

Making Africa's Roads More Resilient to Climate Change

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Abstract—The inevitable impacts of climate change on the already stressed low volume rural road networks in Africa will have dire consequences in many countries. These networks generally suffer from a lack of appropriate construction standards and maintenance and are particularly prone to damage by the vagaries of the climate. As these changes in climatic conditions increase, the impacts on road networks will become more severe.

An assessment of these impacts related to various climatic stressors has indicated a wide range of adaptation measures to improve climate resilience. However, it is essential that the road networks are assessed adequately to identify vulnerable areas and the necessary adaptation techniques. This will involve the visual assessment of all roads within each network by assessors trained to identify specific conditions and consequences. Many of these are geomorphological issues such as run-off, erosion, slope instability and material degradation. In addition, subgrade conditions (materials and moisture) need to be determined.

The paper describes the main stressors and impacts on various components of the infrastructure and identifies the properties that need assessment and how this should be carried out.

Keywords—roads, infrastructure, climate change, vulnerability assessment

I. INTRODUCTION

Although there may be different theories related to it, there is no doubt that the earth's climate is changing. This is likely to have several significant effects on the road infrastructure of most countries, but particularly on the low volume rural road network in sub-Saharan Africa, where the roads are particularly vulnerable. These roads are often constructed to lower standards using local materials and labour and are thus more susceptible to climate damage than higher trafficked roads. It has been estimated that the African continent may be facing a potential liability in excess of USD 150 billion to repair and maintain existing roads damaged from temperature and precipitation changes directly related to predicted climate change through 2100 [1].

To reduce this impact, new roads must be designed incorporating the necessary climate adaptation measures but it will be neither practical nor economical to make every existing road fully resilient to climatic effects. Thus, it is important to identify those roads and section of road that are not resilient and prioritise them for adaptation measures. The priority would be based on the road classification and purpose, the number of people affected and the availability of alternative routes. To implement the necessary adaptations to make roads more climate resilient and assist with the prioritisation, it is necessary to carry out visual assessments (in addition to the conventional routine assessments for pavement management purposes) of existing roads with particular attention being paid to those problems related to changing climatic conditions.

This paper summarises the important potential climate-related problems and methods of assessing their impact, with pointers that can assist with the observations and interpretation of visual assessments. It is based partly on a Visual Assessment Manual being developed to guide and assist assessors [2], which includes more detailed information.

II. CLIMATIC FACTORS

The following main climatic factors may affect different parts of any country in future:

- Increased or decreased average temperatures
- Increase or decrease in number of very hot days (> 35°C)
- Increased or decreased annual precipitation
- Increase or decrease in number of extreme events
- Increased windiness

It is important before carrying out the vulnerability assessment of a road to identify the expected climatic changes along the road (or in the general area and associated drainage basin) and be particularly aware of the consequences of these expected changes over the design life of the facilities along the road (paved or unpaved road surface, earthworks and small and large structures). General indications of future climate changes in the area are available on the internet but greater detail specifically related to the area required should be available through national and district government

departments/offices (e.g. meteorology, agriculture, disaster management offices).

III. DATA TO BE COLLECTED

For the design of climate resilient roads, various issues need to be assessed. These include:

- Erosion potential
- Subgrade material problems
- Drainage efficiency in the road reserve
- Drainage from outside the road reserve
- Slope stability
- Construction quality
- Maintenance effectiveness

Other indications of possible problems may be observed on certain sites, such as the accumulation of sand and debris (due to wind and flooding), excessive vegetation caused by increased rainfall and high temperatures, leading to sight-distance and passability problems, etc.

A degree and an extent rating should be determined for each attribute assessed. These will be determined on a 5-point

scale where they exist as discussed below (0 is entered if there is no evidence of the distress). A typical input would be 3/2 for a degree 3 and extent 2 problem. It should be noted that the majority of vulnerabilities will be related to changes in precipitation, but issues such as temperature changes, increased windiness, etc. should be borne in mind during the field assessments.

A. Degree

The degree of a particular type of distress is a measure of its severity and the urgency of adaptation measures being incorporated. Since the degree of distress can vary over the section assessed (usually 100 m intervals), the degree must be recorded in conjunction with the extent of the occurrence for most parameters; this will provide the best average assessment of the seriousness of a particular type of distress.

The general descriptions of degree of each type of distress are presented in Table I.

B. Extent

The extent of any distress is a measure of how widespread the distress is over the length of the road segment. This is summarised in Table II.

TABLE I: GENERAL DESCRIPTION OF DEGREE CLASSIFICATION (Adapted from [3])

Degree	Severity	Description*
0	-	No potential vulnerabilities visible.
1	Slight	Only the first signs of distress are visible but these are difficult to discern. No vulnerability. No adaptation measures necessary.
2	Slight to warning	Distress obvious but not at degree 3
3	Warning	Start of secondary defects. (Vulnerability notable with respect to possible consequences). Regular inspection should be carried out and adaptation in the medium to long-term may be necessary.
4	Warning to severe	Secondary defects clearly visible but not at degree 5 yet.
5	Severe	Secondary defects are well developed (high degree of secondary defects) and/or extreme vulnerability. Adaptation measures should be implemented immediately.

TABLE II: GENERAL DESCRIPTION OF EXTENT CLASSIFICATION (Adapted from [3])

Extent	Description	Percentage of length*
1	Isolated occurrence - Not representative of the section being evaluated	< 5
2	Occurs over parts of the section length - more than isolated	5 – 10
3	Intermittent (scattered) occurrence over most of the section length (general), or Extensive occurrence over a limited portion of the section length	10 - 25
4	More frequent occurrence over a major portion of the section length.	25 - 50
5	Extensive occurrence over the entire section.	> 50

* The percentage of extent is only a guideline for the assessors and should not be literally interpreted.

The individual descriptors of the potential climatic effects on the roads are best obtained based on experience, but several indicators can be used to assist with early identification of potential problems. These are discussed below relevant to each of the potential problems listed in Section III. It should be borne in mind that, although assessments are best done during or shortly after wet weather, they will often be carried out in the dry season and many of the tell-tale signs may not be present or clearly visible at the time of the assessment.

IV. ASSESSMENT PROCEDURE

The assessor will move along the road (preferably walking but in a slow-moving vehicle if necessary) and assess the features identified in the forgoing text at relevant points along the road. Typically, the data sheet (Appendix A) will be completed after every 100 m (measured with a measuring wheel) with locations of any problems highlighted in the problem row. This differs from routine visual condition assessment for Asset Management purposes, which is generally done from a moving vehicle (up to 80 km/h) over a full road link (3 to 5 km) with occasional stops. However, vulnerability assessments will only be a once-off exercise for each road. The assessment of climate resilience requires experience and knowing “what to look for” as described previously and will usually be carried out by different teams. The team for the vulnerability assessment must be trained to look specifically for geomorphological and soil properties.

It must be remembered that the information obtained pertains only to the observations at the time that they are made and it needs to be carefully interpreted to identify potential longer term or more severe problems. Recent maintenance (prior to the visual assessment exercise) may affect the observations by masking potential problems and must be considered, bearing in mind that the objective is to identify areas where immediate or short-term adaptation measures are necessary to improve the climate resilience of the road. Similarly, a lack of maintenance or overgrown vegetation may make the observation of certain features difficult. The evidence of potential problems is also different during different seasons and climatic cycles.

The data should be recorded directly onto the field sheets (Appendix A) in the field for later use. The data can then be shaded in the spreadsheet, with for instance no colour for 0, green for ratings of 1 and 2, orange for 3 and red for 4 and 5. Concentrations of red on the sheet indicate areas needing urgent attention, while orange indicates areas of warning that should be considered after the severe problems have been rectified with appropriate adaptation measures and are expected to be potentially problematic in the medium to long-term.

V. ASSESSMENT CRITERIA

A. Erosion potential

Erosion of the road surface, embankment slopes and side drains results in significant problems, not only aesthetic and environmental, but more importantly in the road management context, leading to excessive maintenance requirements (both road surface and drains) and potentially to complete failure of the infrastructure facility. Surface damage caused by erosion

leads to concentrations of water, excessive loss of material as silt and increased water flow velocities. Uncontrolled erosion of the road support layers can eventually lead to collapse of the pavement or structure.

During assessment of the erosion potential of various components of the road and associated structures, the following need to be identified:

- Is the soil material making up the subgrade and areas adjacent to the road obviously susceptible to erosion? Typically, single sized materials, fine sands and silts and non-cohesive materials are most prone to erosion. Poor compaction of constructed materials also encourages erosion.
- Does the road surface (carriageway and shoulders) show any evidence of scouring or precipitation-related material loss?
- Are the side and mitre drains smooth and even or has erosion affected their shape and effectiveness?
- Are there any run-off channels or signs of erosion damage on embankment or cutting slopes?

Any significant positive responses to these questions will require some action to be taken to ensure climate resilience of the road as these areas will lead to concentration of water and accelerated erosion. Most of the adaptation/control techniques are relatively inexpensive, and include reshaping and grading of drains and surfaces, bio-engineering techniques, erosion control and protection measures, etc.

Any indication of channelling and material loss on the road surface or the shoulders must be noted. The intensity of the erosion should be described with an indication of the cause, i.e. poor compaction, long slopes, transverse or longitudinal, etc. This information should be sufficient to identify the expected remedial measures. Similarly, erosion of the side drains is usually evident as exposed soil, deep channels and poor flow characteristics. The potential erodibility of the soil, causes of erosion (high water velocities, inadequate drain capacity, steep slopes, etc.) should be noted together with the associated deposition (of the eroded material) locations and problems.

General descriptions of degrees of the various types of erosion are shown in Table III.

TABLE III. TYPICAL DESCRIPTION OF EROSION

Degree	Description
1	Evidence of localised and minor material loss due to water flows
3	Obvious surface erosion and channelling of water – regular inspection necessary
5	Severe loss of material and formation of deep erosion gullies – requires urgent adaptation measures to avoid sever failures

In the manual for assessors, each criterion is provided with a more detailed description than that shown in Table III as

well as examples of the different degrees of the possible distresses as shown in Fig. 1.

	1				
	X	2	3	4	5
	Minor evidence of erosion/material loss in drains due to water flow				
	3				
	1	2	X	4	5
	Erosion of drains requiring periodic maintenance and reshaping to restore flow - still functional but will deteriorate under increased water flows				
	5				
	1	2	3	4	X
	Severe loss of material and deformation of drains - dangerous to traffic and causing severe siltation "down-stream" - needs urgent attention and adaptation measures				

Fig. 1. Example of definitions of erosion of side and mitre drains [3]

The erosion of embankment and cut faces is manifested as channels that allow uncontrolled water to flow down the slope, usually with erosion and or siltation in the drains at the base of the slope or at the base of the slope where no drains exist. The need for water-chutes originating from a surface cut-off drain at the crest of the slope in these areas should be assessed to minimise the problems.

B. Subgrade problems

1) Materials

Changes in precipitation and/or temperature over time will result in larger moisture fluctuations in subgrade materials. Most problematic soils such as expansive clays, dispersive clays, collapsible sands, saline materials, etc. will be affected

by both wetting up of subgrades due to increased precipitation or more extreme events and drying out of the soils caused by longer dry periods, increased temperatures and windiness (e.g. drought conditions).

During the assessment of climate resilience, particular note should be made of the presence of such materials, as further described below. Cognisance should also be taken of areas where the pavement structure is deteriorating due to subgrade conditions, particularly weak materials. This is usually associated with localised drainage problems and the distress would normally be recorded during the routine visual assessment for Asset Management.

The assessor should look at the exposed soil adjacent to the road and in the side drains for evidence of expansive, collapsible, saline, dispersive or slaking materials. Some of these materials are often associated with other problems such as erosion (collapsible soils).

The following issues should be checked for:

a) Expansive soil

Usually black, dark grey or red. Shows distinctive cracking with wide, open cracks. May be masked by vegetation and so one needs to look for open exposed areas. If no cracks are observed the material will be identified as non-expansive. If wide cracks are observed, the material should be identified as highly expansive. These materials also tend to slake (disintegrate to clay) when placed in water.

b) Collapsible soils

Collapsible soils are difficult to identify in the field without very close inspection. These soils consist of individual particles of hard sands that are supported by clay, iron or calcite “bridges” and often contain obvious voids (pinholes). When these materials are loaded under wet conditions, the “bridges” collapse and the material decreases in volume, usually manifested as distinctive rutting in the wheel tracks. Most collapsible soils consist of highly weathered granites or sandstones, or transported sandy soils, although various other materials may have a collapsible structure. In the field, it is thus important to identify the type of material and look for signs of collapse on similar materials in the area.

c) Saline soils

Saline soils contain salts that may or may not be deleterious, but those containing specifically sulphides often present problems, should the salt be in sufficient quantity. Salts are usually observed as deposits or encrustations on the surface after water has evaporated, particularly at the edges of bituminous surfacings and on embankment slopes when the salts are incorporated into the materials or construction water. Particular care should be observed in areas close to oceans or saline lagoons and where materials have been obtained from evaporation pans and enclosed water areas (i.e. where the water does not drain away from the water body). In marine areas, sea water may have been used for compaction and this could introduce high salt contents. Saline ground-water can also cause problems and discussions with local residents and pastoralists will usually indicate the quality of local ground waters.

Saline materials are often difficult to identify, but past experience in the area is useful. Staining of local structures often indicates the presence of sulphides. Many salt deposits can be identified by licking them lightly and tasting for salts.

d) Dispersive soils

Dispersive materials can cause severe problems as fine clays are leached out of embankments and subgrade areas leading to the formation of tunnels and “pipes” which then collapse. Dispersive soils in the area are usually indicated by what appear to be highly eroded areas, but specifically with the presence of the pipes and tunnels. Such soils are best identified as potential problems by placing small clods of the soil in pure (drinking) water and checking the state of the clay suspension after 24 hours. The clods may stay intact or slake, but dispersive clays go into suspension and do not settle out.

e) Other potentially problematic soils

Such materials include dolomites or other soluble materials that could be indicative of karst (sinkhole) problems, soft clays or waste materials, particularly old landfills, industrial waste or mine dumps. Evidence of these should be noted in the Comments area of the assessment form.

2) Moisture

The second potential subgrade problem is the presence of excessive moisture in the subgrade, resulting from the presence of localised natural water and not specifically drainage problems that can be rectified by good control of periodic water. If there is excessive moisture present due to springs, high water tables or marshy areas, this should be recorded as well as the cause of the moisture. During the wet season, it is usually plainly obvious if the subgrade materials are affected by high moisture conditions. However, if the assessment is being carried out in the dry season indicators such as reeds, dry marshy areas, evidence of aquatic animals, etc. adjacent to the road indicate potential water problems.

This issue is of particular importance in terms of climate change as moist areas are expected to change significantly with time, either by drying out with concomitant shrinkage and cracking or by becoming wetter for longer periods. Both of these scenarios will result in significant impacts on the overlying road.

C. Drainage (in road reserve)

The main objective of this rating is to identify whether water moves away from the surface and sides of the road effectively. In this respect, a number of issues need to be assessed, as described below.

It is essential that water is removed from the road surface and close vicinity into suitable side and mitre drains as quickly and effectively as possible. During the assessment, this efficiency needs to be estimated with respect to whether precipitation remains on the road long-enough to cause potential structural damage to the road. Many of these problems are related to poor road shape/profile exhibited by ruts, potholes and depressions on paved roads and lack of camber on unpaved roads. These problems are often caused by a lack of (or just poor) maintenance and this should be noted under the maintenance category during assessment. However,

where the problem is one of design or construction this should be highlighted for rectification.

The removal of water across the road for drainage purposes must be assessed in this category. This should include issues such as the adequacy of culvert numbers and apertures, their effectiveness and indications of silting, recording of damage to the pipes and head- and wing-walls, and whether they are in the correct locations.

Ponding of water adjacent to the road, whether unpaved or paved, can result in localised pavement failures and such areas should be noted. Similarly, shoulders that are higher than the edge of paved road surfaces will cause water to be retained on the road surface, leading to saturation of the vulnerable outer wheel track areas. Shoulders should be well compacted and graded to shed water into the side drains. Depressions in the shoulders and particularly adjacent to the surfacing on paved roads must be recorded. Any side slopes away from the shoulders must be free of excessive vegetation and lead to the side-drains.

The presence of accumulations of fine silty/clayey material in drains is also indicative of poor maintenance or drain design.

Side drains should be at least 3 m from the road and at least 250 mm (dry areas) and 350 mm (wet areas) below the top of the formation and 650 to 750 mm below the crown of the road. They must be shaped to ensure that water flows freely in them towards nearby mitre drains or culverts. Vegetation growth should not be such that flow of water is impeded or sufficient to cause ponding. Signs of surface silt and clay deposits (often with associated drying cracking) usually indicate that water has ponded in these areas.

Mitre drains should conduct the water collected in the side-drains sufficiently distant from the road so that there will be no ponding that will affect the road. These should be open and lead into stream courses or open fields where the water can drain away.

It is often necessary to construct culverts to convey the water collected from the road across the road to avoid damage to the road and ensure that the water is moved away from the road. The effectiveness of these needs to be ascertained – this should include both their positioning with respect to the lowest point in the road as well as their grade and surroundings, to ensure that water is not permitted to accumulate near the pavement structure. This is normally plain to see, but the presence of silt and clay deposits with associated drying cracking should be looked for when assessing the road in the dry season.

It is often seen that the low points in roads move laterally along the road with time (particularly related to flooding and sedimentation) and culverts are no longer in the correct places. This should be noted where observed.

Any damage to structures and/or their associated erosion protection works resulting for flooding or overtopping should be noted.

1) Road shape

The shape of the road will dictate whether water is removed rapidly from the road surface. This is more critical for unpaved roads where retained surface water softens the wearing course material and results in deformation of the road surface.

For paved roads potholes, ruts and deformation will result in water ponding on the surface. However, provided the bituminous surfacing remains intact (i.e. no cracks or potholes) and the depressions are not too deep (< 25 mm), water will usually not be retained long enough to cause any severe distress.

2) Shoulders

The assessment should indicate whether the shoulders are shaped to remove water from the road surface towards the side slopes and side-drains.

3) Side slopes

The side-slopes in this case are normal formation (up to 0.75 m high) and not embankments constructed to raise the road, provide for culverts, etc. Poor side slopes will usually result in erosion and undercutting of the shoulders, or even the road structure, if not repaired properly.

4) Side drains

Erosion of side drains is covered in Section V.A above. Their effectiveness in removing water rapidly and effectively from the side of the road is assessed under this criterion. However, severely eroded drains will usually rate poorly as their effectiveness will be compromised.

5) Mitre drains

Sufficient mitre drains should be constructed to remove water from the side drains to avoid accumulation of water or excessive water velocities such that erosion becomes a problem. The mitre drains should also be sufficiently long to remove water such that it is far enough from the road not to affect the road structure.

D. Drainage from outside the road reserve (streams)

This section describes the drainage of water collected outside the road reserve in larger catchment areas, which has to cross the road through bridges or large culverts. Good observation of the bridge or culvert structure should be carried out to determine high water levels, whether any damage has been done to the structure by water, the presence of any damage to wing-walls, erosion protection measures, erosion of the river bank near the structure or the presence of any debris reducing the capacity of the bridge. During the dry season, the foundations of the abutments and piers may be visible and can be inspected for scouring or damage. Parts of the structure such as drainage pipes, bearings and expansion joint seals should also be inspected for wear or damage, although this would normally be done during assessments for Bridge Management Systems (BMS).

Although the precipitation in most areas of sub-Saharan Africa, and especially southern Africa, is expected to decrease over time, the likelihood of more frequent and more severe

extreme events will be higher. This is expected to increase water flows in valleys requiring greater capacity of the culverts and bridges to handle the increased flows without being damaged.

Approach embankments and fills around the abutments should be inspected for any settlement, erosion, undermining or likely saturation.

E. Slope stability

It is important to ensure that cuts and embankments are stable enough to resist changes in precipitation, particularly under extreme events. This involves a close inspection for any signs of instability. Cut slopes should be inspected for any signs of movement behind the slope (tension cracks or subsidence) or at the toe of the slope (bulging or deformation of side-drains). Signs such as movement of trees or fences, minor cracking, seepage of water from out of the slope, etc. are all indicative of potential instability. Signs of instability in embankments are usually seen as the presence of arcuate cracks in the shoulders or road surface, unusual settlement of parts of the fill, bulging at the base of the fill and periodic seepage of water from beneath the fill. Most properly designed and constructed fills fail through a lack of shear resistance in the subgrade materials, particularly when these are in a saturated or excessively moist condition.

Unlike cuts, there is usually evidence of arcuate cracking on the surface of embankments prior to failure and evidence of such cracking should be investigated. Many high embankments develop one or two longitudinal cracks which are indicative of tensile strains in the upper portion of the fill, but provided that they are sealed will not usually lead to failure. Any significant surface deformations or bulging of the toes of embankments are also indicative of potential stability problems.

F. Construction

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 will be significantly higher than well-compacted materials, and the potential for premature failures due to water ingress is increased.

The overall finish of a road is usually a good indication of the quality of construction and can be used to decide if the construction quality is likely to lead to problems. A paved road that looks well-finished is usually an indication that the contractor was diligent and careful. This issue is particularly relevant to new paved roads as most deficiencies in older roads would have been manifested during their service life. It is difficult to “visually” assess the compaction in paved roads, but a hollow sound when knocked with a hammer usually indicates poor compaction of the underlying layer, although a weak bond between the base and the surfacing will often produce a similar sound.

Construction problems in unpaved roads are usually more easily observed as the wearing course is typically the most sensitive layer and exposure will highlight any deficiencies. Poorly compacted unpaved roads, which are highly susceptible to surface erosion, can usually be identified by being able to easily “scratch” the material at the surface – it should be checked that this “loose” material is not the result of recent deposited material introduced by grader blading.

In addition, existing erosion protection measures must be continuous and intact and be able to perform as intended. i.e. protect the underlying soil from erosion, without being deformed, cracked or disintegrated. New erosion protection measures should be assessed to ensure that they are intact, integral and do not allow water to enter behind or through them. This is normally a simple visual inspection, although the presence of “anchoring beams” may be difficult to observe in some areas.

G. Maintenance

Maintenance is an essential art of preserving any road and should be judiciously carried out. As climatic conditions change, the need for additional and good quality maintenance is going to become increasingly critical. During the assessments issues such as 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 moving over the embankment), cleaning and shaping of side- and mitre drains and ensuring that culverts and drains are not blocked must be noted.

The importance of minimising the risk of wind-induced wild-fires that burn the vegetation and soil cover, allowing exposure of the soil to intense storms (more of these 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.

It is also essential that potholes are repaired regularly with a well-compacted, high-quality impermeable material (e.g. cold-mix asphalt) and all cracks in the road surface are regularly sealed, to avoid the movement of water into the pavement structure.

In assessing the quality of road maintenance, the shape and evenness of the road surface must be analysed. Any depressions will result in the ponding of water, and if unsealed cracking is present, this will lead to permeation into the pavement and weakening of materials. Excessive vegetation on the shoulders and in side drains interferes with water flow and should not be permitted. This excessive vegetation can also have an impact on fire hazard (expected to increase with longer dry seasons and increased windiness), which should be minimised to reduce soil erosion potential.

Effective drain maintenance is essential and the quality and effectiveness of this must be assessed.

H. Comments

There are many other issues that may need taking note of and these will usually be identified as the assessment takes place. A typical example of one of these is the presence of ants

in the road area. Fig. 2 shows ant “holes” that will allow water to penetrate into the embankment (there is usually an extensive network of tunnels beneath such an area) and these should be taken care of.



Fig. 2. Example of ant holes undermining the structural integrity of an embankment

VI. PRIORITISATION AND ADAPTATION MEASURES

Once the vulnerabilities have been identified, it is necessary to prioritise and identify the roads that should be addressed first and to implement the appropriate adaptation measures. The prioritisation will depend on various factors as discussed earlier in the paper, but will generally relate to minimising the potential for loss of life, minimising severance of communities and allowing disruptions that affect the minimum number of people, all at the lowest cost to the road authority.

Most adaptation measures can best be described as good and appropriate engineering solutions and in most cases will make use of existing technologies. However, as the majority of rural roads are low volume, more recourse will need to be made to innovative low-cost solutions wherever possible. Engineering adaptations are not addressed in this paper, but have been discussed in a separate document [4].

VII. CONCLUSIONS

In order to minimise disruption to the transport infrastructure in sub-Saharan Africa resulting from future climate change, it is essential that appropriate adaptation measures are incorporated in new infrastructure and installed in existing infrastructure that will still be required to provide the requisite service in the short to medium term. Due to the large length of rural access roads, the latter will require prioritisation of those most in need of adaptation.

In order to carry this out on an equitable and unbiased basis, a standard method of assessing the vulnerabilities of the roads is necessary. This paper describes the technique for carrying out this assessment, which requires a strong geotechnical/ geomorphological input.

The various factors affecting vulnerability of roads to climate change are described and basic indicators of the assessment process and observations are described.

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