Design and Construction of Sustainable Climate Resilient Rural Access Road Infrastructures

Julius Joseph Komba, Raquel Langa, Phil Paige-Green, Benoit Verhaeghe and Refiloe Mokoena

1.0 Introduction

One of the focuses of the Research for Community Access Partnership (ReCAP) climate vulnerability project was to identify, characterise and demonstrate the appropriate engineering and non-engineering adaptation procedures that may be implemented to strengthen the resilience of rural roads. As part of the project, a 50 km gravel (unpaved) road between Mohambe and Maqueze in the Gaza province of Mozambique was identified for the construction of demonstration sections. The selected road links to a small village that has not more than 2,000 inhabitants that have been isolated during the rainy season. The road is located along the edge of various natural lakes making it more vulnerable to the increased flooding frequently experienced in Mozambique. The road was estimated to carry about 25 vehicles per day on average, with very few heavy vehicles – approximately Traffic Loading Class (TLC) 0.03 (Paige-Green et al., 2019). However, after the completion of the construction works, a significant increase of vehicles was observed.

The road also forms part of a climate adaptation programme funded by the World Bank. Significant damage was done to this road during the 2013 flooding and six concrete fords (under emergency repairs) were installed to improve passability in 2014 and various short sections were spot re-gravelled with a blend of sand and Calcrete material. However, these interventions did not yield positive outcomes, necessitating a comprehensive road assessment to identify problems and design and construct alternative sustainable adaptation measures.

This chapter covers the road assessment, the design of sustainable climate adaptation solutions and the construction of four demonstration sections aimed at demonstrating different sustainable adaptation measures to address climate change-related problems that are causing undercutting of concrete fords/crossings, damage to the road approaching concrete fords, damage to culverts and erosion, and damages to a gravel road. The long-term performance of the demonstration sections is planned to be monitored over time. The outcomes of the monitoring programme are expected to inform on the appropriate adaptation procedures for wider implementation in Mozambique, and possibly elsewhere.

The chapter is organized and structured as follows; this introduction section is followed by an overview of climate change-related challenges affecting Mozambique. The study methodology (approach) is then described, followed by a discussion of findings and quality control test results. This is followed by a brief discussion of the preliminary performance of completed construction works. Conclusions and way forward a presented at the end of the chapter.

2.0 Climate Change Related Challenges Affecting Mozambique

The African continent is one of the most vulnerable regions that the impacts of climate change is much

felt. Like other African countries, Mozambique is facing a challenge of repair and maintaining roads damaged from the effect of climate change (i.e., floods, storms, and cyclones).

Climate change associated road damages have direct socio-economic impacts, particularly to the rural community. To help address this significant threat to Africa's development, the Research for Community Access Partnership (ReCAP), a research programme funded by UKAid, commissioned a project that started in April 2016, to produce regional guidance on the development of climate-resilient rural access in Africa through research and knowledge sharing within and between participating countries (Verhaeghe et al, 2019).

The latest Intergovernmental Panel on Climate Change (IPCC) report AR6 presents ten key areas for the African region relating to observed and projected climatic changes, where in general, an increase in mean and extreme temperature is expected (IPCC, 2021). The rate of increase in surface temperatures has also been a concern, with higher rates observed in Africa than the global average, and this is expected to increase for the foreseeable future. As per IPCC's classification, Mozambique falls under the East Southern Africa (ESAF) area, which is reported to have a decrease in observed mean precipitation. However, a projected increase in heavy rainfall is expected, thus increasing the country's risk and exposure to flooding, causing socio-economic losses and severe infrastructure damage.

Mozambique is also one of the African countries most frequently affected by natural disasters, thus contributing to its high vulnerability and exposure to climate hazards, particularly flooding, droughts, and cyclones (Ferguson, 2005). The country has already experienced three major cyclones in the past two years, namely Cyclone Idai and Cyclone Kenneth, both in 2019, as well as Cyclone Eloise in 2021, all occurring during the country's rainy season between November and April. Between 1975 and 2015, a total of 15 tropical storms were recorded by the International Disaster Database, contributing to 577 deaths caused by storm events alone (Le Roux et al., 2019). Similar figures for flooding revealed 31 recorded flood events (20 due to riverine flooding), resulting in a total of 1738 deaths and nearly 9 million people being affected (Le Roux et al., 2019).

Due to Mozambique's location and geography, large areas are exposed to frequent tropical cyclones and river/coastal storm surge flooding (Zermoglio et al., 2018). Combined with institutional capacity constraints and an already suffering economy, the country is particularly vulnerable to natural disasters. Mondlane (2004) showed that, on average, more than 2 per cent of the country's GDP is affected whenever a natural disaster occurs, undermining its economic development and further

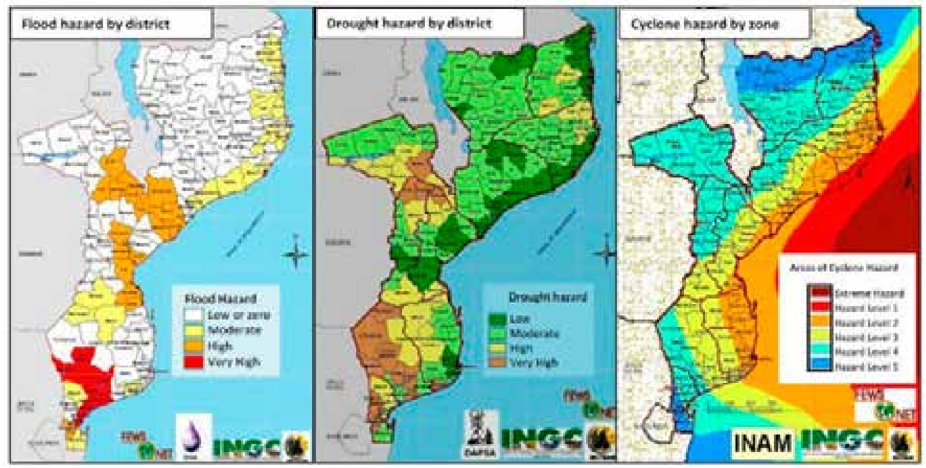

Figure 1 Weather related hazards for Mozambique (Le Roux et al., 2019)

increasing its dependency on external economic relief and survival. In addition, the country has also not been able to preserve and protect its economic infrastructure and national assets.

According to Mozambique's National Road Authority (ANE, 2017), a third of Mozambique's road network is in a poor, very poor or impassable condition contributing to high infrastructure vulnerability of these sections of the road network, particularly to climate hazards. For the study presented in this chapter, the project location falls within the very high-risk category for flood hazard (Le Roux et al., 2019), as depicted in Figure 1.

3.0 Methodology

3.1 Road Selection

As part of the ReCAP climate vulnerability project, the selection of a road for the construction of demonstration sections was required. These roads needed to be on an improvement/upgrading/ rehabilitation programme with funding already allocated for their work. Following discussions with Mozambican National Road Agency, Administração Nacional de Estradas (ANE), the Mohambe-Maqueze road in the Gaza province was selected. This research investigation is a case study. The selected road is particularly troublesome as it weaves among and along the edge of various large natural lakes (Figure 2). The altitude varies between 11 and 30 m above sea level along the entire 50 km road.

Figure 2 Project location and road main drainage features (Google Earth)

Following the selection of the road for the case study, the methodology (approach) for the implementation of the project consisted of three main tasks, namely:

- Road assessment and identification of problems;
- Design of adaptation measures, and
- Construction of demonstration sections.

The subsequent sections describe the activities that were carried out as part of each of the three main tasks.

3.2 Road Assessment and Identification of Problems

The Project Team visited the Mohambe-Maqueze road during Phase 1 of the ReCAP Climate Adaptation project in September 2016, and information regarding some of the problem areas was made available (Verhaeghe et al, 2017). The road was revisited in August 2017, as well as during a climate adaptation workshop held in Chibuto in September 2017, and additional measurements and observations were carried out (Paige-Green et al, 2019). The road assessment was undertaken in accordance with procedures contained in the Climate Adaptation Handbook and associated Guidelines and a Manual, that were developed as part of Phase 2 of the ReCAP Climate Adaptation project (Verhaeghe et al, 2019).

As part of training and capacity building activities of the project, the assessments were undertaken jointly with engineers from Mozambican road authority (ANE), as well as engineers from a Consultant and a Contractor working on the demonstration project. On-site training activities included:

- Condition and vulnerability assessments;
- Selection of appropriate adaptation options, and
- Implementation of the adaptation measures.

A detailed assessment of the Mohambe-Maqueze identified four frequently occurring problems, namely:

- Erosion and undercutting of concrete fords/ crossings;
- Damage to the road approaching the concrete fords;
- Damage to culverts and erosion protection, and
- Damage to the road surface.

The identified problems are briefly described below.

3.2.1 Erosion and Undercutting of Concrete Fords

Erosion and undercutting of concrete fords (Figure 3) were observed at two of the new concrete fords. This was mostly restricted to the lake side of the fords and was either the result of over-topping from the downhill side or more likely softening of the support material (black clay in this case) and subsequent wave action as well as alternative wetting/drying of the clay. Furthermore, the underlying soils (expansive clay) were unsuitable, and susceptible to slaking and collapse when the material moves from a dry to saturated state. Slaking of the dried black cotton soil was demonstrated on site.

Figure 3 Erosion and undercutting of concrete fords.

3.2.2 Damage to the Road Approaching the Concrete Fords

Damage to the approach fill of concrete fords was observed at several locations (Figure 4). The damages were likely to continue to aggravate if the design was not changed. The problem appeared to be exacerbated by braking of vehicles approaching the concrete fords.

Figure 4 Damage to the road approaching concrete fords.

3.2.3 Damage to Culverts and Erosion Protection

Numerous culverts had been damaged by flooding. Most of the damage was caused by erosion at the exits with undercutting (Figure 5) and cracking. The incidence of undercutting of erosion protection measures (mostly grouted stone pitching) was evident at many of the structures. wThis was often due to poor compaction of the embankment material allowing access of water behind the structures as well as surface erosion. The main areas affected were the approach fills that were eroded during flooding, protection works that were left unsupported or washed away, and scour of the stream-bed at the outlets.

Figure 5 Damage to culverts and erosion protection.

CHAPTER 3

3.2.4 Damage to the Road Surface

Damages to the unpaved road surface were observed at several locations (Figure 6). The main causes of the damages were attributed to erosion by uncontrolled water, poor compaction of the materials and the use of erodible materials as the wearing course.

Figure 6 Damage to road surface.

3.3. The Design of Adaptation Measures and Construction Methods

To address the problems identified during the road assessments, four sections of road were identified for the implementation of appropriate adaptation measures. The designs for each of the four adaptation measures and construction methods are described in the subsequent sections.

3.3.1 Undercutting of Concrete Fords

The undercutting of the fords was a major problem requiring urgent repair (see Figure 3). To address the undercutting of the fords problem, the adaptation measure that was proposed was to incrementally construct a vertical concrete wall (200 mm thick with 16 mm Ø reinforcement at base at 250 mm intervals) near the edge of the concrete ford slab (on inert material), backfill the voids with an inert fill and a high slump concrete (0.5 m thick) and then extend the concrete slab to the top of the wall. The wall had to be founded on imported inert material at least 1 m deep and have a concrete protection slab at the base. The schematic sketch of the design of the concrete wall is shown in Figure 7. It should be pointed out that the actual concrete dimensions and depth of the wall depended on the founding conditions. In addition, it was necessary to provide some weep-holes in the concrete wall at 2 m intervals to facilitate drainage.

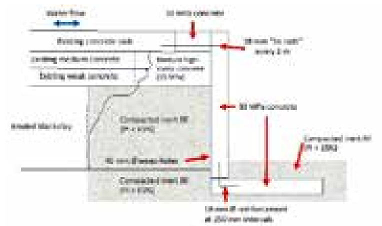

Figure 7 Cross-section of the concrete wall to prevent undercutting of concrete ford

The demonstration section to address the undercutting of the fords was constructed at km 17.6, using an adaptation measure designed. The construction activities involved the following:

- Cleaning of the cavity and placement of inert fill foundation;
- Construction of the wall foundation slab on inert material;
- Incremental increase in wall height with simultaneous backfill behind it up to concrete level;
- Placement of concrete into cavity beneath final slab;
- Insertion of dowels between existing slab and upper portion of concrete wall, and
- Filling of void between existing slab and wall with 30 MPa concrete

3.3.2. Damage to Road Approaching Concrete Fords

The proposed adaptation measure to address the damage on the approach fill to the concrete ford was to construct a 45 m long and 150 mm thick continuous (i.e. unjointed) roller compacted concrete (RCC). However, during construction, the contractor in consultation with the consultant decided to change the design. Instead of constructing the proposed RCC layer, the damage to the road approaching concrete ford was repaired by constructing an improved gravel road, as it was considered cheaper.

The adaptation measure to address the damage to the road fill approaching concrete ford was constructed at km 36, which involved a constructing an improved gravel road. The construction process involved:

- Excavating the existing damaged gravel road;
- Import improved material and compact in layers, and
- Construct 150 mm gravel wearing course, and improvement of the side slopes.

3.3.3. Damage to Culverts and Erosion Protection

Overtopping of the road has resulted in damage to the culverts and erosion protection in several places (see Figure 5). To address these problems, the road had to be properly shaped and levelled off at the top of the culverts with the grade, and 5 per cent camber with a well-compacted wearing course. Any expansive clay to 300 mm depth had to be replaced with inert material.

All damaged protection works had to be removed, and the materials in these areas replaced with inert material and compacted to at least 95 per cent Mod AASHTO density. The stone pitching then had to be repaired with a cement grout filling all joints. The top, bottom and edges of the stone pitching had to be cemented to concrete strips as shown in Figure 8. To avoid undercutting and erosion of the soil adjacent to the stone pitching, lined drains/chutes 150–200 mm deep and 250 mm wide had to be constructed at the edges of the stone pitching and integral to it to guide water from the shaped road surface down the embankments.

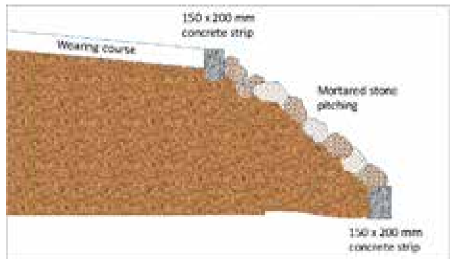

Figure 8 Cross-section of concrete strips to retain stone pitching.

The demonstration section to address the damage of culverts and erosion protections was constructed at km 43. The construction activities involved the following:

- Extension of wing walls of the existing culvert;
- Construction of additional new culvert approximately 45 m south of existing one, and
- Construction of erosion protection and wearing course on culverts approach.

3.3.4. Improved Gravel Road

The road was in a poor state with areas that would be impassable during wet weather (see Figure 6). It was proposed that a 200 m long section of road in Maqueze be upgraded to illustrate that a well-constructed unpaved road can be climate resilient. The cross-section of proposed improved gravel road is shown in Figure 9. It was essential that the wearing course material complied as closely as possible with the standard specification and placed in a 150 mm, compacted layer at not less than 98 per cent mod AASHTO effort. The camber of the wearing course after construction had to be 5 per cent. In addition, the smaller culverts at the start section had to be replaced with larger culvert to improve drainage capacity.

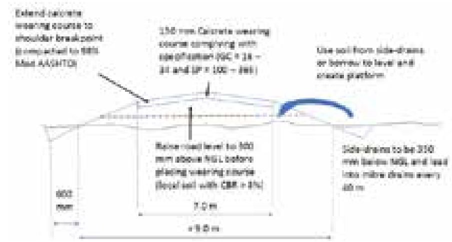

Figure 9 Cross-section of improved gravel road.

4.0 Findings and Quality Control Test Results

This section discusses the findings from the construction of the demonstration sections for each of the design solutions (adaptation measures) that were developed to address the identified problems. The quality control test results of each of the four demonstration sections are also discussed.

4.1 Undercutting of Concrete Fords

Figure 10 depicts the progression of the concrete wall construction activities. It should be noted that, due to practical reasons and the availability of the construction material, the contractor made some modifications to the original design. Instead of using 16 mm reinforcing steel spaced at 250 mm interval, 12 mm steel was used, but at a smaller spacing (i.e., 150 mm). Furthermore, a foundation bed was constructed using low strength concrete, following which the specified foundation was constructed.

Figure 10 Construction of concrete wall.

During the construction of the concrete wall, quality control tests were conducted on the concrete as well as on the gravel material used for backfilling. The material for the concrete consisted of aggregate with 19 mm Nominal Maximum Aggregate Size (NMAS), river sand, and a 42.5N cement class.

Concrete compressive strength tests were conducted on various batches. The tests were conducted 7 and 28 days after concrete casting, according to method D1 of the South African Standard Test Method for Highways 1 (TMH 1). Table 1 provides a summary of the test results. It should be noted that the design for the concrete ford protection wall recommended 30 MPa concrete be used for the construction. However, the average 28 days strength of the concrete used ranges from 25 to 27 MPa, which was considered to be satisfactory, despite being slightly lower than the recommended concrete strength. The 30 MPa specified was to be in line with the original upper concrete layer strength, but as the new concrete is only near the edge, the slightly lower strength obtained would be adequate.

Material for backfilling was sourced from a borrow pit established at km 3. The Liquid Limit (LL), Plastic Limit (PL), Plastic Index (PI) and Linear Shrinkage (LS) of the material as determined according to THM1 methods were 23, 16, 7, and 2.3, respectively. The California Bearing Ratio (CBR) of the material at 98 per cent MDD was 29. Overall, the quality of the backfill material was satisfactory.

	Average compressive strength (MPa)	
Casting date	7 Days after casting	28 Days after casting
06/10/2018	19.17	26.36
16/10/2018	19.27	26.91
17/10/2018	18.10	25.45
18/10/2018	21.60	27.07
22/10/2018	17.97	25.08
23/10/2018	18.09	26.45

Table 1 Summary of concrete compressive strength test results (Paige-Green et al, 2019).

4.2 Damage to Road Approaching Concrete Fords

Figure 11 depicts the condition of the approach to the concrete ford after the construction of the improved gravel road. Calcrete material used for the construction of the improved gravel road was sourced from a borrow pit established at km 39. The liquid Limit, plastic limit, plastic index and linear shrinkage of the material were 46.1, 34.5, 11.6, and 4.3 respectively. The CBR of the material at 98 per cent MDD was 40. After completing the construction, in situ density and moisture content tests were carried out to assess the compaction quality of the improved gravel wearing course. The tests were carried out using a nuclear density gauge. The density and in situ moisture content were determined at three chainages 0 (joint of ford and gravel road), 20 and 40 m away from the ford. For each chainage, the tests were carried out on the right wheel path (RWP), the centre of the lane (CL) and the left wheel path (LWP).

Table 2 presents a summary of the compaction results. The specified compaction density for the gravel wearing course was 98 per cent Mod AASHTO. The test results indicate that the compaction density achieved was generally lower than specification, and highly variable. The percentage compaction at the centre of the lane was generally lower than the wheel paths. This was expected as the tests were conducted approximately four months after the construction of the wearing course; hence, construction and normal traffic may have caused further densification of the gravel wearing course. Furthermore, the compaction densities appeared to decrease with increasing distance away from the concrete ford (i.e., from chainage 0 to 40 m). This could be due to the slow-moving vehicles near the concrete ford.

Figure 11 General view of the approach to concrete ford.

Table 2 Summary of field compaction results (Paige-Green et al, 2019).

Distance from ford (m)	Side	Wet density (kg/m3)	Dry density (kg/m3)	Moisture (per cent)	Compaction (per cent)
	RWP	2066	1980	4.3	97.3
0	CL7	1959	1880	4.2	95.3
	LWP	2039	1965	3.8	97.5
	RWP	1980	1890	4.8	93.8
20	CL	1912	1827	4.7	90.7
	LWP	2040	1943	4.2	96.4
	RWP	1910	1808	5.7	89.7
40	CL	1948	1866	4.4	92.6
	LWP	1971	1875	4.3	93.0

In order to further assess the quality of the gravel wearing course, Dynamic Cone Penetrometer (DCP) tests were carried out at 0, 10 and 20 m away from the concrete ford in the northern direction, and on the left wheel path, the centre of the lane and right wheel path respectively. The DCP results were analysed using ReCAP's Low Volume Road (LVR)-DCP software (De Beer and van Rensburg, 2016). Figure 12 shows layer diagrams of individual DCP tests for the left wheel path and right wheel path. The DCP test results indicate that the structural strength of the gravel road is adequate for TLC 0.03 (i.e., the field DN values are less that TLC 0.03 DN values).

At each of the DCP test point, soil samples were taken for laboratory determination of in situ moisture content using the gravimetric method. The moisture samples were taken from the wearing course (top) and the (subbase) bottom layer. The moisture content results are presented in Table 3. The laboratory determined moisture content values ranged from 5.0 to 10.9 per cent, and are generally lower than those measured using the nuclear gauge device.

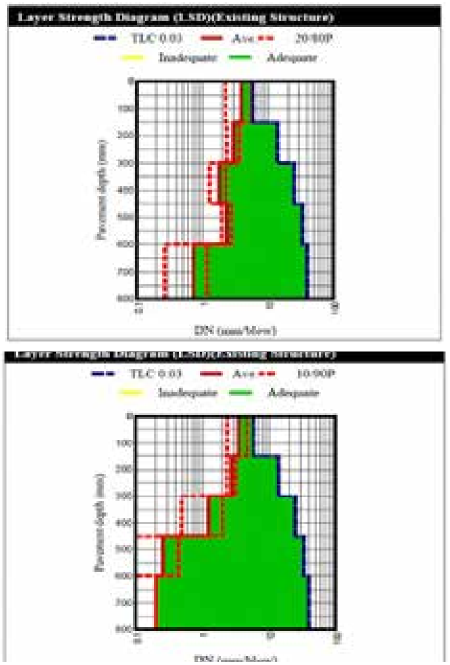

Figure 12 DCP results.

Table 3 Summary of moisture content results (Paige-Green et al, 2019).

Distance from ford (m)	Moisture (per cent)	
	Top layer	Bottom layer
0	5.0	-*
10	6.0	5.4
20	10.9	7.9

**only one layer sampled because the layer thickness was greater than 300 mm.*

4.3 Damage to Culverts and Erosion Protection

Figure 13 depicts the progression of the culverts and erosion protection construction. It should be pointed out that the design for the culvert protection work recommended that the beam had to be constructed first, followed by the stone pitching to ensure adequate bonding between the stone pitching and the beam. During the implementation, the contractor constructed the stone pitching first, followed by the beam; hence, the performance should be closely monitored during the long-term performance monitoring.

Figure 13 Construction of culverts and erosion protection works.

The wearing course of the road approaching the new and old culverts at km 43 was constructed using Calcrete material sourced from a borrow pit established at km 39. After completing the construction of the gravel wearing course, in situ density and moisture content tests were carried out. The tests were carried out at the interface of the culverts and the gravel road (i.e., 0 m) and 10 m away from the interface for both, the new (toward north direction) and existing culvert (towards south direction). For each position, the tests were carried out on the right wheel path (RWP), the centre of the lane (CL) and the left wheel path (LWP). Table 4 presents a summary of the compaction results, which with some exceptions, complies with the specification of 98 per cent Mod AASHTO.

4.4. Improved Gravel Road

An approximately 200 m long of gravel road section to illustrate that a well-constructed unpaved road can be climate resilient was constructed at km 51. The construction activities involved constructing a 300 mm high fill from the existing ground level, followed by a 150 mm gravel wearing course with 5 per cent camber, using good quality Calcrete material. A new culvert to replace the existing smaller culvert was also constructed. Figure 14 depicts the progression of the construction of the improved gravel road and new culvert. Overall, the gravel wearing course appeared to have been constructed properly.

Table 4 Summary of field compaction results at km 43 (Paige-Green et al, 2019)..

Culvert	Distance from culvert (m)	Side	Wet density (kg/m3)	Dry density (kg/m3)	Moisture (per cent)	Compaction (per cent)
New	0	RWP	1931	1852	4.3	95.7
		CL	1999	1918	4.2	98.9
		LWP	1963	1908	2.9	98.4
	10	RWP	1988	1902	4.6	98.0
		CL	2061	1966	5.7	100.5
		LWP	1980	1881	5.5	97.0
Existing	0	RWP	2053	1916	7.2	98.8
		CL	2056	1915	7.4	98.7
		LWP	2123	1979	7.3	102.0
	10	RWP	2078	1937	7.6	99.8
		CL	2036	1922	5.9	99.1
		LWP	2025	1895	6.9	97.7

CHAPTER 3

Figure 14 Construction of improved gravel road at km 51.

5.0 Preliminary Performance of Completed Construction Work

5.1 Technical Performance

Overall, most of the construction activities had been completed satisfactory. Figure 15 shows the before and after construction pictures. The following observation and recommendations were made:

Side slopes of the concrete ford embankments (km 17.6), as well as side slopes of the embankments of the newly constructed approach to the concrete ford at km 36 need to be vegetated to minimise erosion;

Sand was found to have accumulated at the inlet and outlet of the culverts at km 43 as a result of rainfall, necessitating routine inspection and cleaning. Furthermore, side embankments appeared to have been damaged by rain due to inadequate compaction, and required some improvements, and

Some drying cracks were observed on the newly constructed gravel wearing course at km 51. The progression of the cracks should be closely monitored during the planned long term performance monitoring.

Figure 15 Before and after construction pictures of the demonstration sections.

5.2 Cost of Improvements

These actual costs of the improvements will be helpful at the end of performance monitoring to compare the costs of the implemented adaptation measures with conventional construction practices. As part of the final inspection, the total construction costs of each of the four demonstration sections were obtained from the contractor. The costs are summarized in Table 5.

6.0 Conclusions and Way Forward

The chapter presented the outcomes of road assessment and identification of problems, as well as the design and construction of four demonstration sections along the Mohambe and Maqueze road to address climate change-related problems leading to the undercutting of concrete fords, damage to the road approaching the concrete ford, damage to culverts and improved gravel road. Based on the information and discussions contained in this chapter, the following conclusions are drawn, and recommendations made:

Although still preliminary, observations during a rainy season indicated that the demonstration sections are performing well;

The proposed adaptation measures have also been implemented on other roads with similar conditions in Mozambique;

The long-term performance of the demonstration sections had been planned, the outcomes of which

Table 5 Summary of construction costs (Paige-Green et al, 2019).

Section	Total cost (MZN)	Total cost (USD)*
Undercutting of concrete ford	3 250 000	53 719
Damage to road approaching concrete ford	36 000	595
Damage to culverts and erosion protection	2 660 300	43 973
Improved gravel road	1 988 780	32 872P
Sub-total	7 935 080	131 158
VAT	539 585	8 919
Total	8 474 665	140 077

*1 USD = 60.5 Mozambican metical (MZN).

are expected to inform on the appropriate adaptation procedures for wider implementation in Mozambique, and possibly elsewhere, and

Furthermore, the outcomes of the long-term performance monitoring of the demonstration sections are expected to improve manuals and guidelines for the design of low volume climate-resilient roads, and possibly the incorporation of the adaptation options in the Road Asset Management System (RAMS).

7.0 Acknowledgment
This chapter is the result of a research program that was commissioned by the Research for Community Access Partnership (ReCAP), a research program funded by UKAid.

References

- Administração Nacional De Estradas (ANE). (2017). Direcção De Planificação. Relatório: Condições de transitabilidade da rede de estradas classificadas. Maputo: ANE.
- De Beer and van Rensburg. (2016). Improvements to the WinDCP software for Pavement Design of Low Volume Roads – Final Development report. GEN2023A. London: ReCAP for DFID.
- Ferguson, J. (2005). Mozambique: Disaster Risk Management along the Rio Búzi. Düren: Schloemer Gruppe.
- Intergovernmental Panel on Climate Change (IPCC). (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report (AR6-WGI) of the Intergovernmental Panel on Climate Change. Cambridge University Press. [In Press].
- Le Roux, A., Maritz, J., Arnold, K., Roux, M., Head, M., Makhanya, S., Paige-Green, P. (2019). Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa. Management of Vulnerability and Adaptation to Climate Change: Mozambique. Thame: Cardno Emerging Market (UK) Ltd.
- Mondlane, A. (2004). Floods and droughts in Mozambique – the paradoxical need of strategies for mitigation and coping with uncertainty. Risk Analysis IV, 371-379.
- Paige-Green, P., Komba, J., Verhaeghe, B., Langa, R., Dzimba, M. and Alfinete, I. (2019), Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa, Mohambe-Maqueze Demonstration Sections– Mozambique: Design and Construction Report, GEN2014C. London: ReCAP for DFID.
- Technical Methods for Highways (TMH 1), 1986. Standard Methods for Road Construction Materials, Method A2: The determination of the liquid limit of soils by means of flow curve method. DoT, Pretoria, South Africa.
- Technical Methods for Highways (TMH 1). 1986. Standard Methods for Road Construction Materials. Method A3: The determination of the plastic limit and plasticity of soils. DoT, Pretoria, South Africa.
- Technical Methods for Highways (TMH 1), 1986. Standard Methods for Road Construction Materials. Method D1: The making, curing and compressive strength determination of concrete test cubes. DoT, Pretoria, South Africa.
- Verhaeghe, B., Paige-Green, P., Komba, J., Mokoena, R., Rampersad, A. and Arnold, K. (2019). Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa, Completion Report for Phase 2, GEN2014C. London: ReCAP for DFID.
- Verhaeghe, B., Rust, FC., Head, M., Le Roux, A and Paige-Green, P. (2017). Climate Adaptation: Risk Management and Resilience Optimisation for Vulnerable Road Access in Africa: Final Report for Phase 1, GEN2014C. London: ReCAP for DFID.
- Zermoglio, F., Quinn, C. and Apostos, A. (2018). Climate Risk Profile: Mozambique. [online] https://www.climatelinks.org/projects/atlas: USAID, (accessed on 10 November 2021).

Photo by Matt Hardy from Pexels