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

Climate Adaptation Handbook

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

ReCAP Project GEN2014C

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Abstract

The African Development Bank states that Africa is one of the regions in the world that is most vulnerable to the impacts of climate change. The majority of both vulnerability-led and scenario-led studies carried out in the region suggest that damages from climate variability and change, relative to population and Gross Domestic Product, are expected to be higher in Africa than in any other region in the world.

In order to help address this significant threat to Africa's development, the Africa Community Access Partnership (AfCAP) (a research programme funded by UK Aid), commissioned a project that started in April 2016. Its aim was to produce regional guidance and to develop climate-resilient rural access in Africa through research and knowledge sharing within and between participating countries. The output should assist the development of a climate-resilient road network that reaches fully into and between rural communities.

The study focuses on: (a) appropriate engineering and non-engineering adaptation procedures; (b) sustainable enhancement of the capacity of three AfCAP partner countries to deal with the likely impacts of climate change on rural road networks; (c) sustainable enhancement of the capacity of additional AfCAP partner countries; and (d) uptake and embedment of research outputs across AfCAP partner countries.

This Climate Adaptation Handbook provides relevant information and guidance on climate adaptation procedures for rural road access, along with a methodology to address climate threats and asset vulnerability, with the purpose to increase resilience in a systematic manner. It has been developed to cover a wide range of climatic, geomorphologic and hydrological circumstances, based on experience gained in Mozambique, Ghana and Ethiopia, but the guidance provided is equally applicable to any sub-Saharan country.

Key words

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

Research for Community Access Partnership (ReCAP)

Safe and sustainable transport for rural communities

ReCAP is a research programme, funded by UK Aid, with the aim of promoting safe and sustainable transport for rural communities in Africa and Asia. ReCAP comprises the Africa Community Access Partnership (AfCAP) and the Asia Community Access Partnership (AsCAP). These partnerships support 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. The ReCAP programme is managed by Cardno Emerging Markets (UK) Ltd.

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Acronyms, Units and Currencies

$	United States Dollar
°C	Degrees Celsius
ADB	Asian Development Bank
AfCAP	Africa Community Access Partnership
AfDB	African Development Bank
ANE	Administração Nacional de Estradas (National Roads Administration, Mozambique)
AsCAP	Asia Community Access Partnership
CRED	Centre for Research on the Epidemiology of Disasters
CSIR	Council for Scientific and Industrial Research, South Africa
DFID	Department for International Development, UK
EM-DAT	Emergency Events Database
IPCC	Intergovernmental Panel on Climate Change
GDP	Gross Domestic Product
GIS	Geographic Information System
MCA	Multi-Criteria Analysis
MDA	Ministries, Departments, Agencies/Authorities
MDB	Multilateral Development Bank
NGO	Non-Governmental Organisation
NPV	Net Present Value
RAI	Rural Access Index
RAMS	Road Asset Management System
ReCAP	Research for Community Access Partnership
SADC	Southern African Development Community
SCS	Soil Conservation Service
UK	United Kingdom (of Great Britain and Northern Ireland)
UKAid	United Kingdom Aid (Department for International Development, DFID)
UN ESA	United Nations, Department of Economic and Social Affairs
UNISDR	United Nations International Strategy for Disaster Reconstruction

Glossary (based on the Intergovernmental Panel on Climate Change, IPCC, 2018)

Accessibility	The ease for population groups to reach or participate in service activities using a transport network.
Adaptation	In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities (i.e. actions that reduce hazard, exposure and vulnerability). In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects.
Adaptive Capacity	The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.
Adaptation Needs	The circumstances that arise when the anticipated risks or experienced impacts of climate change require action to ensure the safety of populations and the security of assets and resources, including ecosystems and their services.
Adaptation Options	The array of strategies and measures that are available and appropriate for addressing adaptation. They include a wide range of actions that can be categorized as structural, institutional, ecological or behavioural, amongst many others.
Build back better	An approach to post-disaster recovery that reduces vulnerability to future disasters and builds community resilience to address physical, social, environmental, and economic vulnerabilities and shocks
Capacity Building	The ability to enhance the strengths and attributes of, as well as the resources available to, an individual community, society or organisation in response to change.
Change Management	A collective term for all approaches to preparing and supporting individuals, teams, and organisations in making organisational or institutional changes in order to equip them to address and resolve new or recurring challenges impacting on them and their stakeholders (e.g., impacts of climate variability and change on their operations).
Climate Change	Climate change refers to a change in the state of the climate that can be identified (e.g., by 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. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use.
Climate Variability	Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system such as ocean-atmosphere coupling (internal variability), or to variations in natural or anthropogenic external forcing such as variations in solar output or changing concentrations of greenhouse gasses (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 and adverse human, material, economic or environmental effects that require immediate emergency responses to satisfy critical human needs and that may require external support for recovery.
Early Warning Systems	The set of technical, financial and institutional capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare to act promptly and appropriately to reduce the possibility of harm or loss. Dependent upon context, Early Warning Systems may draw upon scientific and/or Indigenous knowledge.
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 by hazards.
Extreme Weather Event	An extreme weather event is 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 that are not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, groundwater floods, and glacial lake outburst floods.
Hazard	The potential occurrence of a natural or human-induced physical event or trend 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.
Impacts (Consequences, Outcomes)	The consequences of realized risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather and climate events), exposure, and vulnerability. Impacts generally refer to effects on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Impacts may be referred to as consequences or outcomes, and can be adverse or beneficial.
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.

Lock-in	The concept of 'lock-in' pertaining to climate change: decisions made now about the location, design and operation of assets will determine their long term resilience to the effects of climate change.
Mobility	The ability to move people and goods efficiently and effectively for socio-economic activities between an origin and destination using a transport network.
Resilience	The capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation.
Risk	The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard, or of adaptation or mitigation responses to such a hazard, on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure. Risk results from the interaction of vulnerability (of the affected system), its exposure over time (to the hazard), as well as the (climate-related) hazard and the likelihood of its occurrence.
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.
Road Criticality	Road criticality refers to the importance of a rural access road to the communities it serves in terms of the community's dependence on a road for accessing markets, goods and services.
Stressors	Events and trends, often not climate-related, that have an important effect on the exposed system and that 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 that attempts to identify the root causes for a system's vulnerability (to climate variability and change).

Executive Summary

Africa's development is highly dependent on an adequate and reliable roads system that also can withstand the impacts of climate change. To help address the significant threat of climate change to Africa's development, the Africa Community Access Partnership (AfCAP), a research programme funded by UKAid, commissioned a project in April 2016 to produce regional guidance on the adaptation of rural access roads to climate change. The project aims to provide pragmatic, cost-beneficial engineering and non-engineering adaptation procedures and guidance to road sector institutions through research and knowledge sharing within and between participating African countries.

The study covers climate threats and adaptation for both existing and new infrastructure. It 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, it provides evidence of cost-, economic- and social-benefit links to rural communities arising from more resilient rural access to support wider policy adoption across Africa.

The study focuses on the following:

a) Demonstration of appropriate engineering and non-engineering adaptation procedures
b) Sustainable enhancement of the capacity of three AfCAP partner countries[1] (i.e. Ethiopia, Ghana and Mozambique) to deal with the likely impacts of climate change on rural road networks – these three countries represent nearly the full range of climatic systems in sub-Saharan Africa
c) Sustainable enhancement of the capacity of additional AfCAP partner countries
d) Uptake and embedment of research outputs across AfCAP partner countries.

This Climate Adaptation Handbook provides a methodology for carrying out a climate adaptation assessment for rural access to assist socio-economic development. It also focuses on those activities and actions that conventional engineering standards and procedures do not necessarily cover. The Handbook is supported by three separate guideline documents that cover the following:

- Change Management[2] (henceforth referred to as the **Change Management Guidelines** in this ***Handbook***) – this guideline covers, inter alia, policy and planning, stakeholder and asset management, and recommendations for the formulation of strategies and programmes for improvement.

- Climate Risk and Vulnerability Assessment[3] (further on referred to as the **Risk and Vulnerability Guidelines** in the ***Handbook***) – this guideline takes users through the steps involved in conducting a risk and vulnerability assessment at national-/district-level, as well as a local-/project-level risk and vulnerability study when implementing new or maintaining/retrofitting existing infrastructure.

- Engineering Adaptation[4] (further on referred to as the **Engineering Guidelines** in the ***Handbook***) – this guideline introduces primary climatic attributes and the potential effects of these, followed by the provision of suggested adaptation measures for each infrastructure component, also highlighting the critical importance of effective drainage provision and of timely and appropriate maintenance of road assets.

[1] The AfCAP Partner Countries currently consist of the Democratic Republic of Congo, Ethiopia, Ghana, Kenya, Liberia, Malawi, Mozambique, Sierra Leone, South Sudan, Tanzania, Uganda and Zambia.

[2] Head, M., Verhaeghe, B. and Maritz, J. (2019). Climate Adaptation: Risk management and resilience optimisation for vulnerable road access in Africa: *Change Management Guidelines,* GEN2014C. London: ReCAP for DFID.

[3] Le Roux, A., Makhanya, S., Arnold, K. and Roux, M. (2019). Climate Adaptation: Risk management and resilience optimisation for vulnerable road access in Africa: *Climate Risk and Vulnerability Assessment Guidelines,* GEN2014C. London: ReCAP for DFID.

[4] Paige-Green, P., Verhaeghe, B. and Head, M. (2019). Climate Adaptation: Risk management and resilience optimisation for vulnerable road access in Africa: *Engineering Adaptation Guidelines,* GEN2014C. London: ReCAP for DFID.

In addition to the above, a Visual Assessment Manual[5] has also been produced which supports the Climate Risk and Vulnerability Assessment Guidelines as well as the Engineering Adaptation Guidelines.

The Guideline targets governments (central ministries, provinces, districts); national institutes and research organisations; the private sector; local-level stakeholders directly affected by the activities of this project; and non-governmental organisations. Specific actors and role players are listed in the table below:

	Entity/Sector	Actors and role players
National /District level	Governments (central ministries, provinces, districts)	▪ National road and transport authorities, including road and transport ministries, departments and authorities ▪ National departments dealing with disaster management ▪ Central government agencies that have a vested interest in road infrastructure planning and development ▪ Other relevant government ministries/departments (e.g. agriculture, environment, science, social and economic development, health, education and relevant technology sectors) ▪ District representatives of central government agencies and departments ▪ Multi-sectorial units/committees ▪ Emergency services ▪ Funders of and investors in road infrastructure projects ▪ National planning commissions
	National institutes, universities, research organisations	▪ Climate change committees ▪ Institutes dealing with meteorology/hydrology (e.g. water resources, hydrology and flood control) ▪ Entities involved in capacity building and research
	Private sector	▪ Businesses (small to large businesses operating in the sector) ▪ Funders of and investors in road infrastructure projects
Local /Project level	Local-level stakeholders directly affected by the activities of the project	▪ Local road engineers ▪ Private companies involved in road construction and/or maintenance ▪ Community representatives ▪ Local government representatives that can link with various district and central government departments and agencies
	Non-governmental organisations	▪ Community Non-Governmental Organisations

[5] Paige-Green, P., Verhaeghe, B. and Roux, M. (2019). Climate Adaptation: Risk management and resilience optimisation for vulnerable road access in Africa: *Visual Assessment Manual,* GEN2014C. London: ReCAP for DFID.

1 Introduction to the Handbook

1.1 Background

According to the African Development Bank (AfDB, 2018), Africa is one of the regions in the world that is most vulnerable to the impacts of climate change. The majority of both vulnerability-led and scenario-led studies suggest that damages from climate change, relative to population and Gross Domestic Product (GDP), could be higher in Africa than in any other region in the world (AfDB, 2011). Studies suggest that adaptation costs in Africa could be in the region of $20-30 billion per annum over the next 10 to 20 years.

Sub-Saharan Africa 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% of rural Africans live within two kilometres of an all-weather road, which makes socio-economic, medical and educational interventions timely, costly and unreliable. Much of the road network that contributes to agricultural and social development in these rural areas can be classified as low volume.

Internationally, development partners are substantially increasing their investments in climate-resilient and low-carbon development programmes - examples:
The World Bank: Since 2016, there has been a progressively larger share of newly approved transport projects embedding climate considerations to: (i) improve the resilience of African transport infrastructure to climate change; and (ii) improve the carbon-efficiency of transport systems in Sub-Saharan Africa. There is a commitment of US$ 1.9 billion, of which 90 percent International Development Association (IDA) funds, for fifteen climate informed projects over the period 2016 and 2018. The latest addition to the Bank portfolio consists of four climate informed transport projects and represents the entirety of the Fiscal Year 2018 transport approvals for Africa, with a combined IDA financing commitment of US$ 553 million. (World Bank, 2018)
The Asian Development Bank (ADB): The ADB's total adaptation financing increased from $558 million in 2011 to $988 million in 2013 – an increase of approximately 77% (ADB, 2011). With the Asian region facing serious environmental challenges, ADB will continue scaling up its support for climate change adaptation, while maintaining its assistance for mitigation through clean energy and energy efficiency projects and sustainable transport. In its Strategy 2030, ADB states that climate finance from their own resources will reach $80 billion cumulatively from 2019 to 2030. (ADB, 2018)

1.2 Scale of the challenge

Africa has experienced dramatic changes in the continent's climate, which is causing widespread damage to road infrastructure and its associated assets (Hearn, 2015; Schweikert et al., 2014). Rural accessibility is being compromised in a number of countries for increasing proportions of the year, and this creates both direct and indirect adverse effects on livelihoods and associated socio-economic development.

Over the past four decades (1975-2015), African countries have experienced more than 1,400 recorded weather-related disasters (CRED, 2016). These disasters have had significant impacts on affected countries' economies and, in particular, on rural communities and their livelihoods. The impacts of these natural hazards (floods, storms, droughts, extreme temperature, landslides and wildfires) were also felt across all economic sectors and infrastructure. Many communities and countries in Africa are socially and economically vulnerable to extreme climate events. Low adaptive capacity, as well as their high exposure to natural hazards, has resulted in the death of more than 600,000 people (mainly due to droughts), left 7.8 million people homeless (99% due to flooding and storms) and affected an estimated 460 million people over the past four decades (CRED, 2016).

As a consequence of the above, several sub-Saharan African countries may be facing a backlog of damage to existing infrastructure assets, and especially to vulnerable low-volume road networks, caused by the effects of changing climate and may not have the capacity, knowledge and resources to deal with this. The severe shortage of funds for maintenance has exacerbated the situation.

1.3 Aims and Objectives

The overall project aim is to **sustainably enhance the capacity of AfCAP partner countries** to reduce current and future climate impacts on vulnerable rural infrastructure. This is to be achieved through the 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*** is to identify, characterise and demonstrate appropriate adaptation procedures that may be implemented to strengthen the long-term resilience of rural access[6], based on a logical sequence of guidance covering the following[7]:

- Climate threats
- Climate impacts
- Vulnerability to impact (risk)
- Adequacy of funding
- Non-engineering adaptations (referred to as *Change Management* adaptations here)
- Engineering adaptations
- Prioritisation

The second objective, which focuses on ***capacity building and knowledge exchange***, is to meaningfully engage with relevant road and transport authorities in a knowledge dissemination and capacity-building programme.

The third objective is to ensure that there is focus on ***uptake and subsequent embedment*** of outcomes 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.

It should be noted that several sub-Saharan African Roads/Transport Ministries, Departments and/or Agencies/Authorities (MDAs) experience difficulty in managing their (low-volume rural) road networks given the often limited financial resources at their disposal, let alone dealing with expansion of their road networks and the consequences of climate change. Hence, for adaptation to climate change, the Handbook also proposes alternative measures that could be implemented in a scenario where budgets are inadequate or absent (i.e. 'low-cost' scenarios).

1.4 Using this Handbook

This Handbook refers to other Guidelines that form part of the documentation set. Sections in this report that are linked to other Guidelines are marked with a green frame marker (see below).

(e.g.) Section linked to the **Change Management guidelines.**

[6] Note that there are potential co-benefits from improving transport networks beyond rural development (e.g. Thambiran and Diab, 2011). Conversely, there could be a range of recognised environmental consequences of major road-building projects (e.g. Laurance et al., 2015; Halsnæs and Trærup, 2009).

[7] Note that the *research methodology* suggests a top-down approach, similar to the approach used by Willows and Connell (2003). This is but one of the approaches that could be adapted. For instance, another approach would be to begin with the overall development objective, the extent of present vulnerabilities, and options to achieve the intended outcome under present weather variability and future climate change (e.g. Wilby and Dessai, 2010). The methodology used in the Handbook is a combination of both approaches, as presented in Part B.

The Handbook also contains *information boxes* to provide additional information or that make reference to added examples. These are indicated in shaded blue boxes (see below).

Information Box

A list of *recommended actions* is also placed in summary boxes that are marked orange (see below).

Recommended Actions

Finally, *general remarks* that amplify or provide additional guidance are provided in green marked boxes.

(General) Remarks

2 Components of Handbook

2.1 Structure

This Handbook provides relevant information on climate adaptation procedures for rural road access, along with instructions on an appropriate methodology to address climate threats and asset vulnerability, so as to increase resilience for the foreseeable future to ensure that the assets meet the expected useful life for which they are designed.

Section 3.2.2: *Prioritisation of adaptation needs*, in **Change Management Guidelines,** provides information on the expected useful life of some road infrastructure assets.

The Handbook has been developed to cover a wide range of climatic, geomorphologic and hydrological circumstances commonly applicable to the three study countries, Ethiopia, Ghana and Mozambique, but is equally applicable to any of the other Sub-Saharan African countries.

The Handbook is an overarching document and illustrates the fundamental principles, processes and steps required for climate resilience. Details regarding actual adaptation measures and vulnerability assessment methodologies are included in the accompanying guideline documents that cover (1) Climate Risk and Vulnerability Assessment; (2) Change Management; (3) Engineering Adaptation, as well as in the Visual Assessment Manual (see Figure 1).

The Handbook is supported by demonstration studies that were conducted to assess the appropriateness and practicality of the recommended approaches for climate adaptation. The studies concerned were carried out in Mozambique.

The three countries in which the studies were based represent nearly the full range of climatic systems in Africa. Mozambique is subject to flooding and extreme events, including tropical cyclones. Both Mozambique and Ghana are on the receiving end of water flowing out of major international river basins, and most of their economic activity and population are concentrated along the coast and in low-lying estuaries and deltas. Ethiopia is a land-locked country with smaller river catchments and extensive mountainous areas.

Figure 1 Overview of Handbook and supporting guidelines

2.2 Application

The Handbook has been produced to provide relevant information on adaptive procedures for **new** and **existing** rural access roads, along with instructions on an appropriate methodology to address climate threats and asset vulnerability and to increase resilience for the foreseeable future. Although produced for *low-volume rural road applications*[8]*,* most of the principles also apply to *high-volume roads.* It is also important to note that the priorities and design parameters for low-volume roads may differ from those found in high-volume roads, and therefore caution is advised.

There are three specific overlapping applications of the Handbook in the context of low-volume roads, as shown in Figure 2:

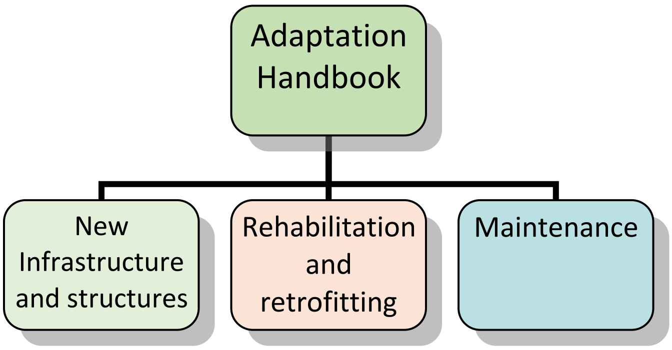


Figure 2 Applications covered in the Handbook

For the three applications:

- Accessibility objectives are the same, but the design and construction processes may be different.
- Principles of adaptation methodology remain the same.

[8] Low-volume rural roads are roads that typically carry less than 1 million equivalent standards axles (80 tonnes) over their service life.

- Existing infrastructure is expected to have more historical knowledge and a better understanding of climatic and hydrological effects.
- Maintenance backlog failures of existing roads are the most problematic and the highest priority.
- Repair/rehabilitation of assets affected by climate events to restore accessibility is not only costly, but sometimes results in fruitless expenditure if the restoration measures are not rendered climate resilient. Hence, the focus should be on 'building back better' so as to reduce vulnerabilities to future disasters.

New Infrastructure and structures

Overall, construction of especially new low-volume rural road infrastructure is rare. The limited funding available is mostly used for upgrading, repairs and rehabilitation, except for limited areas of realignment that are necessary to avoid congestion in cities (e.g. ring roads) or to improve geometric and safety conditions.

Although there are many initiatives to improve rural access, most of these involve the upgrading of existing tracks, earth or gravel roads to higher standards (but still low-volume roads), together with improvement of existing or the construction of new drainage structures. In these cases, knowledge of the historical performance and hydrology is usually available for the upgrades. They provide useful baseline conditions, but the assumptions of stationary design standards may become invalidated by climate change. Hence, where data exist more work may have to be done to mitigate potential risks.

Where totally new alignments are planned, information needs to be acquired regarding the hydrology necessary for the design of structures. The expected changes in future climate in these areas must also be taken into consideration.

Rehabilitation and retrofitting

In cases where the required serviceability criteria can no longer be maintained or where future scenarios are expected to lead to disruption or failure of the infrastructure components, rehabilitation or retrofitting of the existing assets is required. This should also be necessary where the risk levels are considered unacceptable, for example where failure of a structure or a large landslide may lead to loss of life, extended periods of road closure or costly rehabilitation works. Many of the structures on rural access roads in sub-Saharan Africa are rather old or were designed as interim measures; hence they could be susceptible to flood damage.

Rehabilitation is also required where a structure, embankment or cutting has failed through recent or past extreme climate effects, and would require additional measures to ensure future resilience. Past inventories of such failures would support the prioritisation, design and implementation of more resilient measures.

These types of activity are, however, usually very costly.

Maintenance of existing infrastructure

Many of the problems related to climate susceptibility can be minimised by practical and timely maintenance. In most sub-Saharan countries, there is a significant maintenance backlog resulting from historical climatic events as well as the inability to fund routine maintenance. This results in parts of the road network being impassable for varying periods during rainy or wet periods. An important part of the adaptation process is to identify these areas and implement measures to build resilience as soon as possible or as funding permits. There would, however, seldom be sufficient funding for robust measures. Prioritisation of the needs, in line with defined criteria, is therefore essential. Details regarding this prioritisation are provided in this manual.

Failure to address the maintenance backlogs would effectively result in a *do-nothing or do-little* scenario, which would require additional planning, emergency and reactive resources in view of the projected increases in extreme events.

At a strategic level, it is preferable to develop a national climate threat, vulnerability and adaptation strategy aligned with national development strategies that would support the national climate policies. The results would then inform the next steps through the identification of specific vulnerabilities and locations where more resilient infrastructure is needed. This would consider the prioritisation process and its application to the road network at regional and district levels. Greater resolution may be required, depending on the threat and risks involved, and may influence future planning and development decisions. Finally, detailed assessments should be carried out at corridor or project levels and strategies should be refined further, while consideration should be given to budget implications and planning requirements. The tiered process is illustrated in Figure 3.

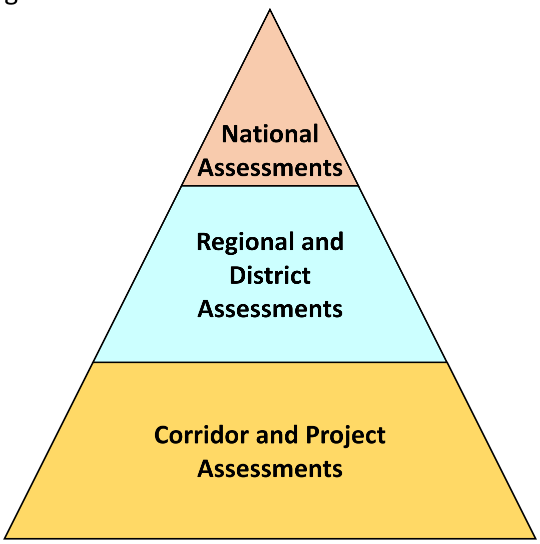


Figure 3 Tiered process of strategic assessments to inform policy

3 Scope of this Handbook

The methodology outlined in this Handbook comprises **five** stages, with each stage consisting of several activities as set out in the table below.

A summary of **PART A: Situational Review and Process Management** is presented in this Handbook with full details contained within the accompanying **Change Management Guidelines**.

Part B: Methodology is set out as five stages, as follows:

Stage 1	*Climate risk screening (national/regional)*
Stage 2	*Impact and vulnerability assessment (project level)*
Stage 3	*Prioritisation, as well as technical and economical evaluation of options*
Stage 4	*Project design and implementation*
Stage 5	*Monitoring and evaluation*

Summary steps and recommended actions are set out in **Part B**, with details contained in the accompanying Guidelines as defined by the colour coding shown later in Table 1. The adaptation methodology would be applied in a slightly different rigour depending on the scale, application and availability of funds (see Figure 4).

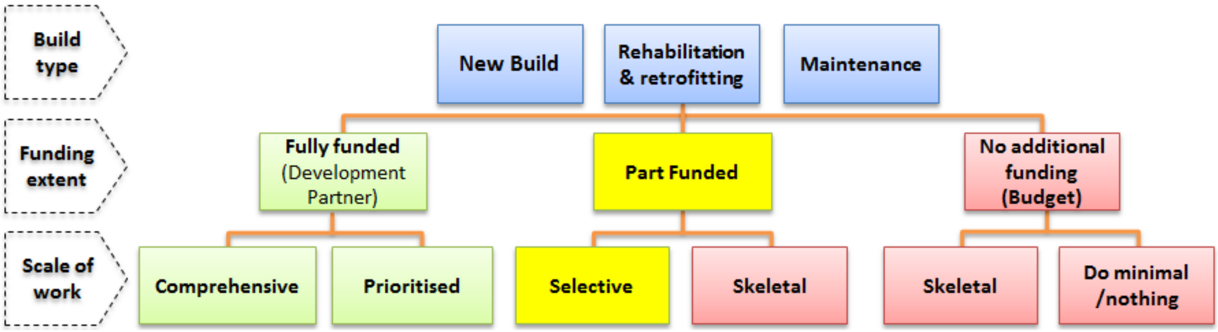


Figure 4 Strategic approach based on type of activity and adequacy of funding available

At one end of the scale is a fully-funded road corridor and at the other a district maintenance backlog with scarce or zero funds. Policy and strategy directives may be in place or they may be absent. Appropriate data support systems may or may not be in place, and the level of technical capacity to implement adaptation is expected to vary significantly. Figure 4 illustrates how the strategic approach could vary based on the type of activity and adequacy of funding available. Development partner funding (in green) would normally be comprehensive/prioritised, whereas part-funded projects would require prioritisation that is highly selective and may, by necessity, be skeletal in the activities that can be funded.

Feedback from AfCAP partner countries identifies maintenance as being heavily underfunded or in some cases almost absent, and therefore activities should be based on available resources.

This Handbook also pays particular attention to management of measures that could be taken when budgets are inadequate or absent under a *'Low-Cost'* Scenario. It is recommended that, in these circumstances, the guidance set out in Section 2.4.4 and throughout Section 3 of the **Change Management Guidelines** be followed under a *'Low-Cost'* Scenario.

This strategic approach is further discussed in Stage 4 of Part B of **this Handbook** (Section B.4: *Project design and implementation*). Further details on how to address poor, inadequate or absent Budget Scenarios are set out in Sections A.5.2, B.3.3 and B.4.1.1.

Table 1 provides an overview of the structure of the Handbook, and on how the Handbook relates to the three Guidelines supporting the Handbook. Parts of Table 1 relate to institutional preparedness to deal with climate change (i.e. Part A, and sub-Stages B.1.1 to B1.1.3 of Part B), others with climate risk screening at national and project level informing needs and priorities (i.e. sub-Stages B.1.4 and B1.1.5 [national] and B.2.1 to B.2.3 [project level]), and the remainder with engineering adaptation at project level.

Table 1 Contents and scope of the Adaptation Methodology

PART A	Situational review and process management	Associated guideline
	Problem identification (including evidence) Identification of probable causes Drivers of change (policy-driven) Change management Approach and delivery Effective data management	**Change Management**
PART B	**Methodology**	**Associated guideline**
Stage 1	***Climate risk screening (national/regional)***	
B.1.1	Needs determination	**Change Management**
B.1.2	Identification and mobilisation of stakeholder/partner involvement	
B.1.3	Setting of policy, objectives and scope (network level)	
B.1.4	Analysis of observed and projected climate effects	**Risk & Vulnerability**
B.1.5	Data gathering and risk analysis	
Stage 2	***Impact and vulnerability assessment (project/local level)***	
B.2.1	Project-level climate risk screening	**Risk & Vulnerability**
B.2.2	Climate-sensitive impact assessments	
B.2.3	Data gathering and vulnerability assessment	
Stage 3	***Technical and economical evaluation of options***	
B.3.1	Identification of strategies and potential adaptation measures	**Engineering**
B.3.2	Impact assessment of 'do something' and 'do nothing'	
B.3.3	Stakeholder consultations	
B.3.4	Prioritisation and selection of adaptation measures	
Stage 4	***Project design and implementation***	
B.4.1	Development of an implementation plan (including 'Low-cost'' scenario)	**Engineering**
B.4.2	Design parameters and optimisation	
B.4.3	Construction supervision and documentation	
Stage 5	***Monitoring and Evaluation***	
B.5.1	Development of a monitoring and evaluation plan	**Engineering**
B.5.2	Reporting and sharing of implementation experiences	

KEY:

Sections covered by the ***Change Management Guidelines***
Sections covered by the ***Climate Threats and Vulnerability Assessment Guidelines***
Sections covered by the ***Engineering Adaptation Guidelines***

PART A: Situational Review and Adaptation Management

Adaptation Management options are often referred to as non-engineering options and consist of a range of policy and management improvements. Associated activities of change management that are used to address adaptation for road infrastructure and asset management tend to be more strategic and organisational in nature than engineering options and **are generally used in conjunction with engineering options in their application**. Engineering climate proofing measures have historically received a greater level of attention. However, the most economically efficient measures may lie beyond engineering measures (such as addressing unsustainable land use practices in an upstream watershed).

A.1 Climate Change Challenges

African countries tend to be particularly vulnerable to the effects of climate variability, and historical weather-related disasters demonstrate how susceptible these countries are. The following primary climate changes are likely to occur to varying degrees in most parts of sub-Saharan Africa (Le Roux et al., 2016):

- Increased temperatures (average, maximum and number of extremely hot days per year)
- Decreased precipitation and longer drier periods, or increased variability in rainfall
- Increases in extreme weather events – violent storms, heavy precipitation, heat waves, etc.
- Rising sea levels
- Migration of the tropical cyclone belt
- Increased wind speeds and dust storms[9]

Sections 2.2 to 2.7: *Climate change effects*, in **Engineering Guidelines,** provide a detailed description of these changes, associated hazards and their effects.

The predominant types of recorded weather-related disasters and the number of people who have historically been affected are illustrated below. Figure 5 shows dramatic increase in the recorded yearly occurrences of weather-related disasters captured in the Emergency Events Database (EM-DAT) between 1975 and 2015 for all African countries (CRED, 2016). The size of the pie charts depicts numbers of people affected relating to the significance of the events. Each chart depicts types of effects – the significance of flooding and drought is particularly noticeable. Also, the additional effects of storms in southern Africa are highlighted.

There is clear evidence that climate change has already affected the magnitude and frequency of climate extremes, causing damage to infrastructure and dislocating rural communities (CRED, 2016). Particularly vulnerable AfCAP partner countries are Ethiopia, Kenya, Mozambique, Ghana, South Sudan, Tanzania and Uganda; however, all African countries are affected to a significant degree.

A.2 Causes and Effects

Figure 6 illustrates the significance of weather-related disasters and number of people affected per year. The number of events, particularly those related to floods and storms, should be noted.

Related secondary effects of climate change could include the following:

- Changes in intensity and frequency of flooding
- Changed frequency of extreme storm surges
- Changes in the optimum construction season (possibly timing and length) and conditions due to precipitation and temperature constraints
- Changes in soil moisture and stability of terrain

[9] Dust storms may contribute to blockages of drainage systems and accumulation of sand and dust on roadways. Globally, dry-land areas have expanded since the 1950s (Prăvălie et al., 2019).

- Changes in groundwater levels
- Changes in land cover and soil stability (i.e. vegetation density and type; rate of growth; longer/shorter growing seasons)

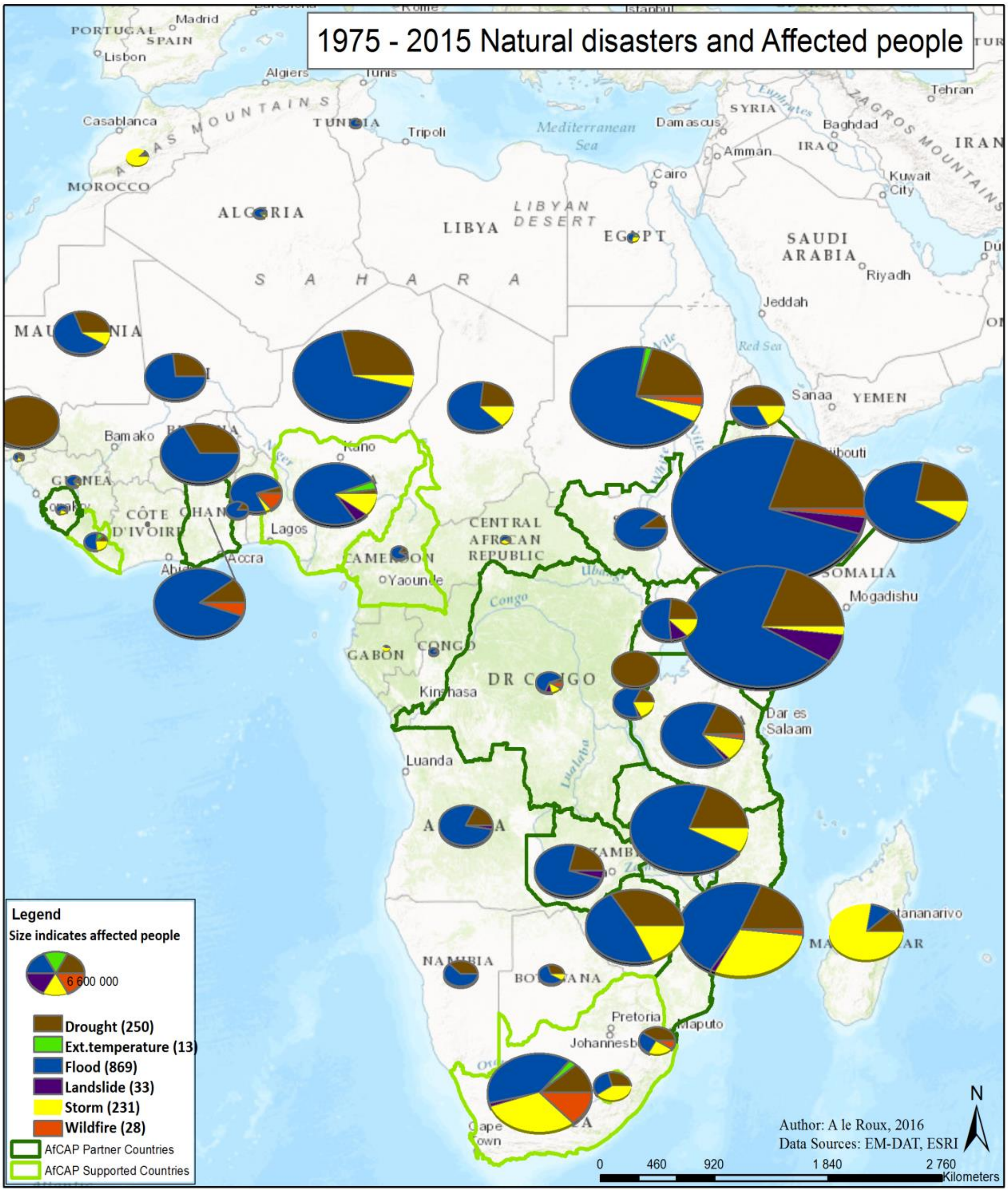


Figure 5 Recorded weather-related disasters and affected populations

(Source data extracted from EM-DAT, 2016)

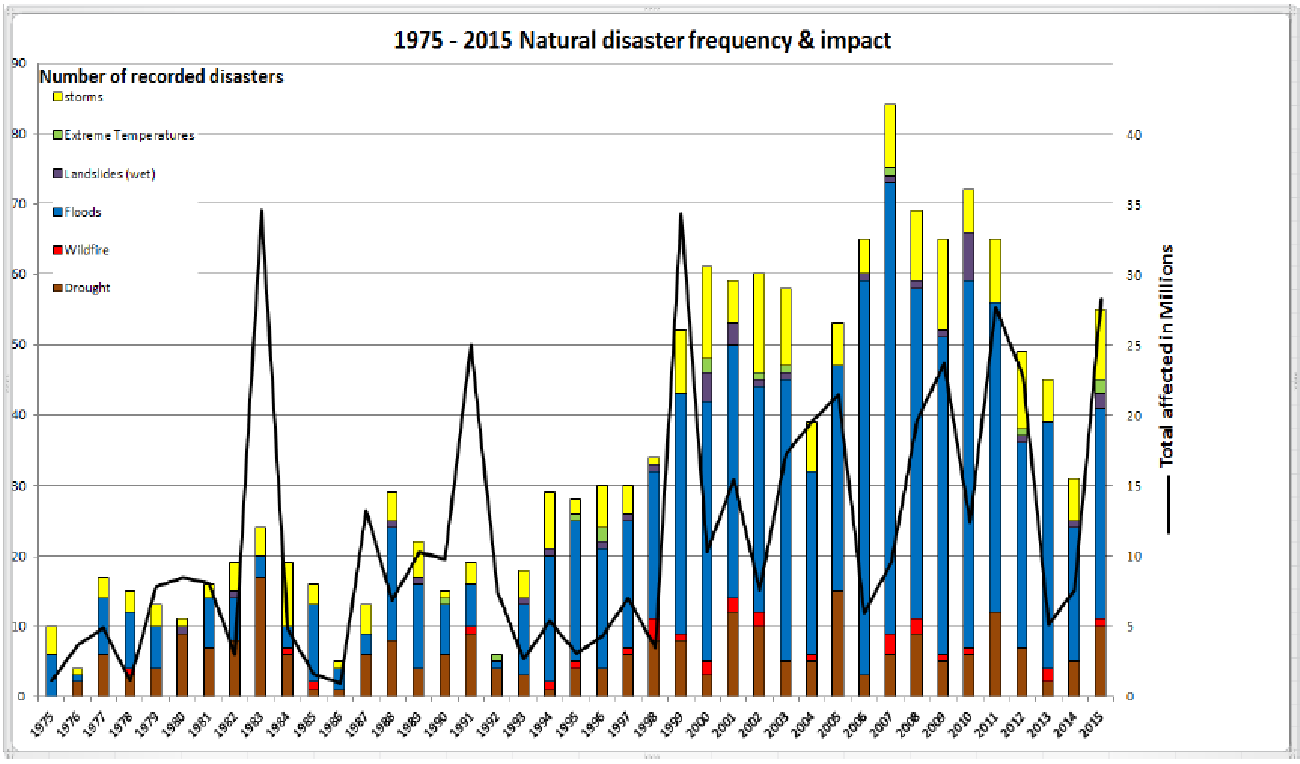


Figure 6 Recorded weather-related disasters and total number of people affected per year from 1975 – 2015
(Source data extracted from EM-DAT, 2016)

A.2.1 Rural access

Low-volume rural road networks vary from simple 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 because 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 often damage these structures, rendering road links impassable for extended periods. Flooding leads to similar consequences. Whereas road pavements can usually be reinstated quickly to restore rideability after extreme events, road closures caused by flooding may take several days or weeks before water levels subside and accessibility can be restored. However, severe harm to 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.

It has been shown in southern Africa that for low-volume road networks (< 1 million cumulative equivalent single standard axle loads over their service life), the environment (mainly climate) plays a much larger role in contributing to deterioration than does traffic (SATCC, 2003).

See Section 1.2.2: *Rural access*, **Engineering Guidelines,** for more guidance on this subject.

Figure 7 Low-volume rural access road in Africa

A.2.2 Poor maintenance

Historically, road asset maintenance has been sporadic and inadequate, resulting in deteriorating assets. Record keeping, management systems, supervision, monitoring and quality control have been weak. Problems have been exacerbated by the reluctance of development partners to set up maintenance funds within their new construction or rehabilitation programmes. Consequently, significant maintenance backlogs, in addition to the pressures of providing improved/new access to rural communities, are commonplace.

A.2.3 'Low-cost' scenario

Capital and maintenance budgets in several African MDAs are often insufficient, even when well-managed road funds have been established to manage these funds. In addition to this, poor prioritisation processes, through for instance not well-established data and management systems, often resulted in the inefficient use of scares funds.

In recent years, increases in extreme weather and unpredictable rainy seasons have created unprecedented backlogs of maintenance and rehabilitation. Emergency funds are often woefully inadequate to address the increasing scale of damage from climate. In the worst cases, backlogs cannot be addressed and maintenance programmes are suspended – except for routine maintenance. Managing access is particularly challenging in these circumstances, often referred to as Do nothing / Do minimal. This Handbook deals extensively with this particularly prevalent situation, which is referred to as the 'Low-Cost' Scenario. In such circumstances, specific actions and plans can be undertaken to reduce the impact of climate events and to manage access through a planned programme of information management, early warning systems, community self-help, emergency planning and stakeholder collaboration.

The **Change Management Guidelines** give detailed guidance on dealing with a poor, inadequate or absent Budget Scenario (see Section 2.3.3: *'Low-cost' scenario*, Section 2.4.4: *Adaptation management in cases of poor or inadequate budget scenarios*, throughout Section 3: *Change Management,* and Section 4.5: *'Low-cost' scenario).*

A.2.4 Projected climate change over Africa

African temperatures are projected to rise rapidly, faster than the global average temperatures, and in the subtropics at a rate of about twice the global rate of temperature increase (Le Roux et al., 2016). Moreover, the southern African region and Mediterranean North Africa are likely to become generally drier, whilst East Africa and most of tropical Africa are likely to become wetter. More uncertainty surrounds the projected climate futures of West Africa and the Sahel, with some climate models projecting wetter conditions and equally credible models projecting drier conditions. For the southern African region, generally drier conditions and the future frequent occurrence of dry spells are likely over most of the interior. Tropical cyclone tracks are projected to shift northward, bringing more flood events to northern Mozambique and fewer to the Limpopo province in South Africa. Further to the north, over Tanzania and Kenya, more large-scale flood events may plausibly occur, should the future climate regime be characterised by a higher frequency of occurrence of strong El Niño events.

Further details on climate change projections are provided in Section 2.2 (**Change Management Guidelines**).

A.3 Drivers for Change

A.3.1 Policy and plans

Although multisector policies on climate change are being addressed in many countries[10], policies and strategies specific to the roads and related infrastructure sector are almost absent.

Government, MDAs (Ministries, Departments and Agencies/Authorities) and national development council policies on climate adaptation set the scope and content for strategic planning for programmes and plans which, when implemented, would be expected to create more sustainable rural access.

Section 2.4.2: *Policy options for climate adaptation* (**Change Management Guidelines**), sets out policy options and provides guidance on how to translate these into strategies and plans.

A.4 Adaptation Management

The implementation of an adaptation management structure in an MDA has the potential to take significant steps towards creating resilience to climate effects in a cost-effective way. It would be expected to cover planning, stakeholder and asset management, and the formulation of strategies and programmes for improvement.

A.4.1 Integrated approach

By implementing an integrated approach, stakeholders can anticipate and mitigate impacts in a more effective way.

Section 3.1 of the **Change Management Guidelines** sets out all activities and actions necessary to achieve an integrated approach:

- Identification and mobilisation of stakeholder and expertise involvement
- Improved network and programme management to anticipate and mitigate impacts
- Improved asset management resilience, inclusive of asset inventory and condition assessments
- Maintenance planning and early warning
- Environmental management
- Hydrological management
- Augmenting standards and design guides
- Road safety
- Research

[10] Adaptation planning at the national scale is often linked to commitments laid out in Nationally Determined Contributions to the UNFCCC process. See: https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs

A.4.2 Managing the adaptation process

Once the process, sequence and necessary adaptations have been determined based on the initial assessments and prioritisation inputs, their implementation needs to be carefully managed.

A.4.2.1 Adaptation options in the roads sector

The types of actions that can be taken to reduce vulnerability include avoiding, withstanding (i.e. building resilience to), and/or taking advantage of climate variability and impacts.

See Sections 4.3: *Prioritisation of adaptation needs* and 4.4: *Adaptation options in the road sector* **(Engineering Guidelines)** for more information.

A.4.2.2 Prioritisation of adaptation needs

Low income communities struggle more than others to cope with and adapt to climate change and natural hazards. There is a downward spiral effect when climate affects economic development and creates loss of access at the same time.

According to the World Bank's *Shock Waves* report (Hallegatte et al., 2016),

- natural disasters push people into poverty and prevent poor people from escaping poverty;
- an increase in natural hazards is already observed and projected to worsen in the next decades;
- these changes in hazards would affect poor people and our ability to eradicate poverty. Because poor people are often most exposed to natural hazards and lose a greater share of their assets and income when hit by a disaster, natural disasters increase inequality and may contribute towards a decoupling of economic growth and poverty reduction.

The process of prioritisation is expected to require significant input from road authorities as well as communities, where differing needs and importance may prevail and typically would require decisions of a strategic nature.

See Section 4.3: *Prioritisation of adaptation needs* (**Engineering Guidelines)**.

Typical criteria for prioritisation, set out in Section 3.2.2 (**Change Management Guidelines**) are:

- Potential loss of life
- Availability of alternative routes
- Cost and consequences of closure
- Environmental/sustainability issues (i.e. loss of habitat and environmental degradation; e.g. Laurance et al., 2015)
- Cost of repair
- Available funds
- Accessibility requirements for local communities.

A.4.2.3 Serviceability

It is important that all roads be carefully and correctly classified in terms of their **main function** (i.e. provision of mobility or access) and their **required levels of serviceability** as a part of the prioritisation process. This serviceability level is a function of numerous factors, but mostly whether the road is purely an access road or whether it is also used for mobility.

From a strategic planning and investment perspective, the classification of serviceability should address various scenarios of mobility and accessibility along a corridor, across a sub-region, regionally, and ultimately, nationally. In other words, alternative route strategies are needed to ensure mainly continuity of mobility, but also continuity of access, through all climate events/seasons.

The proposed classifications of Level of Serviceability for roads that predominantly provide mobility and accessibility are set out in Section 3.2.2 *Prioritisation of Adaptation Needs (***Change Management Guidelines***).*

A.4.3 Embedment

Embedment covers the preparation of full documentation, the implementation thereof and delivery of the adaptation process. The following documentation would need to account for climate variability and change as part of the adaptation process:

- Policy documents
- Strategic and five-year plans
- Management plans
- Planning documents
- Programmes and budgets
- Standards and specifications
- Project plans and designs
- Construction and monitoring plans
- Contingency plans

A.4.4 Capacity building

In order to establish and implement climate adaptation successfully, national capacity needs to be developed across all relevant stakeholders. This includes Roads/Transport MDAs, but should also include a wide range of other participants from central government (e.g. Finance, Environment), cascading all the way through to village groups.

See Section 3.4: *Capacity Building* (**Change Management Guidelines***)* for further details.

Recommended actions *(to be directed and/or coordinated by Roads/Transport MDAs)*
Systematic capacity building may be done as follows:

- Engage stakeholders on capacity development.
- Assess capacity needs and assets.
- Formulate a capacity development response based on
  - institutional arrangements – policies, procedures, resource management, organisation, leadership, frameworks, and communication;
  - leadership – high-level involvement should 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.
- Implement a capacity development response.
- Evaluate capacity development.

A.5 Approach and Delivery

A.5.1 Funding and budgets

After having identified and prioritised development needs, finding the necessary funding to implement climate resilience is going to be one of the biggest challenges for road authorities. Funding is already, and has been for many years, insufficient to even maintain the existing infrastructure. Response to current extreme events results in funding being diverted for other sources, usually maintenance budgets, to 'emergency' funds exacerbating the already underfunded maintenance requirements.

Until recently, most development partners have not implemented robust risk, screening and adaptation methodologies for road infrastructure projects. Experiences are not well developed or documented, which has led to cases of insufficient resilience of assets.

Development partner investment strategies are set out in Section 4.1: *Funding and climate vulnerability screening (***Change Management Guidelines***)*; and Considerations for new infrastructure, rehabilitation, retrofitting and maintenance are presented as Sections 4.2 to 4.4 (**Change Management Guidelines**).

A.5.2 'Low-cost' scenario

Not taking action to address the risks associated with extreme climate events stems from the following three main obstacles to adaptation among others (cf. Eisenack et al., 2014):

- **Lack of knowledge:** not familiar with, or inability to understand, the form or scale of the problem
- **Failure to act:** inability to put appropriate measures in place or unwillingness to address the problem
- **Insufficient funds:** either through not appreciating the scale of the problem or inability to secure funding.

Several Roads/Transport MDAs in sub-Saharan Africa currently lack knowledge and understanding of the scale of the problems associated with climate change. Even where there is a basic understanding there is often a failure to act because adequate policies and strategies are not in place. Also, power structures and deep social inequalities can lead to very uneven benefits from adaptation interventions (e.g. Clay and King, 2019). As such, rural access schemes will benefit some households more than others, so provisions are needed for such inequalities.

Failure to act is likely to increase costs related to dealing with disruption, loss of access, rehabilitation and socio-economic development. Shocks from unexpected extreme climate events are expected to severely undermine community and business resilience.

Doing nothing would often be the result of insufficient funding. If this path is taken in an unplanned way, it may result in frequent disruptions to the infrastructure network, and would generally take longer and cost significantly more in the long run to restore accessibility. It can also cause prolonged negative effects on socio-economic development.

By necessity, this option is becoming much more prevalent as maintenance backlogs increase and funding becomes more problematic. Unfortunately, if part of a *reactive* management programme it becomes difficult to address prioritisation of affected communities in any meaningful manner.

In many circumstances, there is not enough budget to deal with all affected areas, roads and structures impacted by weather events; or that the consequences of climate change are too severe to justify comprehensive physical adaptation from a budget perspective. In these circumstances, prioritisation should be on the basis of socio-economic effects and cost-benefit analyses (See Section B.3.4). A planned programme of dialogue with affected communities, including well dispersed information and contingency programmes, is necessary to moderate the adverse effects of these decisions on those that are likely to be impacted.

The consequences of insufficient emergency funds or backlog maintenance are that routine maintenance and planned rehabilitation could be suspended. Many African countries are experiencing shortages of funds for basic maintenance of low-volume rural roads. In some cases, roads or structures could be abandoned through lack of funds, or because of strategic decisions during prioritisation of investment decisions. In others, assets are left impassable during rainy seasons or part thereof.

A strategic plan for an *Insufficient Budget* Scenario should be prepared in these circumstances, as set out in Section B.3.3.

Recommended actions *(by Roads/Transport MDAs)*

- Take proactive actions to determine the scale of the problem.
- Consult with all relevant stakeholders to agree what type of measures can be funded, if any.
- Develop strategic plan for *an Insufficient Budget* scenario.
- Develop contingency plans.

The subject is covered in more detail in Section B.3.4: *Socio-economic analysis of 'do something' and 'do nothing',* **Climate Adaptation Handbook.**

A.5.3 Management of delivery

Funding is the major stumbling block for many African countries in ensuring resilience of the infrastructure in any area. New construction or major rehabilitation programmes are often funded by multilateral development banks, but some may require additional funding from within the countries' treasury. Rehabilitation/retrofitting may only be partly-funded by outside agencies but is mostly funded by the national treasury (often augmented through dedicated Road Funds). This is likely to be applied selectively to high priority projects with other projects obtaining little or no funding. Maintenance is generally entirely funded from local sources and is inevitably significantly underfunded.

Generally, only selected high-priority projects are fully funded. Rehabilitation and retrofitting may receive part funding for selective high priority programmes but the remainder of the infrastructure network would be subjected to operational budgets that, in many cases, could result in '*do nothing*' or *'do little'* because of budget constraints.

A.6 Effective Data and Asset Management

Shock events related to cllimate occur frequently even within the lifecycle of the shorter-lived road assets and therefore need to be considered as part of the day-to-day business of the road authority. Asset management is an overarching and essential decision-making tool for prioritisation of investments. By the embedment of relevant climate change aspects in asset management systems, it should provide the basis through which climate change initiatives could be readily implemented into a road authority.

For climate adaptation needs and priorities to be incorporated in asset management, additional information would need to be collected such as assessments of potential risks/vulnerabilities to assets so that potential problem areas/structures can be identified.

Described in further detail in Section 2.5 (**Risk and Vulnerability Guidelines**), and in Section 5: *Effective Data Management* (**Change Management Guidelines**).

All available data covering climate change and patterns should be identified and analysed for their usefulness. The same would apply to the inventory of Infrastructure assets and their condition.

All roads should be carefully and correctly classified in terms of their required levels of serviceability as a part of the prioritisation process). This may differ from the existing road classifications, which may be based on traffic counts, demographics or purpose. Since it is not economically possible to address every potential climate resilience problem, it is necessary to prioritise the roads within an area. This should be based on the level of serviceability provided by the road. Decisions on the **classification of level of serviceability** should be based on multi-criteria analysis (MCA) and include social, traffic, connectivity and economic considerations. These analyses should be done at a **strategic level** based on the **inventory of roads** developed as part of the Road Asset Management System (RAMS) as well as existing road condition, to identify any preliminary improvements.

From a strategic planning and investment perspective, the classification of serviceability should address various scenarios of accessibility along a corridor, across a sub-region, regionally and ultimately, nationally. In other words, alternative route strategies are needed to ensure continuity of access through all climate events/seasons

Each project would have to be assessed in terms of the costs of adaptation versus the cost of *doing nothing*, considering all the engineering, social and environmental costs and the discounted overall life-cycle costs to allow fair comparisons.

Climate change has the potential to result in a $3.1 billion impact to roads in Ethiopia when the effects of temperature, precipitation and flooding increases are taken into consideration through to 2100 (World Bank, 2010). These costs could be reduced by 54 per cent if adaptation policies are adopted through policy changes by the government. However, even with these adaptations, the potential cost to Ethiopian roads from climate change could be as high as $1.4 billion (Chinowsky et al., 2011).

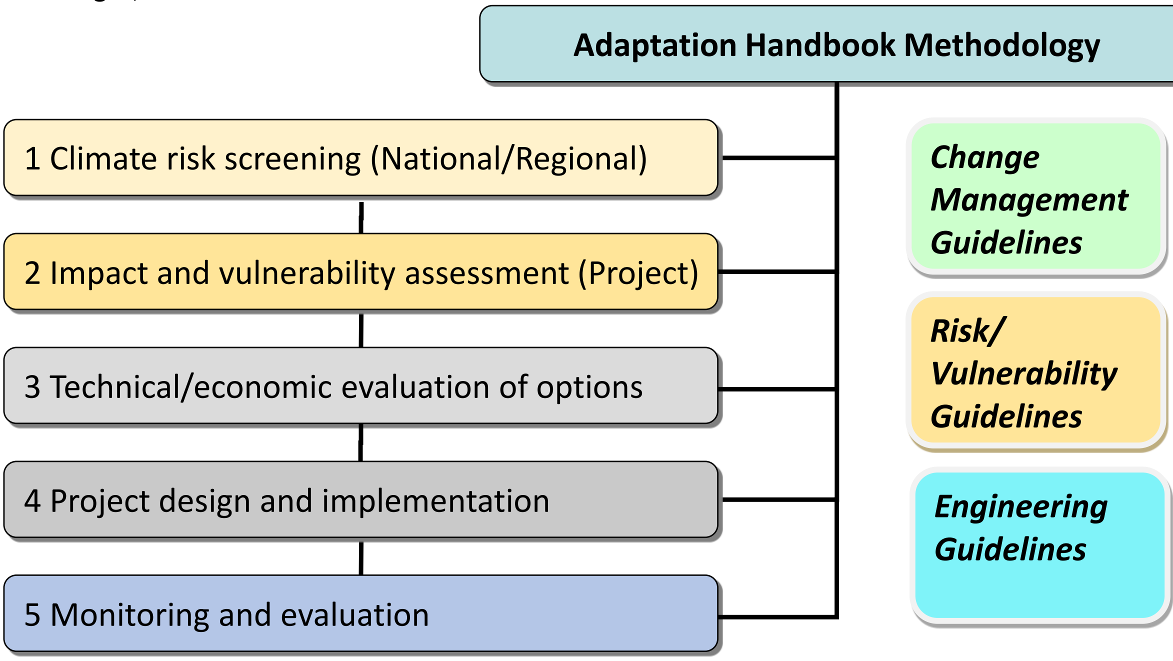
To implement the necessary adaptations to make roads more climate resilient and assist with the prioritisation, it is necessary for Roads/Transport MDAs to carry out visual assessments of existing roads with particular attention being paid to those problems specifically related to climatic effects.

PART B: Methodology

The Adaptation Methodology identifies risks and vulnerabilities, sets out strategies and options and guides design for implementation and review. Adaptation can be defined as:

In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities (i.e. actions that reduce hazard, exposure and vulnerability).

It has five stages, as follows:



This Handbook is the overarching document and illustrates the fundamental principles, processes and steps required for climate resilience. Details regarding actual adaptation measures are included in the accompanying **Guideline documents** covering *Change Management*, *Climate Risk and Vulnerability Assessment* and *Engineering Adaptation*. In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard, or of adaptation or mitigation responses to such a hazard, on lives, livelihoods, health and wellbeing, ecosystems and species, economic, social and cultural assets, services (including ecosystem services), and infrastructure (IPCC, 2018). Within the context of these guidelines, risk is defined as a function of hazards, rural access road exposure and vulnerability in terms of rural community access (le Roux et al., 2016). In particular, the following definitions apply:

- **Hazards:** Climate-related events that can possibly cause damage to and/or interruption of service of rural low volume access road infrastructure as well as potential loss of life (e.g. floods, landslides);
- **Exposure:** Location of low volume road facilities, the associated structures and road environment as well as rural communities in places that could be adversely affected (within the hazard footprint). This also includes indirect impacts, such as disruption of access due to a climate impact on another part of the road network[11];
- **Vulnerability**: Propensity to be adversely affected, considering the dependence of rural communities on these low volume access roads.

[11] For a review of recent research on resilience of transport networks see: Mattsson and Jenelius (2015). Ideally the adaptation planning should adopt an integrated approach to the transport sector (i.e. dependencies between for example road and rail, or road and marine).

A national threat and vulnerability assessment ('Climate Risk Screening', *Stage 1*) should be carried out first. Although climate risk screening is of critical importance for national multi-sectorial planning and decision making, it is not necessarily a requirement for the implementation of an adaptation methodology at project level (*Stages 2 to 5*).

The climate risk screening methodology presented in *Stage 1* thus proposes a rural road risk and vulnerability assessment methodology that speaks to national decision makers, whereas *Stages 2 to 5* propose a methodology for a rural access road risk and vulnerability assessment method on a project level and the identification, prioritisation and implementation of adaptation options, and speaks to road construction and engineering professionals.

B.1 STAGE 1: Climate Risk Screening

A geospatial climate-related road infrastructure risk and vulnerability assessment can provide key geographic information aimed towards supporting decision makers in identifying those roads that should be prioritised for repair, improvement or development in the light of changing climatic conditions.

The level of detail and decision support provided by a risk and vulnerability assessment is highly dependent on the question and scale of the study. At a national scale, a climate vulnerability, threat and adaptation strategy provides strategic-level support for national road and climate policies. At finer scales, regional- and district-level analyses play a vital role in informing future planning and development decisions by prioritising high-risk areas, while local-scale analyses provide highly detailed project-level assessments that support project managers while adapting individual stretches of road or road corridors.

B.1.1 Needs determination

A survey of affected countries (Verhaeghe et al., 2017), followed by meetings with government officials and workshops, has revealed similar experiences and problems to be addressed urgently:

- Climate adaptation is often being addressed as part of a multi-sectoral national approach, but transport and roads are not currently being included in any meaningful way.
- Climate risks and vulnerabilities of low-volume rural road networks need to be identified and addressed.
- Relevant climate-related data needs to be collected to support a new approach.
- Appropriate new policies and strategies that speak to climate change need to be embedded in all programmes.
- Road damage backlogs from climatic effects are increasing at an alarming rate and need appropriate guidance to be addressed.
- Maintenance budgets for capital works and maintenance are not adequate to deal effectively with climate effects.
- Lack of funding is so acute in many countries that specific scenarios for addressing challenges with poor, inadequate or absent funding are required.
- Knowledge and capacity on climate adaptation need strengthening in particular Roads/Transport MDAs.

Recommended actions

- Carry out needs analyses within the roads and transport sector to identify the scope of the activities to be carried out and the outputs needed.
- Consult with all relevant stakeholders so as to establish clear communication and cooperation lines.

B.1.2 Identify and mobilise stakeholder/partner involvement

Stakeholder communication and involvement should occur from the outset and should be ongoing throughout the assessment process, and facilitated through collaborative work sessions and workshops. These knowledge-sharing sessions should be held throughout to enable and support both cross-disciplinary and inter-departmental coordination and collaboration among the public sector, private sector, and local stakeholders to assess impacts, vulnerabilities, and adaptation options.

Stakeholder communication and involvement should include a wide range of participants from central government agencies, all the way through to local communities. The national/regional-level assessment may, however, be most relevant to national or international stakeholders. These stakeholders could include national departments, agencies or authorities, funders of government road asset investment projects, as well as other public and private sector stakeholders that have a vested interest in road infrastructure planning and development.

Recommended actions

- Ensure continuous engagement with a wide range of participants to promote inclusive, effective and efficient stakeholder communication, collaboration and involvement during the work process.
- Include the following stakeholders in ongoing open dialogue:
  - Central government agencies that have a vested interest in road infrastructure planning and development
  - National planning departments
  - National transport sector stakeholders, including road and transport ministries, departments and agencies/authorities (MDAs)
  - Funders of road asset investment projects
  - Multilateral Development Banks (MDBs)
  - Other relevant government ministries/ departments (e.g. agriculture, environment, science and relevant technology sectors
  - Climate change committees
  - Institutes dealing with meteorology/hydrology (e.g. water resources, hydrology and flood control)
  - Emergency services and or the National department dealing with Disaster management
  - Local-level stakeholders directly affected by the activities of the project (this should go down all the way to affected village groups)
- Consult the following stakeholders in cases where poor, inadequate or absent funding scenarios exist:
  - Local communities and businesses
  - Local schools, clinics, hospitals
  - Farmers and traders
  - Charitable organisations, faith groups and NGOs

B.1.3 Setting of policy, objectives and scope (network level)

The application of a climate lens is recommended at the national or sector level examining (OECD, 2009):

- The extent to which the policy, strategy, regulation, or plan under consideration could be vulnerable to risks arising from climate variability and change
- The extent to which climate change risks have been taken into consideration in the course of programme formulation
- The extent to which the policy, strategy, regulation or plan could lead to increased vulnerability, leading to maladaptation or, conversely, to missing important opportunities arising from climate change
- Potentially uneven/distributional benefits of the plan (or projects), and
- Pre-existing policies, strategies, regulations, or plans that are being revised, what amendments might be warranted in order to address climate risks and opportunities.

Recommended actions

- Appoint a Climate Adaptation Programme Manager for implementation
- Climate change impacts are not set by national boundaries; their effects require regional coordination (e.g. for schemes that cross state boundaries and involve multiple nations). Harmonisation between national and regional road network development activities requires coordination at a high level.
- Incorporating adaptation considerations into, for example, transport master plans should further secure the likelihood of meeting transport-related objectives and may also identify new priorities. The simplest way for a transport plan to incorporate climate change adaptation is to acknowledge the relationship between climate change impacts and the plan’s goals, such as safe and effective road networks.
- Align spatial planning policies, national and international technical standards, and economic policies and regulation in support of transport and road infrastructure resilience.
- Policy-driven information gathering, or the explicit link between pilot project and policy mainstreaming. Adaptation strategies are tested and evaluated in the context of a given policy sphere and successful measures are fed back up into the given policy. This integration can help improve the policy's general direction and achievement of its objectives.
- Integrate adaptation strategies into local comprehensive plans.
- Identify and protect high risk infrastructure.
- Develop a programme of training and piloting of the adaptation strategy for technical and operational specialists.
- Agree programmes of vulnerabilities to be progressed to options analysis and action plan development.

B.1.4 Analysis of observed and projected climate effects

The observed climate impacts for AfCAP partner countries were shown in Figure 5: *Recorded weather-related disasters and affected populations* and Figure 6: *Occurrence of recorded weather-related disasters and total number of people affected per year from 1975 – 2015* (cf. Section A.1). Source data can be extracted from the Emergency Events Database (EM-DAT; https://www.emdat.be/database).

District-level risk and vulnerability assessments are needed to facilitate identification of districts where roads are most vulnerable to a changing climate in terms of the impact on rural accessibility. This is done broadly using existing road network and road design principles to determine where roads could potentially be most affected by changes in climate and socio-economic patterns and in more detail based on the visual assessments of vulnerability. The output of the district-level assessment identifies potential high-risk areas (areas that should be prioritised for road adaptation). These results can then be used to determine where in-depth local-level road risk and vulnerability assessments would be most beneficial.

The recommendations presented in this section are based on methodologies that have been applied and tested in three AfCAP African countries, namely Ethiopia, Ghana and Mozambique.

Main projected changes in climate (2071-2100) for AfCAP countries (le Roux et al., 2016):

Zambia

Drastic temperature increases are projected over Zambia under low mitigation – exceeding 6°C over the western parts towards the end of the century. The western part of the country is also likely to become generally drier with a decrease in extreme rainfall events. However, over the far north-eastern parts, increases in rainfall and extreme rainfall events are likely.

Mozambique

General increases in rainfall totals, extreme rainfall events and the landfall of tropical cyclones are likely over Northern Mozambique under climate change. Over the southern parts, including the Limpopo river basin region, rainfall decreases are likely (it should be noted though, that some climate models extend the region of wetter conditions under climate change to southern Mozambique). The projected changes in maximum temperature are smaller than over the southern interior to the west, but may still exceed 4°C.

Malawi
Malawi is located in a region that is considered marginal in terms of its projected change in rainfall. It is located between a large part of the southern African interior projected to become generally drier, and a large part of East Africa (from northern Mozambique in the south to the Horn of Africa) that is projected to become generally wetter. As a result, some uncertainty surrounds the projected rainfall signal for Malawi, with some models projecting general rainfall increases and more extreme rainfall events, but with other models projecting the opposite signal. The projected changes in maximum temperature are smaller than in the subtropics, but may still exceed 4°C for the scenario where the country also becomes generally drier.

Kenya, Tanzania and Uganda
General rainfall increases are projected over East Africa under climate change by most climate models, including over the Kenyan, Tanzanian and Ugandan region. Increases in extreme rainfall events are consistently projected. The projected changes in maximum temperature are smaller than in the subtropics, but may still exceed 4°C.

Ethiopia
General rainfall increases are projected over the Horn of Africa under climate change by most climate models, including over the eastern parts of Ethiopia. Over the western highland regions decreases in rainfall are likely. Increases in extreme rainfall events are consistently projected. The projected changes in maximum temperature are smaller than further to the north, but may still be as high as 4°C.

South Sudan
General decreases in rainfall, with associated increases in extreme rainfall events, are projected by most climate models for South Sudan under climate change. However, a minority of climate models indicate that a generally drier future with a decrease in extreme events is also likely. The projected changes in temperature are smaller than over North Africa to the west, but may still exceed 4°C.

Democratic Republic of Congo (DRC)
General increases in rainfall and extreme rainfall are likely over much of the African tropics, including the DRC. Temperature increases may be as high as 4°C.

Ghana, Liberia and Sierra Leone
Ghana, Liberia and Sierra Leone are in a part of West Africa for which climate models are projecting very diverse rainfall futures, ranging from significantly wetter with more extreme events, to significantly drier with fewer extreme events. Temperature increases may well exceed 4°C.

The methodology for undertaking a risk and vulnerability assessment at district level consists of five phases, each containing a number of action steps:

Phase 1: Identification of hazards affecting the vulnerability of roads

- Step 1.1: Identify current climate hazards that are affecting the vulnerability of roads (based on historical data)
- Step 1.2: Understand future climate hazards that are likely to affect the vulnerability of roads (based on projected climate data)

Phase 2: Data collection and preparation

- Step 2.1: Data collection
  - What data to collect
  - Where to collect data
- Step 2.2: Data preparation, including data quality assurance

Phase 3: Data analysis

- Step 3.1: Determine road exposure to identified hazards
- Step 3.2: Determine road criticality (based on rural accessibility)

- Step 3.3: Determine most vulnerable districts
  - Most vulnerable districts under current climate and socio-economic conditions
  - Future vulnerable districts under a changing climate and growing population

Phase 4: Embedment in the Road Asset Management System

- Step 4.1: Consider climate hazards indicators to be included in the RAMS
- Step 4.2: Export data to the RAMS
- Step 4.3: Analyse data in the RAMS

Phase 5: Climate adaptation (in terms of prioritisation)

- Refer to Change Management and Engineering Adaptation Guidelines

See Section 3.2: *Piloting a district-level risk and vulnerability assessment* (**Risk and Vulnerability Guidelines**) for a full explanation.

The aim of identifying threats affecting vulnerability of roads is twofold; *firstly,* to analyse historical climate data in order to identify the current climate threats that most affect the vulnerability of roads, and *secondly,* to use the identified current climate threats to inform an investigation into the future hazards that are likely to affect the vulnerability of roads under projected climate change conditions.

Recommended actions

- Formulate a national climate threat picture, documents, data and statistics from country-level assessments indicating the type, frequency and intensity of historical climate induced disasters should be sourced.
- Investigate historical climate data archives, country-level assessment reports and knowledge-sharing workshops to inform the process of identifying the climate threats that most affect the vulnerability of roads. Identify and flag the driving forces of vulnerability for further analysis in this assessment process.
- Flood hazards have the greatest impact on rural road infrastructure, where a 100-year flood could damage up to 30% and 10% of unpaved and paved roads respectively (Chinowsky *et al*., 2012).
- Consider two main types of climate-related impacts for rural roads, namely water-related hazards (inundation by flooding and landslides) as a result of rainfall extremes, and road degradation as a result of incremental changes in average rainfall and temperature.
- Also consider other common climatic induced threats such as storms, droughts, windiness and wildfires (if determined to be of high frequency, magnitude and extent).
- Map the results of the climate threat investigation.

The following climate parameters and data can be assessed to determine climate threats:

- Sea level, wave action and rates of coastal erosion (for coastal roads)
- Precipitation intensity and slope of ground (for mountainous regions)
- Intensity duration frequency of peak rainfall events (for designing drainage and protecting infrastructure)
- Profiles of past extreme weather events
- Changes to the onset and duration of rainy seasons (for road maintenance and construction scheduling)
- Wind speed (for erosion, dust movement and wildfire hazard assessments)
- Multi-hazard combinations of the above (e.g. storm surge, high winds and heavy rainfall with fluvial flooding (Gill and Malamud, 2017)

It is also important to understand how climate threats are projected to change into the mid- (2050) to long-term (2100) future. This is done by conducting forward looking scenario studies using climate models and projected data.

Recommended actions

- Use the results of current threats to inform the starting point for conducting forward-looking investigations.
- Use mid-term (2021-2050) future projections that are generally less uncertain than long-term (2070-2100) projections.
- Perform future climate assessments based on high-resolution physical climate change modelling outputs (cf. le Roux et al., 2016). These should include projected changes in climate with regard to temperature and rainfall, as well as changes in extreme events and, where applicable, projected changes in sea level rise and wind velocity in coastal environments (note, however, that projected wind velocities from climate models might not be reliable).
- Map the results of the future climate threat investigation.

B.1.5 Data gathering and risk analysis

A range of data should be sourced as input that supports the risk and vulnerability analyses. As a starting point, road network data, climate threat data and socio-economic data need to be sourced from national authorities and/or open source repositories. Datasets that support analysis, such as district boundary data and town hierarchy data also need to be sourced. Data to support the district-level risk and vulnerability analyses should, ideally, be sourced from relevant country specific national authorities who have been appointed as data custodians.

Once data has been sourced, data preparation should be done to transform data from its original state into variables for rural road specific hazard assessment.

Table 2 outlines the possible data required to perform a district-level risk and vulnerability analysis, together with suggested national authorities responsible for maintaining specific custodian data, or, in the absence of such data, open source data repositories where data can be sourced freely.

The first step of the risk analysis is to conduct a **road exposure and vulnerability assessment** by determining which districts are most at risk to climate threats, and in what condition the roads and structures in these districts are. This information can then be used to determine road exposure vulnerability, where roads and/or structures in poor condition located in districts exposed to severe climate threats are more at-risk.

Recommended actions

- Determine districts most affected by historical climate threats; e.g. aggregate the number of climate threat events per district by obtaining the longest records of threats possible. Where there is no data, informal sources could be used (e.g. newspaper reports, surveys of memorable events).
- Overlay road network condition data with districts most affected by climate threats.
- Map the results of the road exposure to identified threats (based on road network conditions (resilience) and exposure to climate threats).

Secondly, determine road criticality in terms of rural accessibility. At district level, a criticality assessment is used to evaluate the importance of rural access roads to the communities (districts) they serve (e.g. number of people a road serves and/or number of people without access). To allow the criticality assessment to have a region-specific focus, it is considered as an annex to the road asset vulnerability index. Road exposure and vulnerability are considered as one dimension in the criticality assessment, while other dimensions include road capacity and function.

Rural Access Index (RAI) was developed by the World Bank and measures the rural population who live within 2 km (20-25 minutes of walking time) from an access road as a proportion of the total rural population (Roberts *et al*., 2004). Some of the factors to be considered in a rural access index:

- Population distribution and density
- Road network density (coverage)
- Population within 2km of an access road

- Population without road access (in terms of both number of people and percentage of population)
- Availability of alternative routes.

Table 2 Suggested data required to perform a district-level risk and vulnerability analysis and possible data sources

Assessment components	Data type	Country-specific data sources	Open source data
Road network classification	Road network data (Street centre lines with attributes)	National road agency or authority National road asset management system	DIVA-GIS
Climate hazards assessment	Historical climate data (National scale)	National disaster management department National meteorological department	EM-DAT ERA-Interim CRUTEMP4v
	Climate-related hazards data (e.g. flood incidents data on district scale)	National disaster management department National meteorological department National environmental department	Dartmouth Flood Observatory
	Projected climate data (Fine spatial resolution, e.g. 8 km resolution)	National meteorological department	CORDEX Africa ACCESS1-0 CNRM-CM5
Socio-economic analysis	Current population data	National statistical office	WorldPop
	Hierarchy of settlements data	Surveyor-general's office	DIVA-GIS
	Projected population data	National statistical office	UN ESA
Supporting geographic data processing	District boundaries	Surveyor-general's office	DIVA-GIS
	Satellite images Vegetation cover Digital elevation Geology Soil classification	National space agency	Landsat (USGS EROS) ESRI images

Recommended actions

- Calculate rural access index and/or a remoteness indicator (see Section 3.2: **Risk and Vulnerability Guidelines**).
- Obtain a consolidated view of asset criticality per district by aggregating the road exposure and vulnerability index and the rural access index, and then map this.
- The importance of weighting in the aggregation step depends on the need to accommodate preferential information. Use a country-specific multi-criteria analysis as a tool to evaluate overall rural access road risk, given different views on the importance of the various components.
- Finally, map the results of the road criticality analysis and depict the most isolated districts.

Sub-sets of data should be aggregated to produce supplementary maps for determining the most vulnerable districts, and therefore road networks. Such maps should include the following:

- Most vulnerable districts under current climate and socio-economic conditions
- Future vulnerable districts under a changing climate and with a growing population

A full list of indicators that are relevant for an indicator-based vulnerability assessment is set out as Table 4 in Section 3.3: *Summary of proposed indicators* (**Risk and Vulnerability Guidelines**).

B.2 STAGE 2: Impact and Vulnerability Assessment (Project/Local Level)

B.2.1 Project-level climate risk screenings

During the design of new infrastructure, climatic impacts should be determined and included as part of the Environmental Impact Assessment or Strategic Environmental Assessment. These impacts should be considered in the design, as well as which data should be used to incorporate the necessary adaptation measures. This is particularly relevant to large structures, which would normally have a design life extending into the next century. The structural engineers must be aware of the specific future climate threats (more extreme events, higher temperatures, etc.) and consider these in the design.

Figure 8 Flood damage on approach to bridge and to bridge structure

For existing roads, however, during (or parallel with) the routine visual assessment of roads for input into Road Asset Management Systems (RAMS), it would be considered essential to include an assessment of the vulnerability of the road and associated structures (bridges, culverts, embankments, slopes, etc.) to variability and changes in the climate. Potential vulnerabilities and their mitigation would need to be identified. Guidelines for this have been prepared (**Visual Assessment Manual for Climate Vulnerability**) in conjunction with the existing visual assessment manuals for the Asset Management System so as to assist assessors with these decisions. Unlike the prioritisation process, the vulnerability assessment would be a more tactical operation. The climate sensitivity of all components of the road infrastructure needs to be identified in terms of damage and collapse during routine road condition assessments. To minimise the cost of acquiring data on the climate vulnerability of assets, vulnerability assessments should be carried out simultaneously with routine road condition assessments and all necessary data elements should be captured. Although this involves additional training of the assessors, it is possible that the work can be done simultaneously.

See Section 4.1: *The purpose of a local road vulnerability assessment* (**Risk and Vulnerability Guidelines**)
See Section 5.1: *Hazards, exposure and vulnerability* (**Engineering Guidelines**)

B.2.2 Climate-sensitive impact assessments

The purpose of conducting a local/project level road vulnerability assessment is to identify specific threats that currently affect a particular road segment and to assess how likely such threats would intensify or reduce in future. Particular threats include erosion of embankments, flooding of road surfaces, loss of road structure integrity, loss of pavement integrity, etc. (Falemo *et al.*, 2015). The intention is to use the outputs of the local assessment in the following ways:

- To inform engineering design decisions from the road segment level up to the catchment level of a road network
- To identify additional data that needs to be included in road asset management systems for monitoring climate and environmental risks
- To identify other factors that aggravate the effects of climate change on roads and that can be managed through changes in the practices of communities, industry and policy makers

The local assessment involves a five-phase process similar in concept to the district vulnerability assessment. The differences between the district and local assessment are in the detail of each step. The local assessment framework consists of the following phases, each with a number of actions:

Phase 1: Contextualisation of the local area
- Step 1.1: Collect and prepare local-level data

Phase 2: Climate-sensitive visual assessment
- Step 2.1: Capture data though fieldwork and community participatory mapping

Phase 3: Climate-sensitive road vulnerability analysis
- Step 3.1: Assess road condition deficiency
- Step 3.2 : Assess road maintenance
- Step 3.3: Assess road criticality
- Step 3.4: Calculate road vulnerability index

Phase 4: Embedment into road asset management system (RAMS)
- Step 4.1 : Export data to the RAMS
- Step 4.2: Communicate with stakeholders

Phase 5: Climate adaptation
- Adapt road according to prioritisation and climate-sensitive engineering designs (Refer to Change Management and Engineering Adaptation Guidelines)

See Section 4.3: *Methods for local assessment of road vulnerability to climate hazards* (**Risk and Vulnerability Guidelines**) for a full explanation.

The method proposed for local-level climate impact and vulnerability assessment relies on micro-level assessment data, in addition to data extracted from national and international spatial databases. The micro-level assessment in this case refers to the field (or road) surveys conducted periodically by local/district road engineers to report on road reserve conditions. In the case of climate adaptation, data on resilience aspects are also collected during the climate-sensitive visual assessment. This includes observations on environmental conditions outside of the road reserve, including topography, land cover and use, identifying pathways of surface runoff, extreme weather events or disaster incidences. The latter activity can be enhanced by employing **community participatory mapping** tools as techniques that consider local inhabitants as repositories of expert knowledge of the environment – all of which can be captured into a geographical framework.

The sub-regional or local road authorities and communities are therefore key stakeholders in a local-level climate risk and vulnerability assessment of roads. The involvement of communities in data collection is crucial. It is also crucial that they understand factors that render roads in their community vulnerable to climatic impacts.

General remarks

- If a district-level assessment was done prior to the local assessment, then GIS layers can be extracted on current and future hazards that were identified for that district. However, in a district-level assessment, some hazards that directly affect particular roads within a district are likely to be missed in country-specific departmental reports and databases (i.e. main sources). Therefore, hazards that affect that particular road environment (erosion of embankments, flooding of road surface, loss of road structure integrity, loss of pavement integrity, landslides, etc.) also need to be identified using data from district road authorities and local government departments.
- In the event that a district-level assessment was not conducted prior to the local assessment, then data for a particular district can be extracted from global, departmental and country-specific databases in addition to district-specific data sources.
- The impact of climate change on roads requires that vulnerable sections of the road infrastructure be identified and that engineering adaptations be made to minimise potential future climate-related damage. Consideration of climate impacts on the road requires a different kind of field assessment than the standard road condition assessment because environmental and socio-economic factors beyond the road reserve need to be considered.
- An example of a field assessment form that accommodates the entry of environmental data is the climate-sensitive visual assessment form, which is explained at length in the **Engineering Adaptation Guidelines** and in the **Visual Assessment Manual**.

B.2.3 Data gathering and vulnerability assessments

A range of data should be sourced to contextualise and give background to the local area where road engineers should carry out climate resilience visual assessments including climate threats data, environmental data, road network data and socio-economic data (see Phase 1: Contextualisation of local area under Section 4.3.2. Local-level risk and vulnerability analysis steps and guidelines of the **Risk and Vulnerability Guidelines**). This is done by identifying, sourcing and mapping data that would aid in contextualising the environment around the roads being assessed. A local climate-oriented assessment requires attribute data about the road segment being assessed and the surrounding environment (vegetation, soil and water catchment areas), including hazards that have affected and may continue to affect that particular road. Gathering data on the availability of alternative routes when the road is inaccessible and obtaining clarity about the use of the road by the community are also important.-Local road authorities and government departments would be the custodians of local spatial data on these categories. Additionally, data from the road/project site is vitally important in a local-level analysis. These should ideally be extracted from the RAMS. In the case that field assessment data is not warehoused in a RAMS as spatial data, there will be an additional step of digitising the data spatially.

Data from local sources are likely not to be in a GIS format; hence, appropriate steps should be taken to digitise the data in a GIS, or to map the data obtained from community participatory mapping exercises. In the local assessment, vulnerability to specific threats is considered separately, which is different to the district assessment where districts are given a single overall vulnerability score, based on the combination of all threats.

Assessments are made of rural road vulnerability to the following threats:

- Flooding of road surface
- Erosion of embankments and foundations
- Deformations
- Loss of pavement integrity (cracking and aggregate loss)
- Failure of drainage structures

The assessor using the climate resilience visual assessment form scores each item out of five (0 being not applicable; 1–2 being acceptable and 4–5 being areas of concern) for both degree and extent.

See the **Visual Assessment Manual** where the climate resilience visual assessment process is explained at length.

General remarks

At the local scale, the impacts of climate changes cannot be assessed in isolation. The environmental conditions need to be considered using environmental variables. The following parameters can be assessed to determine the greatest climate-related threats:

- Distance to the coast for coastal roads because of the risk posed by coastal erosion and by rising sea levels and wave heights exceeding particular thresholds
- The combination of precipitation intensity and slope for run-off and landslide risk in mountainous regions
- For the design of drainage infrastructure, the combination of watercourse maps, topography, previous flood extent, road infrastructure location and land cover (these are important considerations when assessing peak and moderate to heavy long-duration rainfall events)
- Profiles of past extreme temperature events and droughts in combination with soil and land-cover maps (these are useful in assessing erosion and loss of road surface structure or integrity as vulnerability factors)
- Changes to the onset as well as duration and intensity of rainy seasons as a threat to road maintenance and construction scheduling
- Deforestation and land-cover change in general for landslide risk
- Change in vegetation cover as a modifying factor in flooding

Data collected from visual assessments provide insights on sections of the road that may be vulnerable to climate effects as a result of, for instance, their design and/or their condition vis-à-vis the environment in which they operate (see Phase 2: Climate resilience visual assessment under Section 4.3.2. Local-level risk and vulnerability analysis steps and guidelines of the **Risk and Vulnerability Guidelines**). The visual assessment form itself can be used by the engineers to make decisions regarding areas that need urgent intervention. However, for decisions about roads that need to be prioritised for climate adaptation, a network-wide view is necessary. Therefore, it is essential that the data captured in these forms are stored in a RAMS for easy extraction when local road vulnerability assessments are performed.

Data analysis provides insights about sections of the road that are prone to different threats, such as waterlogging and flood inundation, erosion, landslides and loss of surface materials. Information on the variability of vulnerability to specific threats along the road helps in deciding where to implement specific engineering adaptation options and where changes need to be made to current practices to reduce the risk for damage in case of adverse climate events.

Using the field data from the climate resilience visual assessments, community participatory mapping and area contextualising maps, a road vulnerability index should be calculated. This is a composite value varying between 0 and 5, and consisting of the sum of weighted combinations of degree and extent of the vulnerable issues (road condition deficiency, road maintenance and road criticality).

An example of a scoring framework for computing the road vulnerability index (RVI) is set out in Section 4.3.2. Local-level risk and vulnerability analysis steps and guidelines under Phase 3: Road vulnerability analysis (**Risk and Vulnerability Guidelines**).

Remarks on road vulnerability analysis

- The outcome of the local climate vulnerability assessment is a multi-dimensional road vulnerability index (RVI), computed firstly per 100 m assessment segment and secondly for the entire road section, from node to node in the RAMS.
- The RVI integrates three composite indicators, namely an indicator of *Road Condition Deficiency* to the impacts of climate (the Di score), an indicator of *Maintenance Efficacy* (the Mn score), and an indicator of *Road Criticality* (the Cr score).

- *Road Condition Deficiency* is a composite indicator of climate-specific deficiencies in road condition and is an aggregation of specific vulnerability factors that represent the physical/structural insufficiency of the infrastructure to withstand negative climate impacts.
- *Road Maintenance* factor is an indicator of maintenance efficacy in terms of frequency (quantity) and quality of maintenance activities.
- *Road criticality* pertains to the importance of that particular road for access to markets and public facilities. On a local scale, a narrative about the community's use of a particular road is important to put into perspective the losses incurred by the community when access is interrupted due to climate events.

- For easy extraction and computation for substantial sections of the national road network, as is recommended for the mainstreaming of climate adaptation in the rural roads sector, the road vulnerability analysis should ideally be done in an object-orientated database such as a RAMS.

For a future vulnerability scenario at a local/project level, taking into account climate and population change, the RVI can be modified multiplicatively based on scenario modifications in the deficiency, maintenance and criticality scores. The scenario approach is preferable as one can account for uncertainty in population projections and therefore derive criticality scores corresponding to the different growth trajectories. Similarly, in the case of climate change, there is a choice of using outputs from an ensemble of climate simulation models and in that way incorporating the uncertainty associated with climate projections into the deficiency and maintenance indicators. It is recommended that scenarios for climate and population change be limited to three as this already results in nine permutations for the calculation of the RVI. It should be noted that if the upper and lower bounds of the uncertainty ranges for population and climate were used, this would yield a two-by-two matrix with no central scenario. Irrespective as to whether a three-by-three or a two-by-two matrix is used, decision-makers would most likely select the central or average result.

General remarks

- Data on expected future climate conditions is used to determine how the identified local-level hazards are likely to change under climate change scenarios.
- Assessment requires future climate information as input, which ideally should be the result of regional downscaling models from Global Climate Change models (the same data as used in the district-level assessment).
- The choice of the mid-term projection period (2021-2050) is based on practical terms for population and economic outlook and for the lifespan of roads, whereas a long-term projection period (2071-2100) could be used for the lifespan of major structures such as bridges. (See Table 7 in Section 3.2.2 of **Change Management Guidelines** for an indication of the expected useful lives of road assets.)

Using GIS makes the management of all the input and output data efficient, and also enables easier communication with stakeholders through maps. Data can furthermore be easily shared for further evaluation and applications.

The recommended way to incorporate climate change as a risk in a RAMS is to embed the data captured from the climate-sensitive visual assessment as well as from the local-level vulnerability assessments and indicators quantified into the RAMS of road authorities. In this way, climate change can be considered as a risk when using data from the RAMS for planning.

B.3 STAGE 3: Technical and Economic Evaluation of Options

B.3.1 Strategies and potential adaptation measures

The purpose of undertaking a climate vulnerability assessment is for the information generated from the exercise to inform the prioritisation of engineering and non-engineering adaptation options. These strategies and measures are meant to be exceptional and beyond the normal engineering solutions, but they could become the norm in future if climate effects were to affect road infrastructure on a more frequent basis.

Based on an understanding of expected and current climate change impacts and vulnerabilities, the project team can identify strategies for a wide range of adaptation options.

Examples of adaptation strategies are provided in Section 4.1: *Adaptation strategies* (**Engineering Guidelines**).

Adaptation strategies aim to reduce the **impacts** of specific types of climate effects by identifying and prioritising adaptation options such as the following:

- Protecting existing assets or relocating assets away from vulnerable areas to preserve functionality
- Retrofitting vulnerable facilities
- Improving overall catchment/stormwater drainage
- Constructing new facilities
- Adopting an *Inadequate Funding* scenario approach and diverting funds/efforts towards facilities with greater priority

In selecting an adaptation strategy one should take cognisance of the fact that climate change is not an exact science. Climate change modelling provide projections of possible futures, and not reliable inputs for road infrastructure engineering. Hence, decision-making frameworks should take this uncertainty into consideration, although it is highly likely that infrastructure will have to cope with a larger range of climate conditions than before. For these frameworks and adaptation strategies the following examples of approaches could be considered (Hallegatte, 2009)[12]:

- *No regret strategy* – strategies that will yield benefits even in the absence of climate change (examples of adaptation options: restrictive land-use planning; development of early warning systems, emergency response and evacuation schemes, supported by well-maintained weather monitoring networks; climate proofing of new infrastructure; storm/flood proof infrastructure)
- *Reversible strategies* – strategies that are reversible and flexible over irreversible choices with the aim so as to keep as low as possible the cost of being wrong about future climate change (examples of adaptation options: stage construction; easy-to-retrofit coastal protection; 'building back better' responsibly)
- *Safety margin strategies* – strategies that reduce vulnerability at null or low cost (example: doubling of conventional storm return periods for all new designs of drainage infrastructure or the rehabilitation/retrofitting of existing infrastructure)
- A *mix of above strategies*

In some cases, the best adaptation option(s) may be beyond the scope of an existing project or beyond the remit of the road authority. For example, realigning roads away from floodplains may be the most appropriate option in some situations, but may be difficult to address at the project stage and almost impossible to address where the facility already exists; lock-in of assets may be a significant issue. Other options may include protecting the road infrastructure at the expense of accessibility during flooding (i.e. locate infrastructure at ground level instead of on embankments – the latter posing a greater risk of getting damaged during flooding). Similarly, watershed reforestation may be the most appropriate option in some situations. These should be taken up as part of an upstream planning process and can be flagged for higher-level discussions.

The main objective when designing adaptation measures is to understand the geotechnical or structural problem and then to develop techniques to resist the expected threats. In most cases, this would consist only of good engineering, using well-understood and often conventional techniques.

[12] A distinction could also be made between incremental and transformational adaptations (see: Kates et al., 2012).

B.3.2 Stakeholder consultations

As noted in Step B.1.2, stakeholder communication and involvement should occur from the outset and should be ongoing throughout the assessment, design and implementation process. Also the identification of adaptation options would thus necessarily have to involve inputs from a number of stakeholders. Conducting roundtable consultations provides useful input for the process of identifying and appraising the whole range of adaptation options.

The sub-regional or local road authorities and communities are key stakeholders in a local-level climate risk and vulnerability assessment for roads. The involvement of communities in data collection is crucial. It is also crucial that the locals understand factors that render roads in their community vulnerable to climate. The benefit of increased community awareness includes road authorities' receiving early warning about emerging structural damage on the roads, reduction of climate impacts through the modification of land use practices and frequent clearing of debris and vegetation from culverts, bridges, etc. Local government representatives from the environmental, emergency and disaster management, agricultural and social development departments are important stakeholders in terms of the provision and uptake of information to ensure that additional data gathered from local assessments is integrated into national spatial data repositories. They are also well positioned to implement change management recommendations on factors that are not intrinsic to the road infrastructure, such as land use management (e.g. erosion prevention by reforestation/revegetation), community preparedness in case of loss of access, etc.).

Full stakeholder consultations are recommended, and particularly when *Inadequate Funding* scenario options are being considered, so as to look at consequences and mitigation strategies.

B.3.3 'Low-cost' strategy

Where an absence of adaptation policies, plans and programmes, and lack of funding create severe constraints to proper management of the road infrastructure, a strategy for a *'low-cost'* scenario should be developed. The term '*do nothing'* is often wrongly used to imply little or no designated budgets or funds to deal with adaptation relating to vulnerability threats, existing damage backlogs, or maintenance issues relating to road assets. The term is also wrongly used to signify that few actions can be undertaken. In a scenario of *'low-cost'*, proactive management strategies should still be developed to minimise disruption to rural access and socio-economic development.

Where relevant policies are absent or restricted, these should be developed or augmented to cover adaptation in its broadest sense and account for the *'low-cost'* scenario specifically.

The strategy should be directed at those areas or regions where there is evidence of adverse effects and where the vulnerability assessment has identified the greatest risks to assets, businesses and communities. The *'low-cost'* strategy should implement the following types of components to allow maximum active management of the network and help to communities and local economies:

- A community-based communication centre for awareness and preparedness training and for planning, inter-community logistics and mobilisation of relief actions in case of emergencies, among others
- Agreed emergency plans with police, emergency services and the military (the latter as a last resort)
- Preferred serviceability and accessibility criteria (this is the baseline against which all options can be gauged)
- Key focal points requiring normal and emergency access
- An early warning centre
- An emergency response centre/unit
- Collaboration within the structures of vulnerable communities to help maintain emergency access (e.g. rope or other temporary bridges to facilitate access of emergency supplies)
- Contingency plans to be developed at a readiness state for implementation in isolated communities
- Key A to B routes with active diversions: to be deployed as part of a communication campaign; temporary diversions to be developed and managed
- Routes closed for short/long periods and permanently: contingency plans to be developed.

Many of the activities listed above are generally described as enabling or low regret measures (e.g. Wilby and Keenan, 2012). Note also that some, like the early warning system, could be costly to implement; most imply labour costs. The strategy should be a balance between active and reactive management, involving all stakeholders and communities. It requires a **management plan, communication plan** and an **implementation plan** with associated actions and responsibilities. These plans should form the basis of a **cooperative communication and action campaign.** Modern smartphones permit almost immediate and detailed photographic indication of any problems following climatic impacts to be distributed from almost anywhere to those involved in implementing a rapid-response intervention[13].

Recommended actions

The actions that are necessary to maintain a safe and serviceable network should include the following:

- Develop a proactive strategy and programmes to identify where options can be applied in a strategic way.
- Develop contingency plans based on, inter alia, anticipate needs of communities when isolated.
- Ensure delineation of alternative routes.
- Address implications and consequences of *doing nothing* and have mitigation plans in place.

Full details and guidance are presented in Section 2.4: *Drivers for change* (**Change Management Guidelines**).

B.3.4 Socio-economic analysis of 'do something' and 'do nothing'

The goal of an economic analysis of adaptation options is to provide decision makers with information on expected costs and benefits of each technically feasible option identified, and to rank these options according to the net total benefit (measured in present value terms using a representative discount rate[14]) that each delivers. The options should then be compared with an equivalent *'do-nothing'* scenario in order to fully appreciate the implications. Once these two scenarios are defined, the benefit of the adaptation option is assessed as the difference in the quantified and monetarised impacts with and without the options in place.

When implementing a *'do-nothing'* strategy, several sub-scenarios should be developed and tested to determine which actions reduce the cost and benefits least.

Given the significant uncertainty associated with the predicted impacts of climate change, conducting a cost-benefit analysis of adaptation options requires paying particular attention to the treatment of risk and uncertainty.

Among others, at least the following should be considered (ADB, 2011):

- Some adaptation options may also deliver benefits (co-benefits) additional to the climate-proofing benefits (e.g. the reforestation of a hillside to protect the road from landslides may also deliver fruit crops). These positive additional benefits need to be considered and may affect the ranking of the adaptation options based on a net present value criterion.
- While all adaptation options should aim to 'climate proof' the transport infrastructure, some adaptation options may do so at the expense of other sectors of the economy. For example, a floodwater diversion option may keep the transport infrastructure functional but increase flooding in another area. These indirect costs, whether intentional or not, need to be accounted for.

[13] See also Douvinet et al. (2017)

[14] The choice of an economic discount rate is critical in determining the case for adaptation (for guidance see: Stakhiv, 2011). Typically, low discount rates (say 2-3%) should be used for long-life infrastructure (e.g. bridges) and higher discount rates (say 6-7%) for assets with a 10-15 year life expectancy (e.g. road surfacings).

- Vulnerability may change over the lifetime of the project. Benefits of adaptation may be considerably different if based purely on an assumption of existing population or land-use, and if ignoring that future population or land-use may change. These changes in vulnerability need to be explicitly accounted for in the cost-benefit analysis.

Accounting for risk and uncertainty is particularly acute in the context of climate change. ADB (2011) recommends the following two approaches:

Approach 1: Sensitivity analysis

For conducting a cost-benefit analysis of an adaptation option, this simple type of analysis involves changing the value of one or more variables at a time and re-computing the option's net present value for each change. This exercise may be repeated as many times as necessary. In sensitivity testing, switching values are often computed, where a switching value is the value of a specific variable that makes the net present value switch from positive to negative, or conversely.

The purpose of such sensitivity testing is to raise the level of confidence when recommending the adoption or rejection of an adaptation option.

A key advantage of sensitivity testing is that it is extremely easy to conduct, but has a number of severe limitations, including the following:

- Testing is highly subjective in that there is often no specific reason justifying the direction (smaller or larger) or the extent by which the value of a specific variable may be assumed to change.
- Testing does not take into account the probability that the value of any specific variable may differ from the value originally estimated. While sensitivity analysis allows computing a range of net present values within which the actual net present value of the adaptation option may fall, it does not allow computing the expected net present value of the adaptation option.

Approach 2: Probabilistic (or risk) analysis

Conducting a 'probabilistic cost-benefit analysis' involves attaching a probability distribution to the possible value of any given specific cost or benefit component of the project, instead of attaching a single deterministic value. Such probability distributions may be constructed using historical data.

Probabilistic (or risk) analysis allows selecting multiple variables that can all be varied simultaneously according to the specific probability distribution attached to each variable. This process, known as a Monte Carlo simulation analysis, involves randomly generating a specific value for each individual variable (cost component or benefit component) according to the specific probability distribution attached to each variable. For any given draw of specific values, the net present value of the adaptation option is calculated. This process is then repeated many thousands of times by means of computer.

The outcome of the analysis is a probability distribution of net present values. This probability distribution allows the computation of an 'expected' net present value of the option, instead of solely a given net present value or a range of net present values. The same probability distribution also allows computing the probability that the net present value of the adaptation option will be negative.

Conducting probabilistic (or risk) analysis can be demanding if performed manually. However, packaged software allows Monte Carlo simulation analyses to be completed relatively simply.

From an economic point of view, and by using a high discount rate for instance, not climate proofing a transport infrastructure may seemingly be the best course of action in certain circumstances. The outcome of the analysis of options, summarised as the net present value (NPV) of these options, should guide the nature of the recommendations. The *decision rule* guiding the selection of adaptations is similar to the decision rule for any investment project. If only one technically feasible adaptation option exists, then the *decision rule* is as follows:

- *If expected NPV > 0: Recommend implementing the adaptation option based on the outcome of the economic analysis.*
- *If expected NPV < 0: Recommend rejecting the adaptation option (do nothing) based on the outcome of the economic analysis.*

If more than one technically feasible adaptation option exists, then the *decision rule* is to select the option with the largest expected NPV. If all adaptation options yield a negative expected NPV, then the best option is to do nothing.

B.3.5 Prioritisation and selection of adaptation measures

The adaptation assessment results in a prioritised list of adaptation options for implementation, which are selected from among several possibilities or scenarios. Their prioritisation can be based on an assessment of their technical feasibility, their benefits and costs, their social acceptability, the opportunities they may offer for synergies with national priorities, and their co-benefits. While the use and outcome of a cost-benefit analysis is often given more weight in the prioritisation process, it is important to recognise that other factors and criteria may also influence decision making.

The expertise required is multidisciplinary and, as such, it is one of the more challenging aspects of adaptation planning. Roundtable discussions involving different stakeholders can work well and may include, for example, the project engineers, environmental specialists, social safeguards experts, nongovernment organisations, implementing entities, and national climate change representatives.

Where budgets are restricted, options should revolve around maintenance and emergency measures. Where budgets are absent, measures should pertain to community involvement and self-help.

Whichever climate adaptation measures are implemented, they are almost inevitably going to increase the cost of providing the majority of new roads or involve costs for the retro-fitting of such measures to existing infrastructure.

A World Bank study (Hughes et al., 2010) found that the cost of adapting to climate change, given the baseline level of infrastructure provision[15], is no more than 1 to 2% of the total cost of providing that infrastructure. However, being climate resilient may decrease costs over a longer period by preventing damage to and interruptions of the infrastructure, as well as improving social conditions. In general, the cost of adaptation is small in relation to other factors that could influence the future costs of the infrastructure.

Adaptation initially requires the prioritisation of needs. The process of prioritisation needs significant input from both road authorities and communities where different needs and priorities may prevail. This would typically require decisions of a strategic nature as discussed in Section A.4.2.2.

Generally, safety (loss of life) considerations should take precedence over the others. However, other than landslides, the safety implications of road failures are generally minimal. It should be borne in mind that roads being used for mobility (i.e. primary and secondary road network) generally attract a higher priority for investment than access roads (i.e. tertiary low-volume rural roads) to ensure that they are affected minimally by "shock" climatic effects, not only to sustain socio-economic activity, but also to facilitate emergency responses and close-by access to isolated communities. The latter, however, would depend on the density of the primary and secondary road networks.

For more information, see Section 4.2: *Methodology* **(Engineering Guidelines)**.

Based on an understanding of expected and current climate change impacts and vulnerabilities, a wide range of adaptation options can be identified. Once all adaptation options have been identified, consultations should take place, followed by economic analysis and prioritisation of options.

15 Note that the assumption seems to be on incremental rather than transformational costs of adaptation. Also refer to Kates et al. (2012).

Figure 9 **Example of adaptation measure to protect a drift/ford against flood damage**

B.4 STAGE 4: Project Design and Implementation

Current national design guides are probably sufficient for critical infrastructure if implemented properly (i.e. with allowances made for changes to storm return periods, for instance) and with provisions for *adequate drainage* facilities for extreme events[16]. The application of designs, however, needs a thorough understanding of the effects and impacts of climate issues on the roads and structures from both inside and outside its boundaries. An overriding problem affecting resilience is a *lack of appropriate and timely maintenance*.

B.4.1 Development of an implementation plan

The types of actions that can be taken to reduce vulnerability include avoiding, withstanding, and/or taking advantage of climate variability and impacts (cf. Hallegatte, 2009). Avoiding areas projected to have a higher risk of potentially significant climate impacts is an important factor in taking planning decisions, but it is often limited by other constraints (e.g. economic, environmental or social). If such locations cannot be avoided, steps need to be taken to ensure that the road infrastructure can withstand the projected changes. For example, the potential for increased flooding might be a reason to increase bridge elevations beyond what historic data might suggest.

Secondly, the result of adaptive action either decreases a system's vulnerability to changed conditions or increases its resilience to negative impacts. For example, increasing temperatures could cause bituminous pavements on the highway system to fail sooner than anticipated. Using different materials or different approaches that recognise this vulnerability should lead to pavements that will survive expected higher temperatures better.

With respect to resilience, operational improvements could be made to enhance detour routes around flood-prone areas. Another example of resiliency is well-designed emergency response plans that can increase resilience by quickly providing information and travel alternatives when roads are closed and by facilitating rapid restoration of damaged structures. This could often involve institutional changes that allow rapid procurement processes and reserves (stocks) of necessary resources and plants. By increasing system resilience, even though a particular facility might be disrupted, the road network as a whole should still functions.

The following are the primary engineering options:

- *Subsurface conditions* – The stability of any type of infrastructure depends on the materials on which it is built (subgrade). An important factor pertains to the degree of soil saturation, fluctuations in moisture content and the expected behaviour of the soil under saturated conditions.
- *Material specifications* – Materials of appropriate quality must be used in both unpaved and paved roads, and unsuitable materials may have to be replaced or enhanced to preserve the expected lifetime of the road or structure.

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[16] Note that some national authorities are incorporating climate change allowances in detailed engineering designs. See for instance Environment Agency (2016); ADB (2018) and UDGS (2013).

- *Cross-section and standard dimensions* – Standards may need to be revised, for example, to increase the crossfall of pavements in areas where one can expect a need to remove more water from the road. Similarly, standards (or guidelines) pertaining to road elevations or the vertical clearance of bridges may have to be revised upward.
- *Drainage and erosion* – Upgraded standard designs pertaining to drainage systems, open channels, pipes, culverts and surfacing options (e.g. for steep hill road sections) are needed to reflect changes in future expected runoff or water flow, and the consequential potential for damage caused by erosion.
- *Protective engineering structures* – These can be used to address rivers in flood, rising sea levels and storm surges. Structures may include drifts, dykes, seawalls, rocky aprons and breakwater systems.
- *Maintenance* – It is essential that all aspects of maintenance related to roads, drains, structures and vegetation control be diligently and timeously addressed. Most problems should be precluded by good maintenance.

The above are covered in more detail in Chapter 5 of the **Engineering Guidelines**.

Recommended actions

Developing an implementation plan would require the following:

- Reduce vulnerability by avoiding, reducing or taking advantage of impacts (Hallegatte, 2009).
- Take steps to ensure that the road infrastructure can withstand the projected changes.
- Enhance detour and emergency response plans.
- Follow primary engineering options as set out above.

B.4.1.1 Insufficient funds scenario

Often there is not enough funds budgeted to deal with all affected areas, roads and structures, or the consequences of climate change are simply too severe to justify comprehensive physical adaptation. In these circumstances, a planned programme of dialogue with affected communities, well-dispersed information and contingency programmes are necessary to minimise the adverse effects of these decisions.

Under these circumstances, a continuous programme of monitoring and evaluation is needed in those areas where no physical interventions take place, so that all unexpected circumstances can be dealt with, including emergency response.

This option is covered in more detail in Sections A.5.2: *'Low-cost' scenario* and in Section B.3.3: *'Low-cost' strategy* (**Climate Adaptation Handbook**).

B.4.1.2 Summary of adaptation methodology

Appropriate and economic methodologies for risk and vulnerability assessments, prioritisation of adaptation interventions, and optimisation of asset resilience in the context of low-volume rural access roads should be developed and reported. In addition, evidence of economic and social benefit links to rural communities arising from more resilient rural access is needed to support wider policy adoption across Africa. Assessment concentrates on future road scenarios for which climate projections are available.

The objectives are achieved through the following:

- Completion of climate vulnerability assessments and development of adaptation strategies
- A methodology for adaptation
- Provision of options to create resilience
- Provision of guidance for building adaptation strategies into roads policy, planning and standards
- Careful management of a *'do-nothing'* scenario

The following activities should be conducted/ developed:

- Produce country-specific climate maps containing all essential information to assist road engineers with design and implementation.
- Make an inventory of all road elements that should be considered when addressing climate change effects.
- Prioritise needs and options for adaptation strategies, including engineering and non-engineering options.
- Identify the potential hazards relating to the different expected climate stressors for all relevant facilities.
- Incorporate adequate drainage in timely and good maintenance practices, as it is of critical importance.

Typical adaptation strategies that are suggested include the following:

- Upgrade earth roads at least to the standard of engineered earth roads or gravel roads.
- Improve material selection, construction practices, and compaction and maintenance practices.
- Use innovative compaction techniques and water-reducing technologies.
- On paved roads, use appropriate designs and surfacing, including good drainage and maintenance.
- Apply the correct remedial procedures for problematic subgrades.
- Improve culvert and bridge designs and maintain them properly.
- Improve maintenance procedures and training, and consider community maintenance programmes.
- Upgrade gravel roads to paved standard where applicable.
- Stabilise slopes by applying vegetation, bio-engineering techniques.
- Use appropriate bituminous binders for surfaced roads (e.g. higher viscosity yet ageing-resistant binders for high road surface temperature environments).
- Enhance concrete mix designs and reinforcing.
- Apply precautionary measures against sand accumulation due to increased windiness.
- Use soaked subgrade designs for increased storm surges.
- Increase road level to a minimum of 0.5m-0.65m above normal groundwater level where possible and appropriate.
- Protect weaker subgrades with thicker pavements.
- Make use of sub-surface drainage systems, where appropriate.

Ideally, some of the above measures should be embedded in norms and standards so as to ensure that they are applied routinely.

Potential adaptation measures for each climate variable and engineering issue are presented in tabular format in Section 5.10 of the **Engineering Guidelines**.

B.4.2 Design parameters and optimisation

During the design of new projects, it is essential to identify as many appropriate adaptations as possible to improve the resilience of the project components to climatic effects, and to incorporate them in the design as economically possible. The importance of these adaptations would depend on the nature of the project components. For example:

- An unpaved road is expected to always be susceptible (to varying degrees) to the vagaries of climatic influences and should be designed with a relatively short-term vision, as periodic maintenance is frequent and can overcome most climate-related problems.
- Bridges, on the other hand, even associated with relatively minor roads, are designed to provide a much longer service and should incorporate as many adaptations as necessary to ensure their long-term serviceability.

It is difficult and expensive to retro-fit prematurely failed bridge components or to reconstruct bridges that have failed. Similarly, the bituminous surfacing of paved road structures is rejuvenated or overlaid regularly and can be ‘repaired’ during these interventions. The pavement structures and support layers must last the design life of the pavement and should thus incorporate as many adaptation measures as are necessary, as these are costly to repair later during the pavement operation.

It is more difficult to implement adaptation measures on existing roads. Although the potential problems and vulnerable areas are often identified during current inclement weather conditions, there is seldom funding available for the rectification of all (or often even some) such problems and for the effective implementation of resilience adaptations. However, it is important that as much resilience engineering as possible is implemented in the highest priority areas and that during any upgrading, reconstruction or rehabilitation, the remaining measures are implemented (i.e. 'build back better').

B.4.2.1 Design to improve resilience

Whilst engineering solutions to make a climate-resilient road are similar to those found in existing national design manuals, knowledge of appropriate hydrology (storm return periods, groundwater and water flows) is generally poor. There are many adaptations or specific design decisions that can increase the resilience of roads to climate change. Also, climate change allowances or safety margins in standards for detailed engineering design should be incorporated.

> A full description of these, along with design considerations, is set out in Section 5.3: *Roads* and in Section 5.4: *Subgrade soils* (**Engineering Guidelines)**.

Adaptations required for different road attributes explained in the **Engineering Guidelines**, along with respective *design considerations*, are classified as follows:

- **Roads**
  - Unpaved roads
    - Un-engineered earth roads
    - Engineered earth roads
    - Gravel roads
  - Paved roads
    - Thin bituminous surfacing
    - Asphalt surfacing
    - Concrete surfacing
    - Other non-bituminous surfacing
  - Earthworks
    - Cuttings
    - Embankments
    - Erosion
- **Subgrade soils**
  - Expansive clays
  - Dispersive/erodible/slaking materials
  - Saline soils
  - Soft clays
  - Wet areas/high water tables
  - Collapsible soils

B.4.2.2 Drainage

Water that falls directly onto the road carriageway, shoulders and embankment slopes and that ultimately flows into the side drains, requires particularly good control. The primary objective is to make sure that this water does not get into the pavement structure or subgrade – regardless of whether it is an unpaved or a paved road. Other requirements are the following:

- The water does not accumulate on the surface of unpaved roads (leading to softening and deformation).
- The water flows off paved roads so as to minimise the risk of skidding/aquaplaning.

- Movement of the water off the surface does not lead to erosion of the road surface (paved or unpaved) or the shoulders.
- The water actually gets into the side drains where it can be effectively removed from the road environment into mitre drains or culverts.

Scope for a climate change allowance in some of the design options, to contend with higher rainfall intensities and/or increased flood risk should be considered.

How to deal with water from within and from outside the road reserve is addressed in Sections 5.5 and 5.6: *Drainage* (**Engineering Guidelines)**. Design considerations for bridges and culverts are provided.

B.4.3 Construction, maintenance and supervision

During the predicted extended ***dry periods*** in some areas (when it is also ***hotter***), the availability of construction water may be limited for longer periods and longer haulage distances may be necessary. The cost of the water is then also expected to rise as construction competes with other uses, and the quality of available construction water is expected to deteriorate. Moreover, the water applied to the layers during these periods for compaction would be expected to evaporate much more quickly and greater quantities of water would be required.

During extended ***wet periods,*** *site* access can become difficult or even impossible, and compliance with specifications may not be practicable. Many countries cease both construction and maintenance during rainy seasons.

The main construction problem affecting the resilience of roads to extreme climatic conditions is the lack of compaction. Poor compaction within the formation/embankment materials, the shoulder materials or even the structural layers is usually manifested as rutting, undulations or excessive vertical deformation in affected areas. These conditions need to be identified, as the permeability of the materials in these areas would be expected to be significantly higher than well-compacted materials and the potential for premature failures due to water ingress is increased.

Maintenance techniques are unlikely to change significantly for adaptation needs: however, the frequency and types of maintenance may have to be increased to address changes in climate, especially extreme weather events. Maintenance is an essential part of preserving any road and should be judiciously carried out. As climatic conditions change, the need for more, and good quality, maintenance is going to become increasingly critical. During the assessments, issues that must be noted are the retention of shape of shoulders, cutting and clearing of vegetation, removal of termite nests and bushes on embankments (that are likely to induce turbulent flow of water over the embankment), cleaning and shaping of side- and mitre drains, and ensuring that culverts and drains are not blocked.

Further guidance is provided in Section 5.8: *Maintenance* (**Engineering Guidelines)**.

The importance of minimising the risk of wind-induced wild-fires that burn the vegetation and soil cover, thus allowing exposure of the soil to intense storms (more of which are expected) and consequent erosion, cannot be overemphasised. This is particularly relevant on embankment and cut slopes, around drainage structures and in areas where the soils are inherently susceptible to erosion. Increased damage to wooden structures and road furniture can also be expected if vegetation growth is not controlled.

It is furthermore essential to repair potholes regularly with a well-compacted, high-quality impermeable cold-mix asphalt and to seal all cracks in the road surface regularly.

B.5 STAGE 5: Monitoring and Evaluation

B.5.1 Development of a monitoring and evaluation plan

This is one of the most important aspects of climate adaptation. It is essential that the effectiveness and performance of any adaptation measures be fully monitored and evaluated. It is only in this way that shortcomings, problems and inefficiencies can be identified, and future modifications or alternative solutions can be implemented with the advantage of hindsight. This is easier done for roads and structures with short design lives, but is more problematic for larger structures with design lives of 50 or 100 years.

There is little experience worldwide of the actual level of effectiveness of the different options to reduce vulnerability to climate change, and this makes monitoring and evaluation all the more important to develop and improve knowledge. There are a number of challenges to doing so, including the long-term nature of actual climate change, the need to acquire appropriate baseline data and metrics for measuring vulnerability, and isolating vulnerability to climate change from other sources of pressure.

The development of outcome-level and output-level indicators to assess the impacts of adaptation investments is ongoing[17]. ADB (2011) identifies three levels of results monitoring, namely impacts, outcomes, and outputs.

Various issues can be monitored to identify the effectiveness of the adaptations:

- Reduction in delays: Number of days that the roads within the network are impassable or journey times are increased
- Cost implications: Changes in costs of maintaining and repairing the road network after climatic effects
- Social implications: Improved accessibility, mobility and economic development, either measured, observed or perceived by the local communities

Table 3 provides some examples of indicators at each level. Given the challenges related to measuring for impact (which may occur beyond the project life), output-level indicators may be the most robust.

Table 3 Typical indicators of results monitoring (adapted from ADB, 2011)

Indicator type	Indicator
Impacts (long-term effect)	▪ Increased robustness of infrastructure design and long-term investment development ▪ Increased resilience of vulnerable natural and managed systems, such as flood management
Outcomes (process indicators)	▪ Percentage reduction in road closures due to structural failure, landslides or flooding ▪ Percentage reduction in flooding where drainage capacity has been increased ▪ Number of sector and district-level plans that explicitly include climate considerations ▪ Improved rural access
Outputs	▪ Transport sector planning and documents include adaptation strategies ▪ Design and specification documents have in-built resilience measures ▪ Maintenance programmes routinely cover preventative measures ▪ Length of road constructed to withstand climate change impacts ▪ Area of environmental protection measures

[17] Note that there are many different ways of evaluating the efficacy of adaptations, See: Adger et al (2005); Moser and Boykoff (2013). There is also the matter of adapting institutions, See: Wilby and Vaughan (2011)

B.5.2 Report and share implementation experiences

An adequate adaptation strategy is likely to be composed of a number of activities, including *engineering measures* (e.g. incorporating design changes) and *non-engineering measures* (e.g. ecosystem resilience measures and early warning systems for disasters). Lessons from adaptation measures undertaken at a project level should inform policy makers about appropriate approaches at sector and/or national level.

There are several recommended ways of reporting and sharing experiences, such as the following:

- Briefing documents, for circulation and distribution
- Programme/Project reports
- Monitoring and evaluation reports; fact sheets
- Feedback reports to stakeholders, both at policy level and at donor level
- Published case studies and demonstrations
- Lectures, conferences and discussion forums
- Seminars, workshop and training events
- Capacity building programmes, including train-the-trainer programmes

4 Conclusion

The Climate Adaptation Handbook is an overarching document that provides information on climate adaptation procedures for rural road access. It offers instructions and guidance on methodologies to address climate risks and asset vulnerability so as to manage climate resilience in a responsible and systematic manner.

It provides relevant information on adaptive procedures for both new and existing rural road access. It covers a wide range of climatic, geomorphological and hydrological circumstances based on application in Mozambique, Ghana and Ethiopia, but is equally applicable to any country in Sub-Saharan Africa. Similarly, although produced for low-volume roads, most of the principles also apply to higher-volume roads, even though there will be differing priorities and design parameters to be considered for such roads.

The Handbook has been designed to provide succinct yet informative guidance and direction to readers. This was done intentionally. While the Handbook is the overarching document that outlines the basic principles, processes and steps required to address the challenges of weather variability and climate change, it is supported by three Guidelines and a Manual to empower practitioners/stakeholders with the necessary information, processes and guidance they will require. These four documents are:

1) *Change Management Guidelines:*
   These guidelines cover, inter alia, policy and planning, stakeholder and asset management, and recommendations for the formulation of strategies and programmes for improvement.

2) *Climate Risk and Vulnerability Assessment Guidelines:*
   These guidelines take users through the steps involved in conducting a risk and vulnerability assessment at national/district-level, as well as a local/project-level risk and vulnerability study when implementing new or maintaining/retrofitting existing infrastructure.

3) *Engineering Adaptation Guidelines:*
   These guidelines introduce primary climatic attributes and the potential effects of these, followed by the provision of recommended adaptation measures for each infrastructure component, also highlighting the critical importance of effective drainage provision and of timely and appropriate maintenance of road assets.

4) *Visual Assessment Manual*:
   The Manual supports Guidelines (2) and (3) above. It describes the nature and collection of data that normally does not form part of routine condition data collection for asset management purposes. This includes issues such as erosion; problem soils; drainage from the road and its near environment as well as from outside the road reserve; instability of embankments and cuttings; construction issues as well as maintenance problems.

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