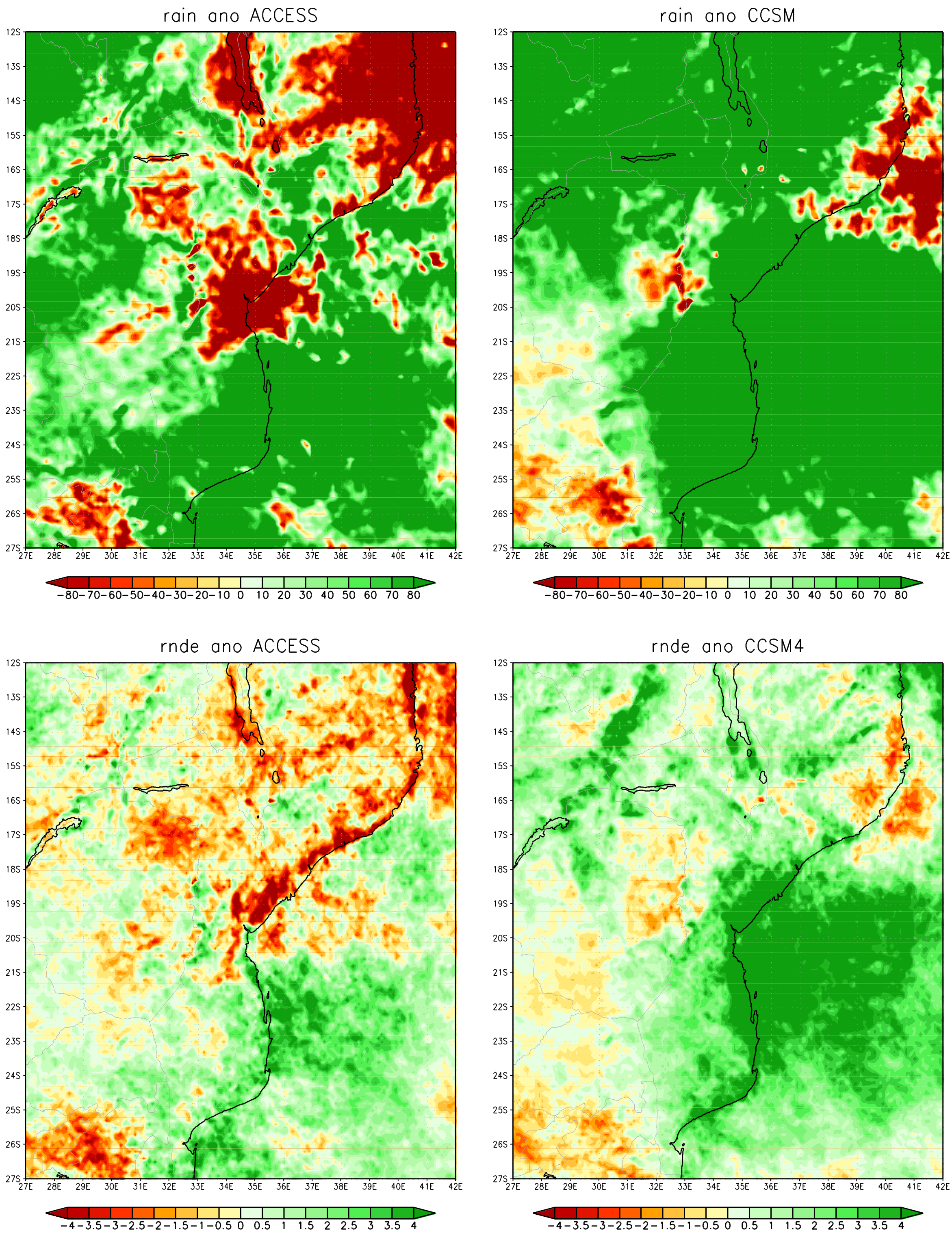


Figure H.4: CCAM projected changes in annual average rainfall totals (mm, top) and the annual number of extreme rainfall days (number of events per grid point per year, bottom) over Mozambique, for the ACCESS1-0 (left) and CNRM-CM5 (right) downscalings. The projections are for the period 2071-2100 relative to 1971-2000 under low mitigation (RCP8.5).

Annex I: Projections of Future Climate Change in Ghana

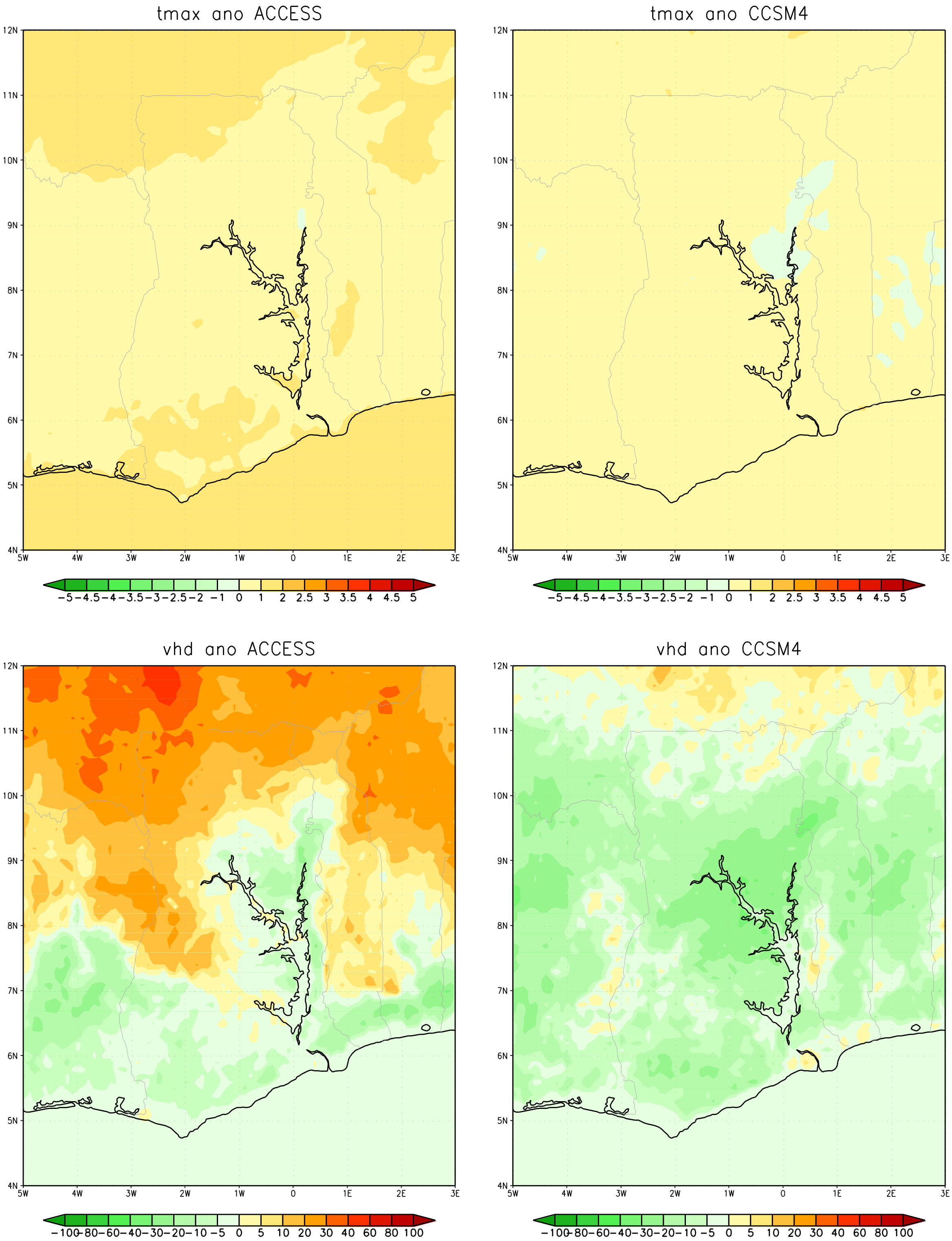


Figure I.1: CCAM projected changes in annual average maximum temperatures (°C, top) and the annual number of very hot days (number of events per grid point per year, bottom) over Ghana, for the ACCESS1-0 (left) and CNRM-CM5 (right) downscalings. The projections are for the period 2021-2050 relative to 1971-2000 under low mitigation (RCP8.5).

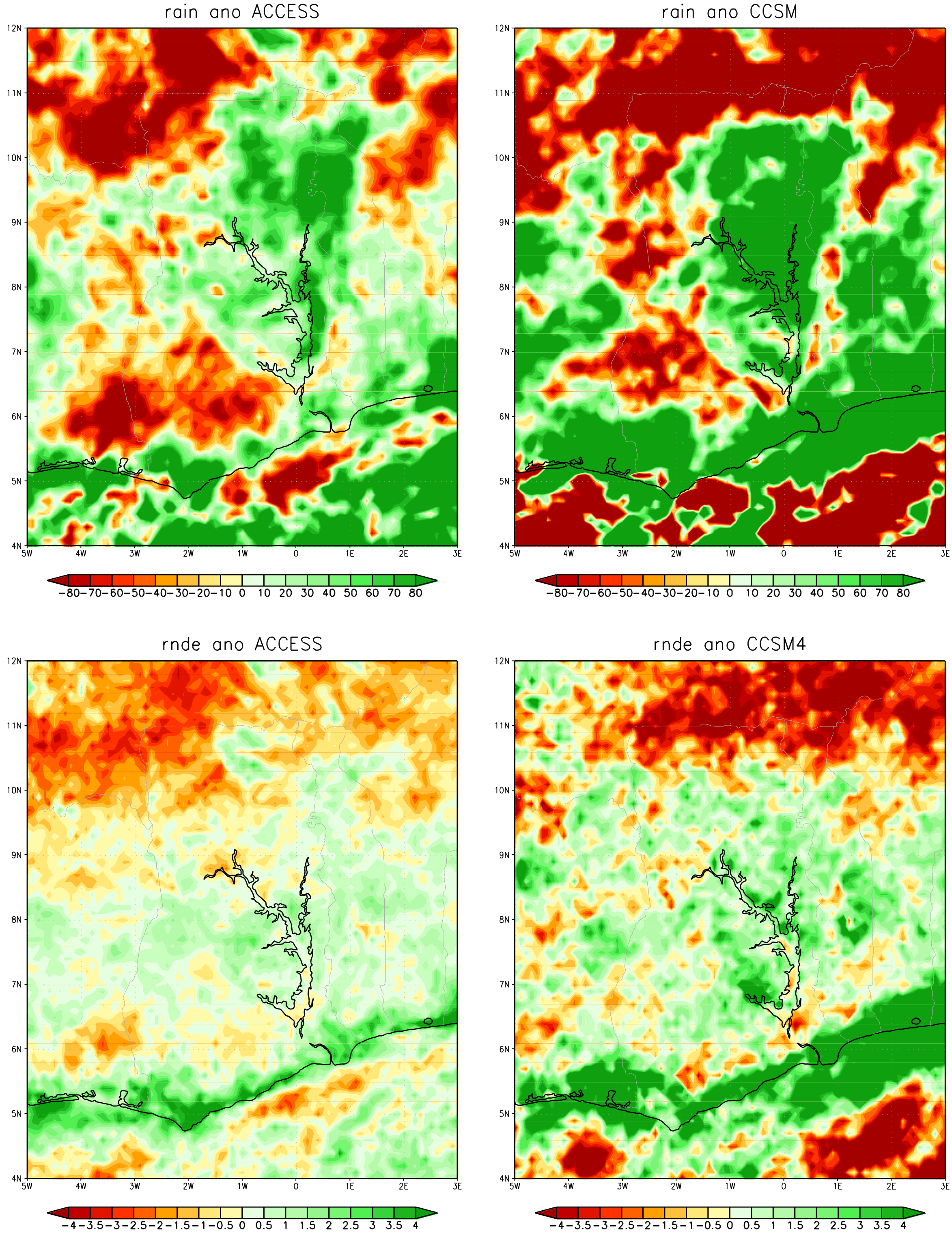


Figure I.2: CCAM projected changes in annual average rainfall totals (mm, top) and the annual number of extreme rainfall days (number of events per grid point per year, bottom) over Ghana, for the ACCESS1-0 (left) and CNRM-CM5 (right) downscalings. The projections are for the period 2021-2050 relative to 1971-2000 under low mitigation (RCP8.5).

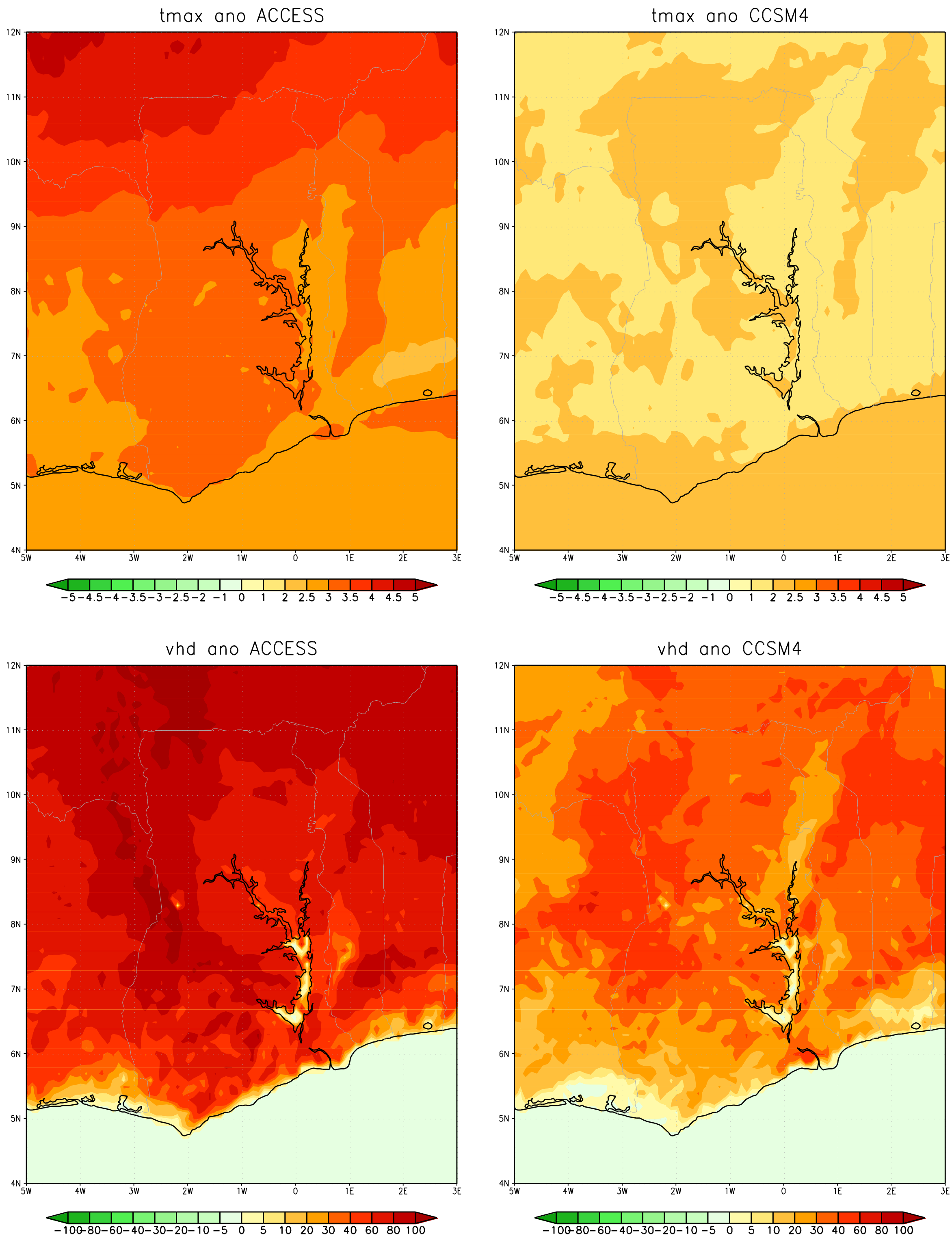


Figure I.3: CCAM projected changes in annual average maximum temperatures (°C, top) and the annual number of very hot days (number of events per grid point per year, bottom) over Ghana, for the ACCESS1-0 (left) and CNRM-CM5 (right) downscalings. The projections are for the period 2071-2100 relative to 1971-2000 under low mitigation (RCP8.5).

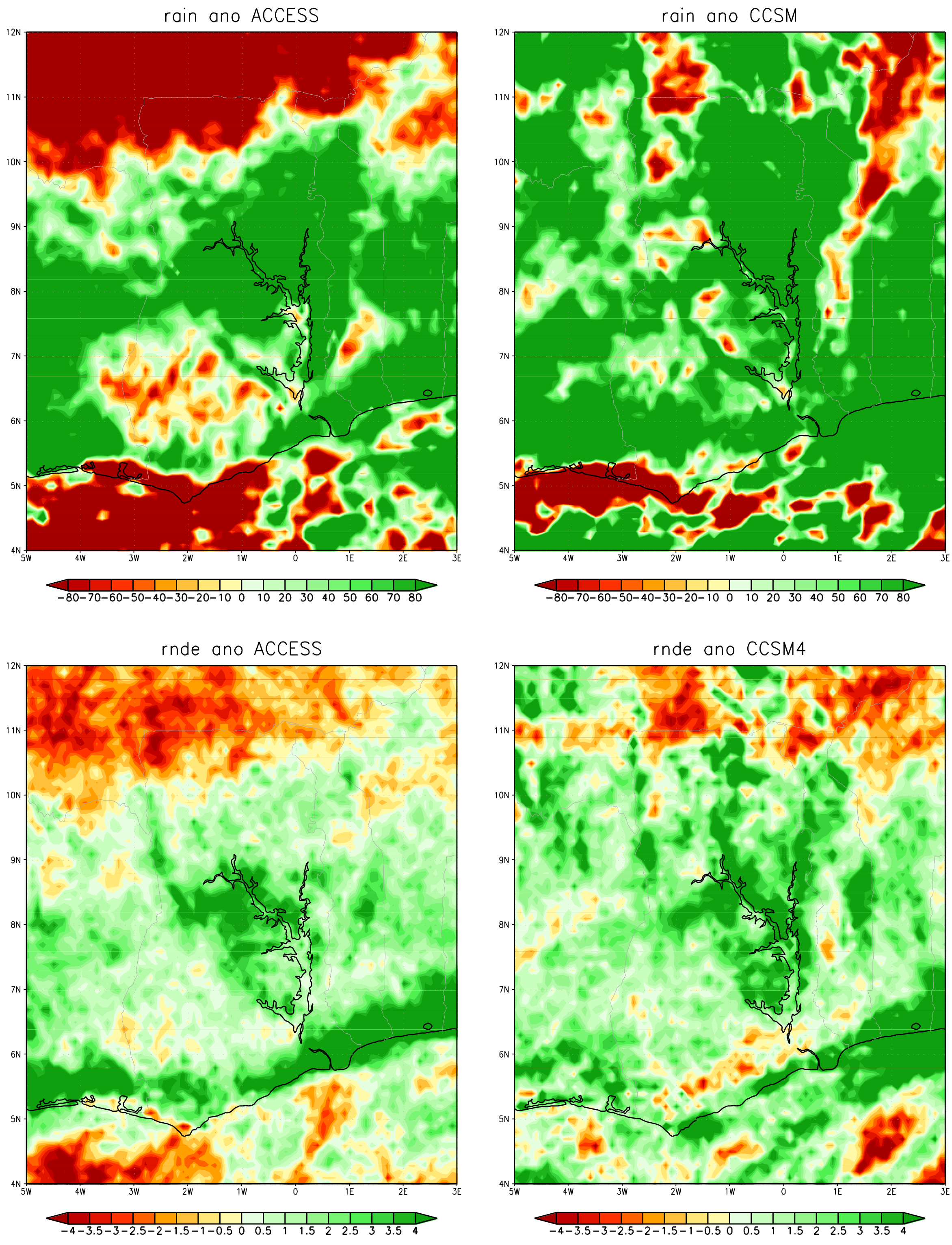
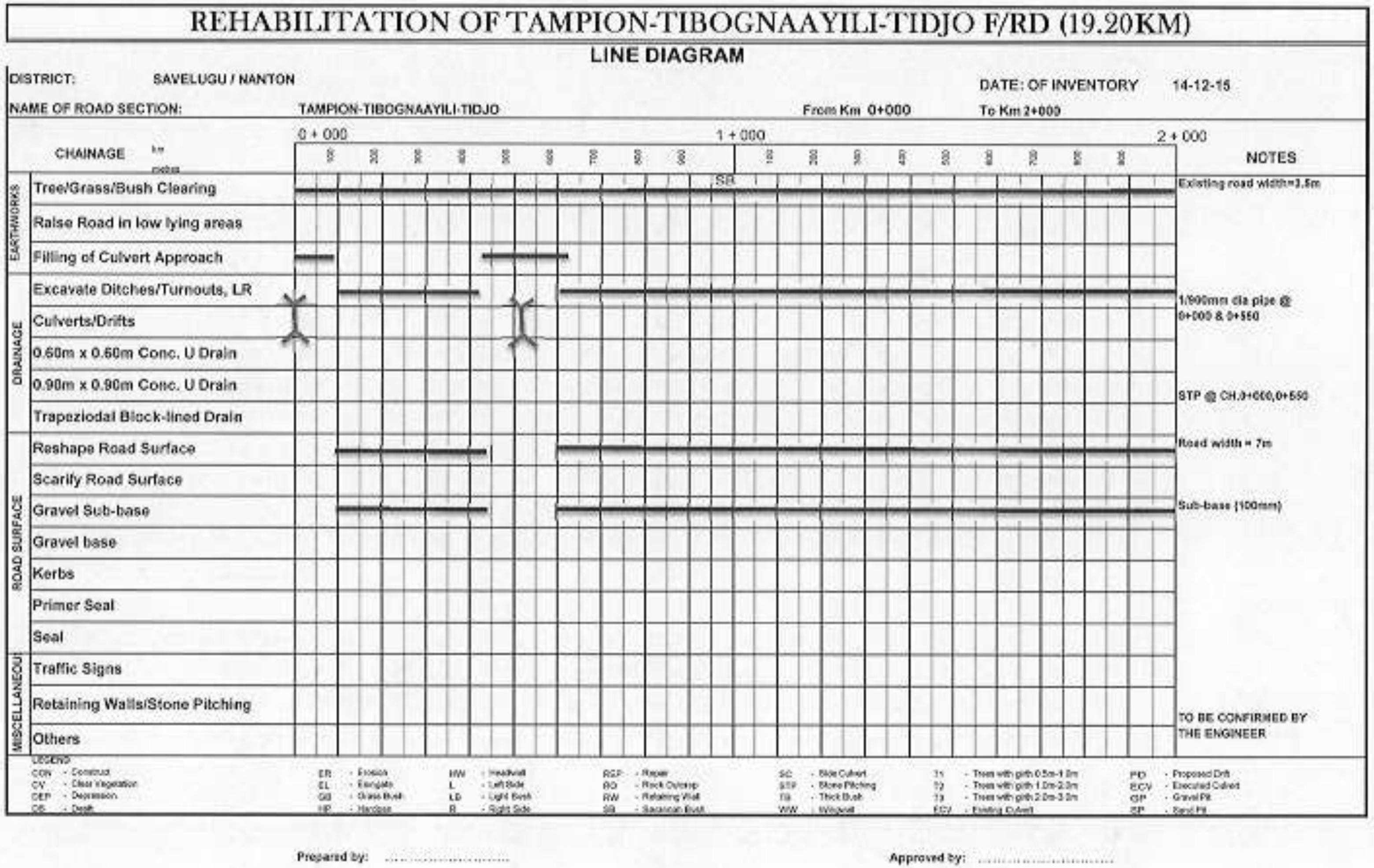


Figure I.4: CCAM projected changes in annual average rainfall totals (mm, top) and the annual number of extreme rainfall days (number of events per grid point per year, bottom) over Ghana, for the ACCESS1-0 (left) and CNRM-CM5 (right) downscalings. The projections are for the period 2071-2100 relative to 1971-2000 under low mitigation (RCP8.5).

Annex J: Preliminary Line Diagram for Proposed Upgrading of Tampion-Tibognaayili-Tidjo Road in Ghana


REHABILITATION OF TAMPION-TIBOGNAAYILI-TIDJO F/RD (19.20KM)
LINE DIAGRAM
DISTRICT: SAVELUGU / NANTON
DATE: OF INVENTORY 14-12-15
NAME OF ROAD SECTION: TAMPION-TIBOGNAAYILI-TIDJO
From Km 0+000
To Km 2+000
CHAINAGE
0 + 000
1 + 000
2 + 000
NOTES
EARTHWORKS
Tree/Grass/Bush Clearing
Raise Road in low lying areas
Filling of Culvert Approach
DRAINAGE
Excavate Ditches/Turnouts, LR
Culverts/Drifts
0.60m x 0.60m Conc. U Drain
0.90m x 0.90m Conc. U Drain
Trapeziodal Block-lined Drain
ROAD SURFACE
Reshape Road Surface
Scarify Road Surface
Gravel Sub-base
Gravel base
Kerbs
Primer Seal
Seal
MISCELLANEOUS
Traffic Signs
Retaining Walls/Stone Pitching
Others
SB
Existing road width=3.5m
1/900mm dia pipe @ 0+000 & 0+550
STP @ CH.0+000,0+550
Road width = 7m
Sub-base (100mm)
TO BE CONFIRMED BY THE ENGINEER
LEGEND
CON - Construct
CV - Clear Vegetation
DEP - Depression
ER - Erosion
EL - Elongate
GB - Grass Bush
HW - Headwall
L - Left Side
LB - Light Bush
R - Right Side
REP - Repair
RO - Rock Outcrop
RW - Retaining Wall
SC - Side Culvert
STP - Stone Pitching
TB - Thick Bush
WW - Wingwall
T1 - Trees with girth 0.5m-1.0m
T2 - Trees with girth 1.0m-2.0m
T3 - Trees with girth 2.0m-3.0m
ECV - Existing Culvert
PD - Proposed Drift
ECV - Executed Culvert
GP - Gravel Pit
SP - Sand Pit
Prepared by: ....
Approved by: ....

REHABILITATION OF TAMPION-TIBOGNAAYILI-TIDJO F/RD (19.20KM)

LINE DIAGRAM

DISTRICT: SAVELUGU / NANTON

DATE: OF INVENTORY 14-12-15

NAME OF ROAD SECTION: TAMPION-TIBOGNAAYILI-TIDJO

From Km 2+000 To Km 4+000

CHAINAGE km / metres: 2 + 000 … 3 + 000 … 4 + 000

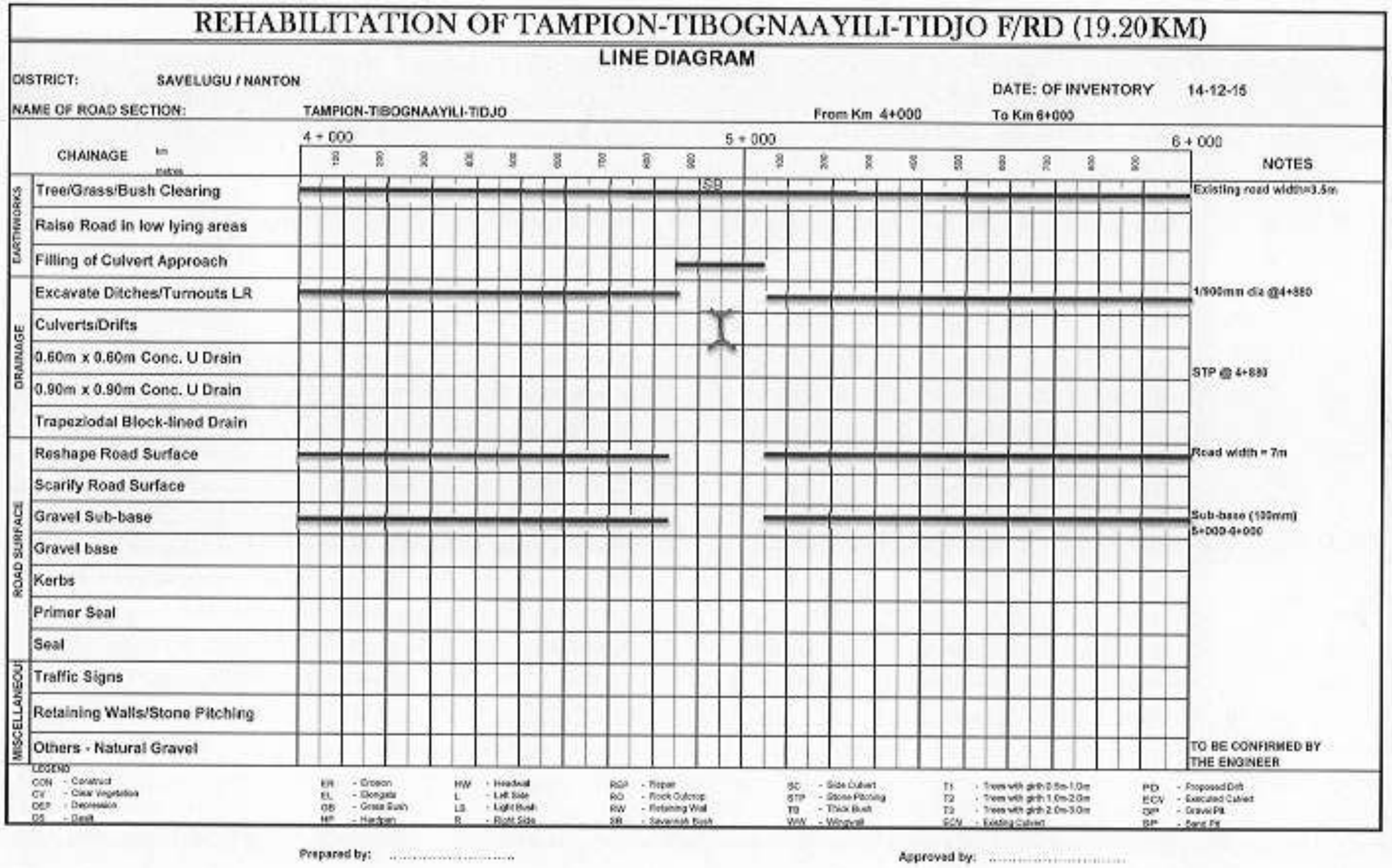
	CHAINAGE		NOTES
EARTHWORKS	Tree/Grass/Bush Clearing	SB	Existing road width=3.5m
	Raise Road in low lying areas		
	Filling of Culvert Approach		
DRAINAGE	Excavate Ditches/Turnouts LR		
	Culverts/Drifts		
	0.60m x 0.60m Conc. U Drain		
	0.90m x 0.90m Conc. U Drain		
	Trapeziodal Block-line Drain		
ROAD SURFACE	Reshape Road Surface		Road width = 7m
	Scarify Road Surface		
	Gravel Sub-base		Sub-base (100mm)
	Gravel base		
	Kerbs		
	Primer Seal		
	Seal		
MISCELLANEOUS	Traffic Signs		
	Retaining Walls/Stone Pitching		
	Others - Natural Gravel		TO BE CONFIRMED BY THE ENGINEER

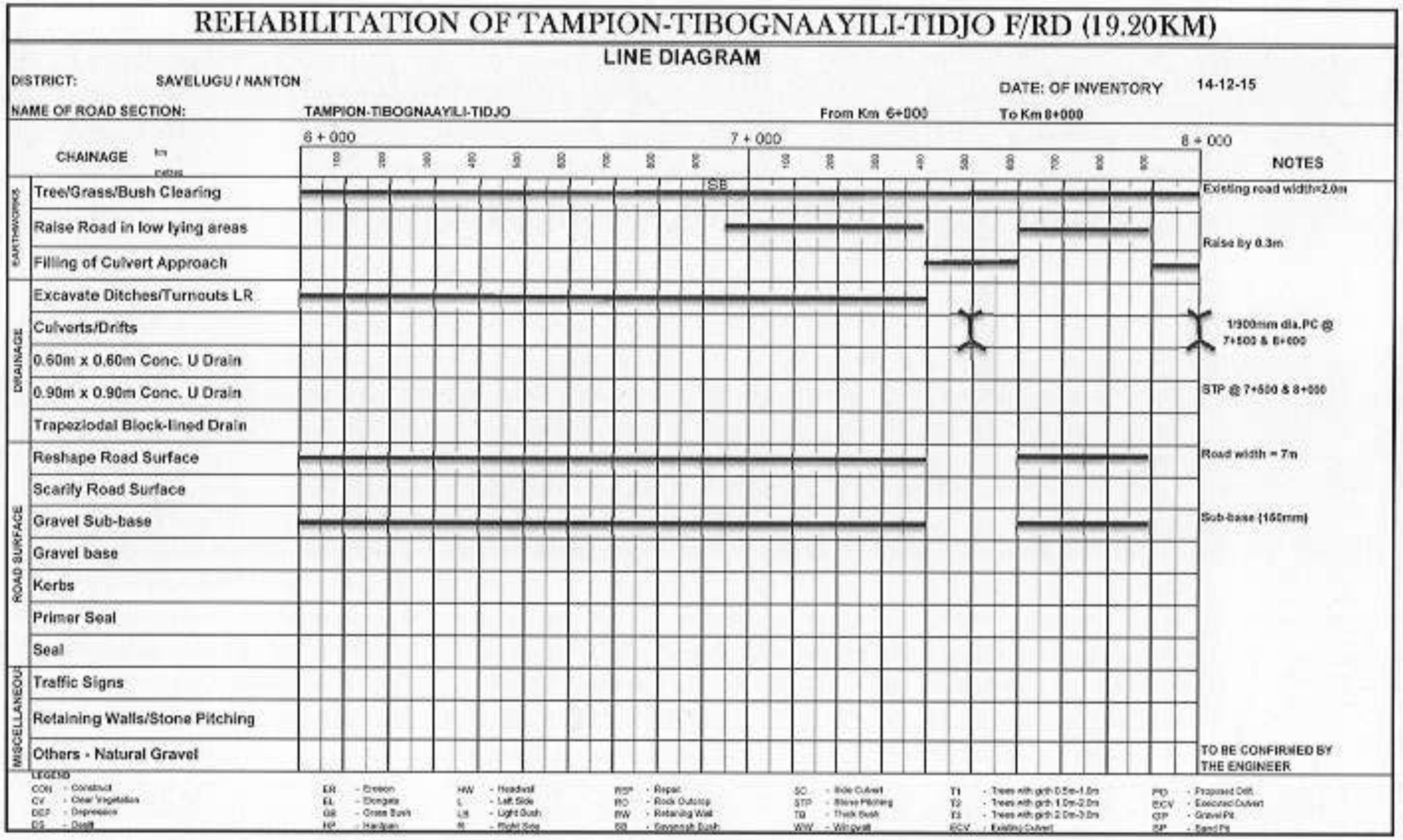
LEGEND

CON - Construct; CV - Clear Vegetation; DEP - Depression; DS - Desilt; ER - Erosion; EL - Elongate; GB - Grass Bush; HP - Hardpan; HW - Headwall; L - Left Side; LB - Light Bush; R - Right Side; REP - Repair; RO - Rock Outcrop; RW - Retaining Wall; SB - Savannah Bush; SC - Side Culvert; STP - Stone Pitching; TB - Thick Bush; WW - Wingwall; T1 - Trees with girth 0.5m-1.0m; T2 - Trees with girth 1.0m-2.0m; T3 - Trees with girth 2.0m-3.0m; ECV - Existing Culvert; PD - Proposed Drift; ECV - Executed Culvert; GP - Gravel Pit; SP - Sand Pit

Prepared by: ……………………

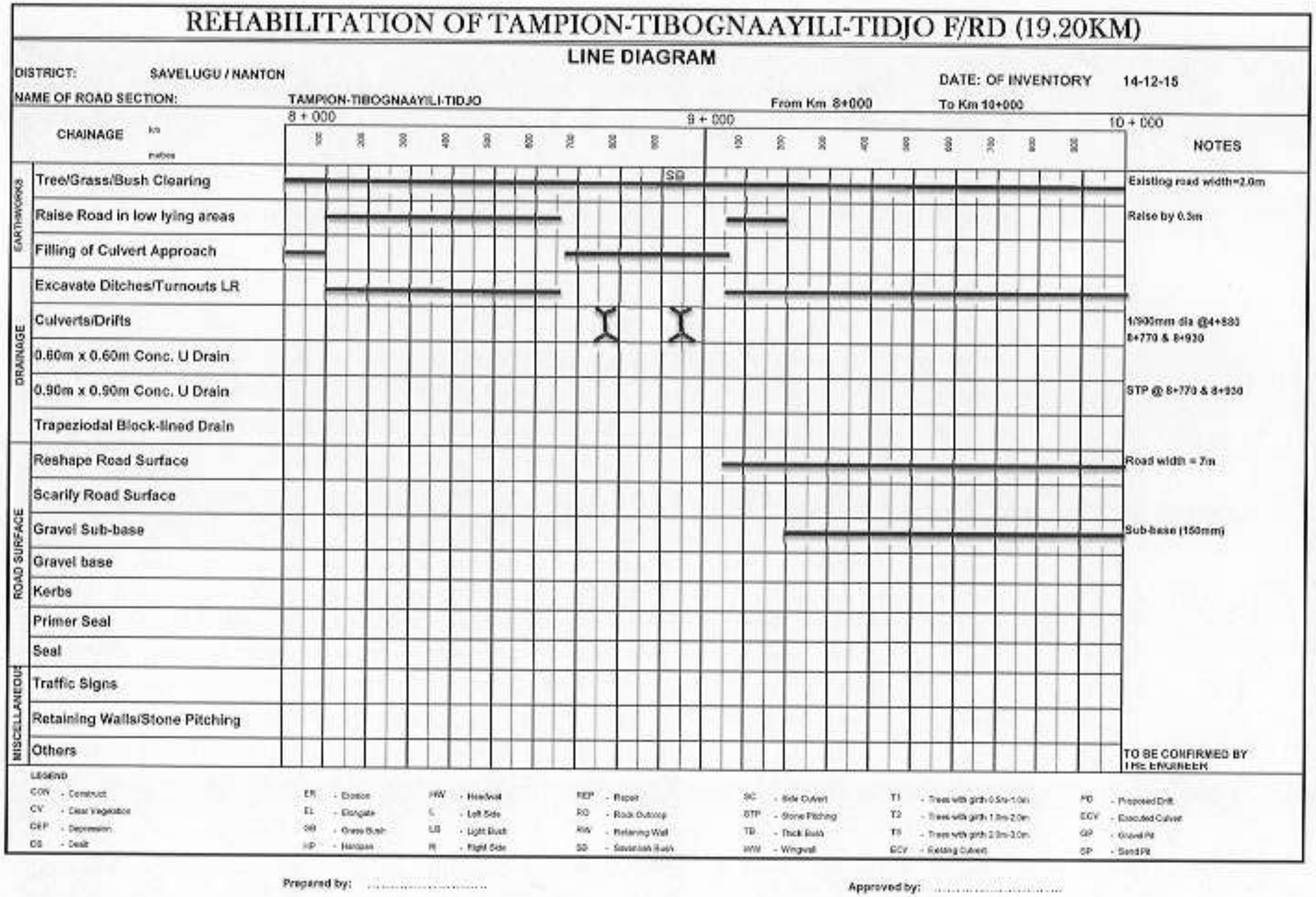
Approved by: ……………………

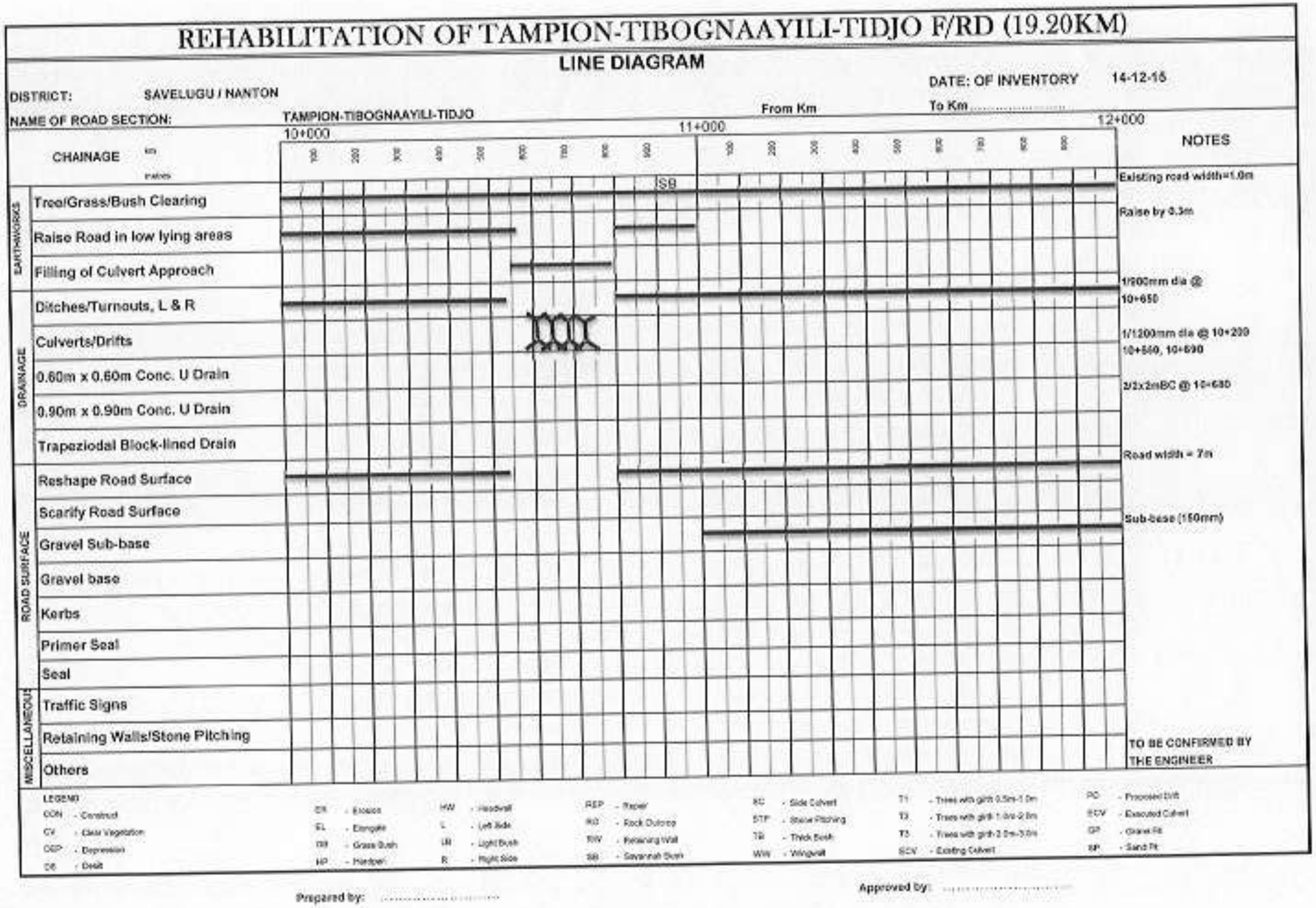

REHABILITATION OF TAMPION-TIBOGNAAYILI-TIDJO F/RD (19.20KM)
LINE DIAGRAM
DISTRICT: SAVELUGU / NANTON
NAME OF ROAD SECTION: TAMPION-TIBOGNAAYILI-TIDJO
DATE: OF INVENTORY 14-12-15
From Km 4+000
To Km 6+000
CHAINAGE
4 + 000
5 + 000
6 + 000
NOTES
EARTHWORKS
Tree/Grass/Bush Clearing
Raise Road in low lying areas
Filling of Culvert Approach
DRAINAGE
Excavate Ditches/Turnouts LR
Culverts/Drifts
0.60m x 0.60m Conc. U Drain
0.90m x 0.90m Conc. U Drain
Trapeziodal Block-lined Drain
ROAD SURFACE
Reshape Road Surface
Scarify Road Surface
Gravel Sub-base
Gravel base
Kerbs
Primer Seal
Seal
MISCELLANEOUS
Traffic Signs
Retaining Walls/Stone Pitching
Others - Natural Gravel
SB
Existing road width=3.5m
STP @ 4+880
Road width = 7m
Sub-base (100mm)
5+000-6+000
TO BE CONFIRMED BY THE ENGINEER
LEGEND
CON - Construct
CV - Clear Vegetation
DEP - Depression
ER - Erosion
EL - Elongate
GB - Grass Bush
HW - Headwall
L - Left Side
LS - Light Bush
R - Right Side
RO - Rock Outcrop
RW - Retaining Wall
SB - Savannah Bush
SC - Side Culvert
STP - Stone Pitching
TB - Thick Bush
WW - Wingwall
ECV - Existing Culvert
PD - Proposed Drift
GP - Gravel Pit
SP - Sand Pit
Prepared by: ....
Approved by: ....

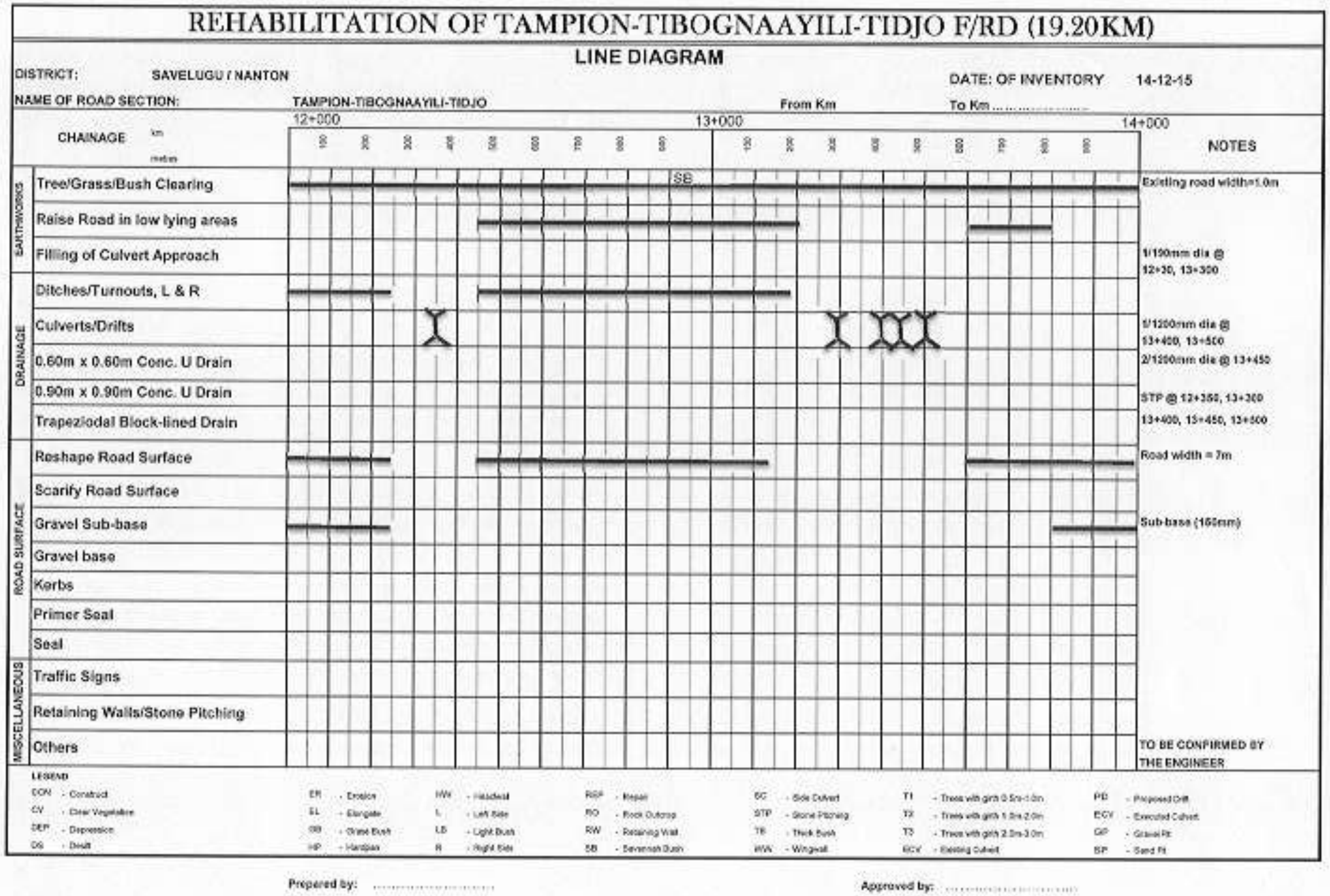


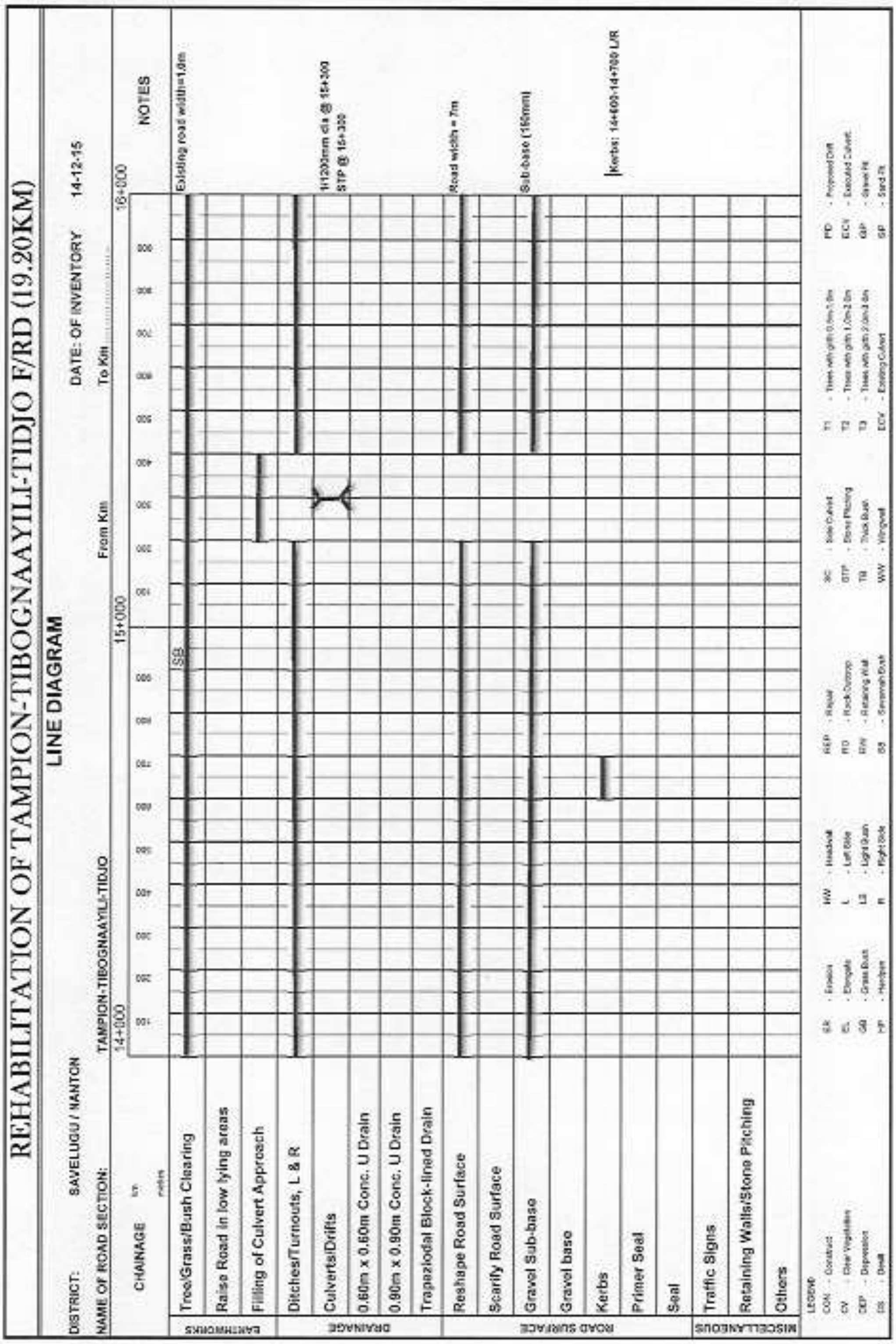
Prepared by: ....

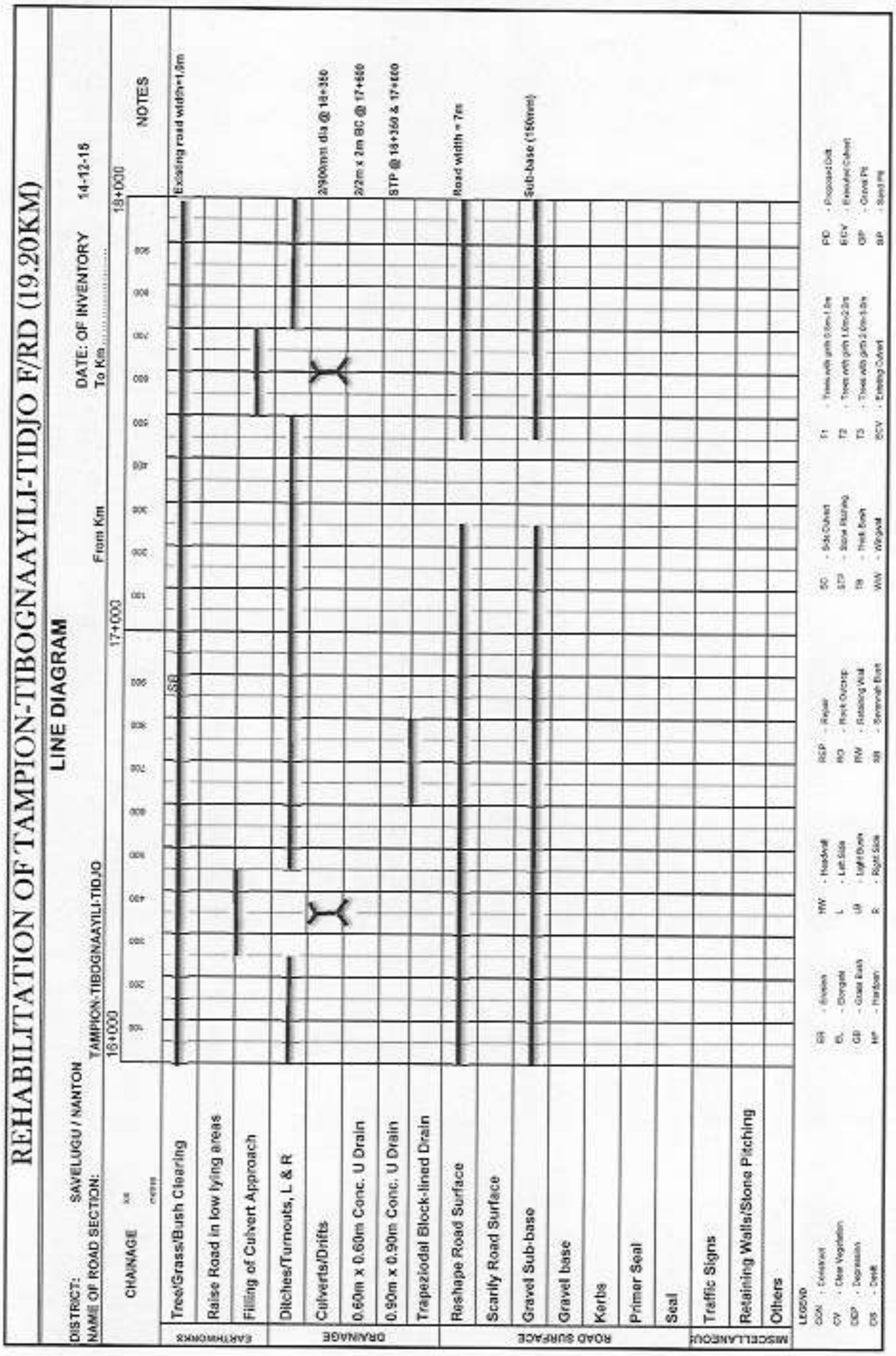
Approved by: ....

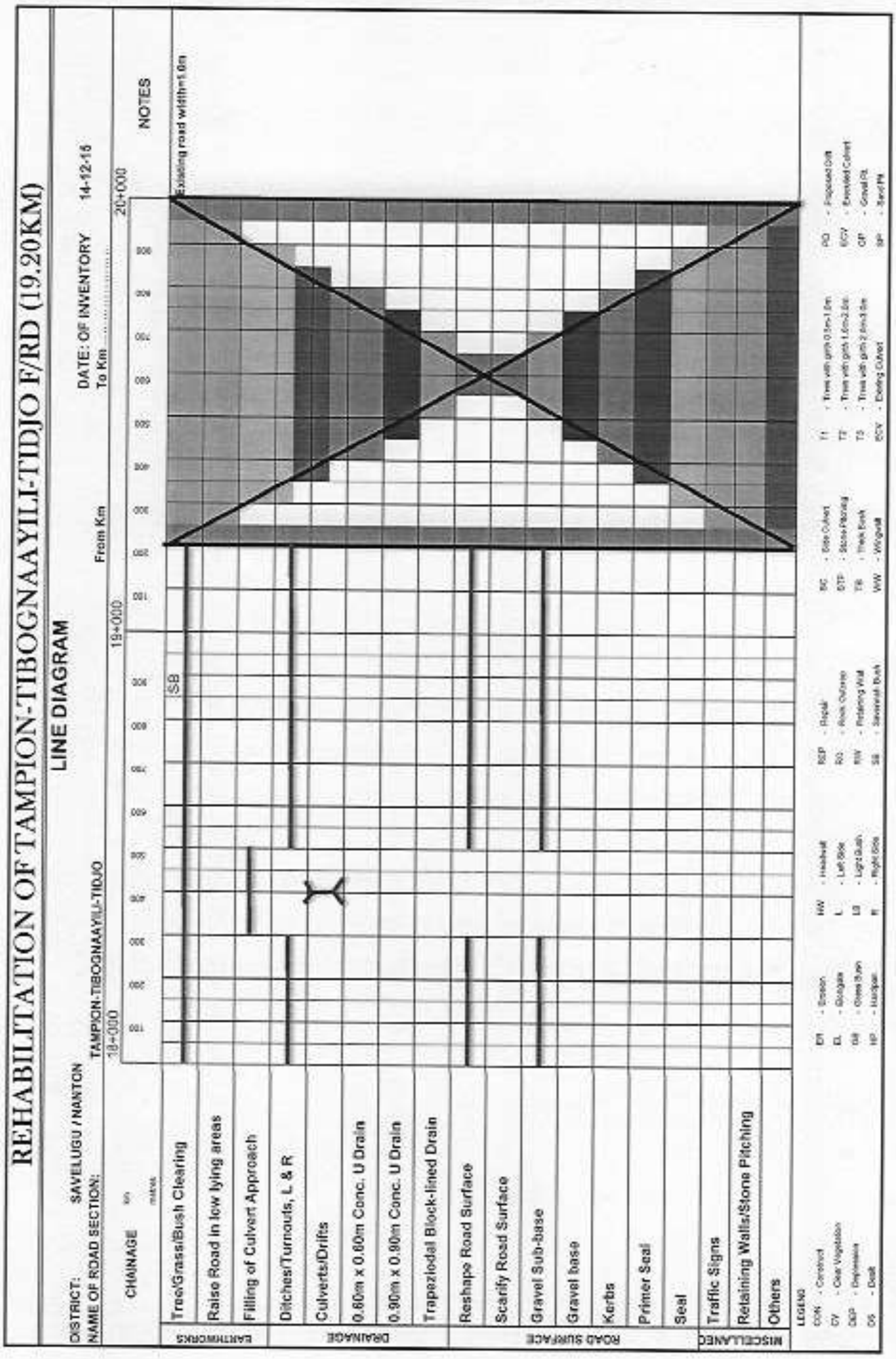

REHABILITATION OF TAMPION-TIBOGNAAYILI-TIDJO F/RD (19.20KM)
LINE DIAGRAM
DISTRICT: SAVELUGU / NANTON
NAME OF ROAD SECTION: TAMPION-TIBOGNAAYILI-TIDJO
DATE: OF INVENTORY 14-12-15
From Km 8+000
To Km 10+000
CHAINAGE
8 + 000
9 + 000
10 + 000
NOTES
EARTHWORKS
Tree/Grass/Bush Clearing
Raise Road in low lying areas
Filling of Culvert Approach
DRAINAGE
Excavate Ditches/Turnouts LR
Culverts/Drifts
0.60m x 0.60m Conc. U Drain
0.90m x 0.90m Conc. U Drain
Trapeziodal Block-lined Drain
ROAD SURFACE
Reshape Road Surface
Scarify Road Surface
Gravel Sub-base
Gravel base
Kerbs
Primer Seal
Seal
MISCELLANEOUS
Traffic Signs
Retaining Walls/Stone Pitching
Others
SB
Existing road width=2.0m
Raise by 0.3m
1/900mm dia @4+880 8+770 & 8+930
STP @ 8+770 & 8+930
Road width = 7m
Sub-base (150mm)
TO BE CONFIRMED BY THE ENGINEER
LEGEND
CON - Construct
CV - Clear Vegetation
DEP - Depression
DS - Desilt
ER - Erosion
EL - Elongate
SB - Grass Bush
HP - Hardpan
HW - Headwall
L - Left Side
LB - Light Bush
R - Right Side
REP - Repair
RO - Rock Outcrop
RW - Retaining Wall
SS - Savannah Bush
SC - Side Culvert
STP - Stone Pitching
TB - Thick Bush
WW - Wingwall
T1 - Trees with girth 0.5m-1.0m
T2 - Trees with girth 1.0m-2.0m
T3 - Trees with girth 2.0m-3.0m
ECV - Existing Culvert
PD - Proposed Drift
ECV - Executed Culvert
GP - Gravel Pit
SP - Sand Pit
Prepared by: ....
Approved by: ....


REHABILITATION OF TAMPION-TIBOGNAAYILI-TIDJO F/RD (19.20KM)
LINE DIAGRAM
DISTRICT: SAVELUGU / NANTON
NAME OF ROAD SECTION: TAMPION-TIBOGNAAYILI-TIDJO
From Km
DATE: OF INVENTORY 14-12-15
To Km
10+000
11+000
12+000
CHAINAGE
NOTES
SB
EARTHWORKS
Tree/Grass/Bush Clearing
Raise Road in low lying areas
Filling of Culvert Approach
DRAINAGE
Ditches/Turnouts, L & R
Culverts/Drifts
0.60m x 0.60m Conc. U Drain
0.90m x 0.90m Conc. U Drain
Trapeziodal Block-lined Drain
ROAD SURFACE
Reshape Road Surface
Scarify Road Surface
Gravel Sub-base
Gravel base
Kerbs
Primer Seal
Seal
MISCELLANEOUS
Traffic Signs
Retaining Walls/Stone Pitching
Others
Existing road width=1.0m
Raise by 0.3m
1/900mm dia @ 10+650
1/1200mm dia @ 10+200 10+560, 10+690
2/2x2mBC @ 10+680
Road width = 7m
Sub-base (150mm)
TO BE CONFIRMED BY THE ENGINEER
LEGEND
Prepared by:
Approved by:


REHABILITATION OF TAMPION-TIBOGNAAYILI-TIDJO F/RD (19.20KM)
LINE DIAGRAM
DISTRICT: SAVELUGU / NANTON
NAME OF ROAD SECTION: TAMPION-TIBOGNAAYILI-TIDJO
From Km
DATE: OF INVENTORY 14-12-15
To Km
CHAINAGE km metres
12+000
13+000
14+000
NOTES
SB
EARTHWORKS
Tree/Grass/Bush Clearing
Raise Road in low lying areas
Filling of Culvert Approach
DRAINAGE
Ditches/Turnouts, L & R
Culverts/Drifts
0.60m x 0.60m Conc. U Drain
0.90m x 0.90m Conc. U Drain
Trapeziodal Block-lined Drain
ROAD SURFACE
Reshape Road Surface
Scarify Road Surface
Gravel Sub-base
Gravel base
Kerbs
Primer Seal
Seal
MISCELLANEOUS
Traffic Signs
Retaining Walls/Stone Pitching
Others
Existing road width=1.0m
1/150mm dia @ 12+30, 13+300
1/1200mm dia @ 13+400, 13+500
2/1200mm dia @ 13+450
STP @ 12+350, 13+300
13+400, 13+450, 13+500
Road width = 7m
Sub-base (150mm)
TO BE CONFIRMED BY THE ENGINEER
LEGEND
CON - Construct
CV - Clear Vegetation
DEP - Depression
DS - Drift
ER - Erosion
EL - Elongate
GB - Grass Bush
HP - Hardpan
HW - Headwall
L - Left Side
LB - Light Bush
R - Right Side
REP - Repair
RO - Rock Outcrop
RW - Retaining Wall
SB - Savannah Bush
SC - Side Culvert
STP - Stone Pitching
TB - Thick Bush
WW - Wingwall
ECV - Existing Culvert
PD - Proposed Drift
ECV - Executed Culvert
GP - Gravel Pit
SP - Sand Pit
Prepared by:
Approved by:


REHABILITATION OF TAMPION-TIBOGNAAYILI-TIDJO F/RD (19.20KM)
LINE DIAGRAM
DISTRICT: SAVELUGU / NANTON
DATE: OF INVENTORY 14-12-15
NAME OF ROAD SECTION: TAMPION-TIBOGNAAYILI-TIDJO
From Km
To Km
CHAINAGE
14+000
15+000
16+000
NOTES
EARTHWORKS
Tree/Grass/Bush Clearing
Raise Road in low lying areas
Filling of Culvert Approach
Ditches/Turnouts, L & R
DRAINAGE
Culverts/Drifts
0.60m x 0.60m Conc. U Drain
0.90m x 0.90m Conc. U Drain
Trapezoidal Block-lined Drain
ROAD SURFACE
Reshape Road Surface
Scarify Road Surface
Gravel Sub-base
Gravel base
Kerbs
Primer Seal
Seal
MISCELLANEOUS
Traffic Signs
Retaining Walls/Stone Pitching
Others
SB
Existing road width=1.0m
1/1200mm dia @ 15+300
STP @ 15+300
Road width = 7m
Sub-base (150mm)
Kerbs: 14+600-14+700 L/R
LEGEND
Prepared by:
Approved by:


REHABILITATION OF TAMPION-TIBOGNAAYILI-TIDJO F/RD (19.20KM)
LINE DIAGRAM
DISTRICT: SAVELUGU / NANTON
NAME OF ROAD SECTION: TAMPION-TIBOGNAAYILI-TIDJO
From Km
DATE: OF INVENTORY 14-12-15
To Km
CHAINAGE
16+000
17+000
18+000
NOTES
EARTHWORKS
Tree/Grass/Bush Clearing
Raise Road in low lying areas
Filling of Culvert Approach
DRAINAGE
Ditches/Turnouts, L & R
Culverts/Drifts
0.60m x 0.60m Conc. U Drain
0.90m x 0.90m Conc. U Drain
Trapeziodal Block-lined Drain
ROAD SURFACE
Reshape Road Surface
Scarify Road Surface
Gravel Sub-base
Gravel base
Kerbs
Primer Seal
Seal
MISCELLANEOUS
Traffic Signs
Retaining Walls/Stone Pitching
Others
Existing road width=1.0m
2/900mm dia @ 16+350
2/2m x 2m BC @ 17+600
STP @ 16+350 & 17+600
Road width = 7m
Sub-base (150mm)
LEGEND
Prepared by: ....
Approved by: ....


REHABILITATION OF TAMPION-TIBOGNAAYILI-TIDJO F/RD (19.20KM)
LINE DIAGRAM
DISTRICT: SAVELUGU / NANTON
NAME OF ROAD SECTION: TAMPION-TIBOGNAAYILI-TIDJO
From Km
DATE: OF INVENTORY 14-12-16
To Km
CHAINAGE
18+000
19+000
20+000
NOTES
Existing road width=1.0m
SB
EARTHWORKS
Tree/Grass/Bush Clearing
Raise Road in low lying areas
Filling of Culvert Approach
DRAINAGE
Ditches/Turnouts, L & R
Culverts/Drifts
0.60m x 0.60m Conc. U Drain
0.90m x 0.90m Conc. U Drain
Trapeziodal Block-lined Drain
ROAD SURFACE
Reshape Road Surface
Scarify Road Surface
Gravel Sub-base
Gravel base
Kerbs
Primer Seal
Seal
MISCELLANEOUS
Traffic Signs
Retaining Walls/Stone Pitching
Others
LEGEND
Prepared by:
Approved by: