Responding to climate change effects on rural roads through application of cost effective erosion control measures. A case study in Zimbabwe

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A. Abstract

Rural roads provide essential access to rural communities and a fundamental lifeline to the population by enabling access to health, education, administration and social services, improvement of agricultural capacity and commerce. Erosion damages have long been a problem for the maintenance of these roads by causing extensive damages to the road system necessitating expensive repairs. The damages from erosion effects are rising. This is mainly due to the loss of vegetation cover resulting from population pressures, poor land management practices and droughts. Climate change is increasing the severity of droughts and extreme rainfall incidents resulting in increased runoff and siltation that overwhelms the road drainage systems and cause extensive damages.

Dealing with erosion is a universal problem, however various measures can be taken to improve the resilience of rural roads by reducing the erosion effects through use of bio-engineering and appropriate technologies to provide cost effective solutions. The Zimbabwe "Erosion Control Programme", (part of Zimbabwe Rural Road Programme under which 23 000 km rural road was rehabilitated) ran from 1996 to 2002, provides evidence of the effectiveness of this type of intervention. To reduce effects of erosion on the network Erosion Control Units were set-up countrywide. They tackled identified erosion damages following a planned approach utilizing gabions and deep-rooted vetiver grass. Community participation was crucial in implementing the measures. The effectiveness of this type of approach to achieve a long-term solution to erosion problems was demonstrated by the successful reduction in erosion problems. Recent follow-up inspections to selected sites have confirmed that the measures are still effective after 15 over years of implementing the project. However more research is needed in investigating various erosion control measures that can be applied to other areas, through improving erosion awareness and the benefits, costs and effectiveness of adopting this approach.

Key words:

Erosion Control, Rural Roads, Community-Participation, Appropriate Technologies Climate Change, Bio-engineering

B. Introduction

Rural access roads are the lifeline of the rural people. A comprehensive and serviceable rural road network provides essential access to rural communities and a fundamental lifeline to the population by enabling access to health, education, administration, and social services along with enabling development of agricultural capacities and improved commercial activities.

However erosion damages have long been a problem to the maintenance of these rural roads. Erosion causes extensive damages to the road carriageway, drainage system and surrounds disrupting and at times completely cutting off access to rural communities. These damages are frequently beyond the scope of routine maintenance operations and require additional resources to be allocated for repairs. Often these additional resources are not available resulting in the damages not being repaired and the serviceability of the network deteriorating.

According to a paper written by Dalal Clayton (2015) titled ‘Southern Africa beyond the millennium and beyond, trends and scenarios,’ he notes that "After a prolonged period of time of largely unsustainable development in Africa, the livelihoods and lives of many people and the economic prospects of most countries continue to be threatened by environmental degradation. Most SADC countries now face a formidable series of critical demographic, social, economic, agricultural, energy, technological and institutional transitions in order to move toward development that is economically, socially and environmentally sustainable".

This paper looks at some successful erosion control measures that were developed and implemented for the Zimbabwe Rural Road Programme in the 1990s. A follow-up of some sites that were worked on 15 years ago has been made to check on their effectiveness and the results are encouraging.

C. Background

An Example of a Road Based Erosion Control Programme

Under the Zimbabwe Rural Road Programme (RRP) which ran from 1985 to 2003 more than 23 000 km of rural road serving rural communities were rehabilitated under a joint Government of Zimbabwe / KfW Development Bank funded programme. The work was project managed by Gitec Consult and Stange Consult GmbH. By 1995 the RRP was well established, with some 15 000 km of road having been constructed and an appropriate road maintenance system developed and installed looking after the roads.

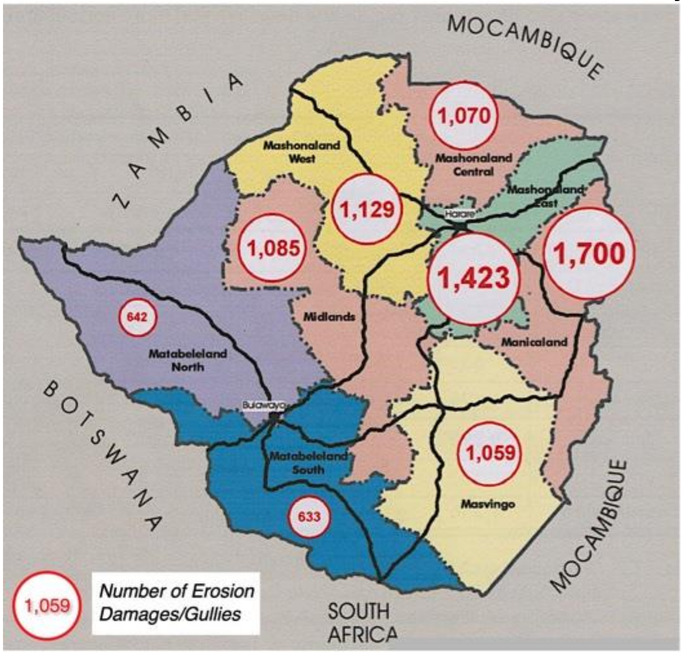
By 1995 the RRP had been running for 10 years and while the routine maintenance system was well established, its effectiveness was being threatened by increasing erosion damages to the roads that were putting unsustainable strain on maintenance resources. The erosion problem was mainly due to increased rain run-off resulting from deforestation and loss of vegetative cover as an outcome of population pressures, poor land management practices and unplanned developments. Additionally Zimbabwe has a lot of sandy loam type soils that are extremely vulnerable to erosion damages when stripped of vegetation cover, and this situation becomes even worse during drought cycles. The increased run-off overloads natural and road drainage systems causing uncontrolled water flows, which often result in erosion damages. This erosion either scours the ground causing sheet erosion or gullies to form, or blocks existing channels when the highly silted water deposits the sediment into drains and drainage structures.

Fig. 1: Landscape in Murehwa District showing lack of vegetation cover.

Some of the typical the road related erosion damages were:

- Scouring of drainage channels causing deepening and widening of drainage channels;
- Siltation of drainage channels, relief culverts and cross road drainage structures causing overtopping and/or breaching of the road carriageway;
- Un-planned drainage from settlements and cultivation flowing onto the road at unexpected locations overloading the road drainage system;
- Encroachment of erosion gullies into the road reserve and road carriageway.

Fig 2: Map of Zimbabwe showing number of significant erosion problems affecting the roads and distribution within the country by 1996.



Map showing distribution of erosion damages throughout country – highest incidence in east where hilly terrain, higher rainfall and populations falling off to west the terrain is rolling or flat with low rainfall and populations.

While various actions were taken under the road maintenance and emergency repairs to try and deal with these erosion damages it was realised that due to the magnitude of the problem a standardised, consolidated approach was required to improve the effectiveness of the control measures. In 1995 it was agreed that the District Development Fund, with the financial assistance from the KfW Development Bank and Technical Assistance from Stange Consult (the consulting firm appointed to provide technical support to the District Development Fund) should launch a pilot project for erosion control.

The Erosion Control Pilot Project was therefore setup with the main objectives to :

- Evaluate various erosion control measures which could be used to protect the drainage system and the carriageway of roads built under the Rural Road Programme;
- Develop an erosion control operation to plan, organise and manage the erosion control activities for the road network; and,
- Integrate the erosion control operation into the existing road organisation management and operations.

Analysis of the Problem and Defining the Approach.

Erosion being a common problem a number of erosion control techniques were already being used by the various ministries, authorities and organisations such as Transport, Agriculture, National Parks, Municipalities and District Rural Councils. Available information and experiences from these authorities was reviewed and it was decided to concentrate on 2 main control areas; 1) using bio engineering to re-establish vegetation cover and improve soil stability, and 2) the placement of mechanical bolsters and retaining walls to stabilise drainage channels and erosion gullies in order to prevent further deterioration. This was aimed at preventing further erosion of damages by stabilising the area.

Bio-engineering

Vetiver grass was already being used quite widely in Zimbabwe especially in the agriculture sector as an erosion control measure and seemed to have the right attributes for soil stabilization and enabling regrowth of vegetation. The Vetiver Grass has the following special characteristics:

- Deep and massive fine roots going up to 2 -3m deep;
- A tensile strength of between 40 – 180 MPA (Hengchaovanich & Nilaweere 1996);
- Stiff and erect stems that can stand up to 0.6 – 0.8m of water flow;
- Can endure extreme climatic variation such as prolonged droughts, floods, submergence and extreme temperatures -14ºC - 55ºC (Trung et al 1996);
- High level of tolerance to soil acidity, salinity, sodicity, and acid sulphate conditions (Truong 2003);
- Vetiver grass can be propagated by root-stock making it non-invasive.

A literature review on erosion control projects in Asia "Catchment Approach to Managing Soil Erosion in Asia" by A R Maglinae and C Valentin, where over 60% of the land surface is covered by mountains and high plateaus resulting in severe erosion caused mainly by the intense rainfall falling within in few months of the year, listed a number of the bio-engineering related projects done in Asia using vetiver grass for slope protection and surface erosion control, some examples being:

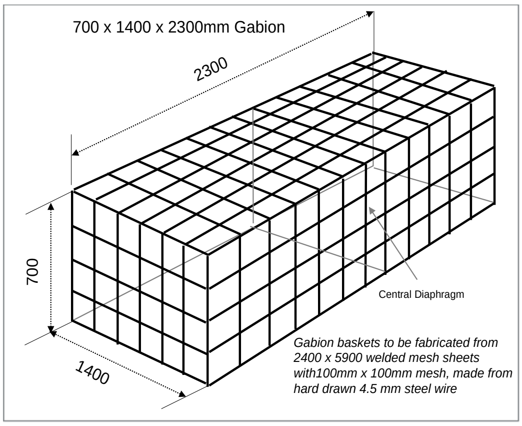
Malaysia	Slope protection and surface erosion control on the East West Highway running though steep slopes and fragile soils.
Australia	Northern Australia Cocktown road to Cape York Peninsular.
Thailand	Department of Highways road maintenance and construction programme for the Northern and Southern regions of Thailand using vetiver grass for sole protection and surface erosion control.
China	Guangdong Province has used vetiver grass on five major projects including protection works on a major hydro electric power station for slope stabilization.

Vietnam Used on the Ho Chi Min Highway.

Gabion Bolsters

In order to arrest further erosion in gullies and channels some form of bolsters and mechanical slope protection was required to stabilize the channel floor and side slopes, and to reinforce points where water enters the gully or channel. With Zimbabwe having adequate stone resources in most areas this pointed to using stone filled gabions, which were flexible, easily transported, did not require specialist inputs and could be constructed using labour intensive techniques. The gabions could be easily configured according to specific requirements of each damage, and when properly constructed with adequate bedding and keying into slopes form a cost effective and robust structure to protect vulnerable areas.

Fig 3 : Detail of Gabion Basket



Gabions were already being used by a number of different authorities in a variety of slope and channel applications so information regarding their use and placement was readily available along with experiences regarding effective designs. It was decided to use a locally produced welded mesh sheet for the gabion baskets which was the cheapest available material suitable for gabions available and had been proved to be effective and have adequate life span. Due to foreign currency restrictions at the time imported gabions could not be considered..

These Erosion Control activities were mainly labour intensive with the work comprising clearing of erosion site, excavation and backfill for placing gabions, collection of stones for gabions, placing stones in gabions and preparation of ground for planting and the planting of vetiver grass. Basic equipment such as tractor, trailer and water bowser were also required for transport and grass planting.

Pilot Project

A pilot project was carried out 1995/96 to evaluate the selected methods in the Manicaland province, which was chosen as this area had the highest incidence of erosion problems and offered a diverse range of erosion types and sizes that could be used to trial the selected methodologies. This was successful in terms of implementation process and the effectiveness of the measures taken on the roads and it was agreed to expand the programme to cover 50 districts.

D. METHODOLOGY

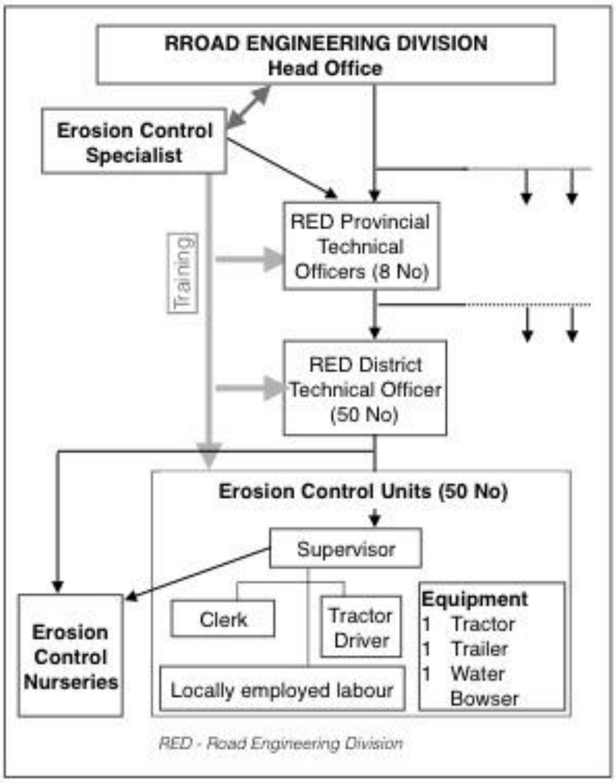
Management and Organization

The inputs for organization and management of erosion control could not be under estimated. The erosion problems were widespread and varied considerably. In order to accurately assess the erosion control requirements required carrying out inspections and surveys of the numerous sites and preparation of designs along with quantity and cost estimates for programming and budgeting. The implementation then had to ensure the organisation of the required resources to carry out the work along with supervision, monitoring and support to the field units.

An Erosion Control Section was established within the District Development Fund Road Engineering Division. The section was headed by an Erosion Control specialist who was responsible for overall management of the operations working with existing technical staff at provincial and district level in the design, planning, programming, supervision and monitoring of the control measures.

Fifty Erosion Control Units were set up country wide under the district technical officer and operating from the district maintenance base camps. Each Erosion Control Unit was headed by a supervisor responsible for the implementation.

Fig. 4: Organogram of Erosion Control Section



Vetiver Grass Nurseries

A problem using vetiver grass is that with the high number of plants needed, the cost of transportation can become expensive. The closer the sources of grass can be to the sites where they are required the more cost effective the operation. It was therefore decided to establish vetiver grass nurseries using existing road maintenance camp infrastructure for which some 190 maintenance base camps and over 600 satellite pull in camps had been built. Initial stocks of vetiver grass root-stock was procured from local sources, and this was established in central nurseries where it was propagated for distribution to district nurseries over a two year period to build up the necessary stocks for implementation.

Training

All road engineering management staff received technical training in the erosion control methods. Full job descriptions for the various erosion control staff were prepared accordingly, along with the units mission and function and appropriate training materials developed.

In order to standardise the approach the main types of erosion problems that may be found on a road were defined, along with the types of control measures to be used for that problem type. This formed the basis for the technical training that was carried out as mixture of formal training to cover basic theory followed by on site practical training.

Awareness building with local community was also carried out to improve local residents understanding of road drainage requirements and practices and to improve communications with the communities and local authorities regarding erosion issues. The main agencies that were involved were the Natural Resources Board, Agritex (Agricultural Technical and Extension Services) and the Forestry Commission. These organisations were included in training and seminars to identify areas of cooperation. E.g Agritex district officers cooperated with improving drainage from cultivated lands onto roads. Local schools were also involved where possible with visits to working construction sites and explanations regarding the erosion control measures.

Planning and Preparation

An inventory of the erosion damages was carried out to establish the locations, extent, sources and the effects of the erosion on the local communities to be used for planning and estimates of work requirements and costs. A prioritised list of the erosion problem areas was prepared based on a number of criteria including risk of further damage to the road, location, capacity of the erosion control units and estimated cost.

The erosion damage inventory covered all 54 districts of Zimbabwe and identified some 8,740 gullies/erosion damages that were affecting the rural road network and needed some form of intervention. These damages comprised 5,440 small gullies/erosion damages (< 1 m2 cross section - requiring vetiver grass only) and 3,300 medium and large gullies/damages that required both gabions and vetiver grass.

Erosion Control Design:

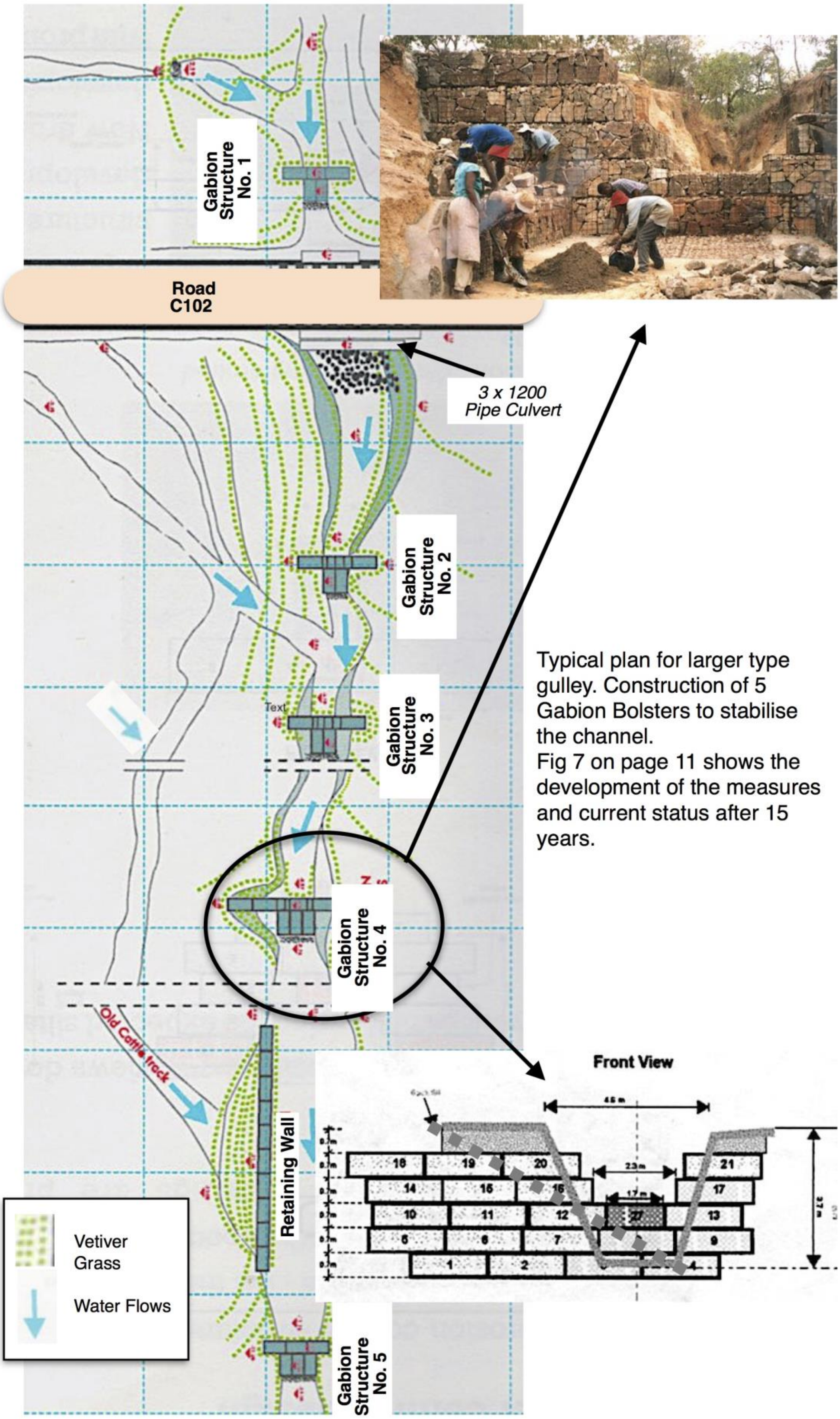
Site surveys were carried out according to the priority listing, and designs prepared for the selected erosion sites detailing types of intervention, location of gabions and areas for planting grass. Design of structures with gabions had to be designed at the provincial office as they are structures and subject to specific design criterias. The design included hydrological information, plans, long sections, detailed designs of each gabion structure and work plans. The larger gullies would often require a phased work programme over a number of years. A typical larger erosion gully plan is shown in fig. #.

Implementation of The Erosion Control Activities

The district technical officer was responsible for implementing the work on site with the Erosion Control Unit. The officer with assistance from the provincial officers would set-out the works, prepare site work programmes for the erosion control unit supervisor and supervise the works. All work was fully recorded and reported back to Head office.

During the main implementation phase of the programme from 1998 to 2001/2 fifty erosion control units were operational and they constructed some 7,000 gabion baskets (1.2m x 2,4m x 0.6m) and planted 3 million vetiver grass plants.

Fig. 5: Example of an Erosion Control Site Plan showing main features



E. Discussion

The Zimbabwe Erosion Control Programme was implemented from 1996 to 2002 (19976/97 pilot project/ 1998 – 2001/2 main project) and was effective both from the implementation procedure and the observed results in reducing the effect of erosion damages on the roads. One of the indicators for the programme was that the applied erosion measures should result in at least a 20% reduction in extraordinary repairs to roads under the maintenance system. Up to 2000 this could be monitored and was achieved. From 2000 financial constraints reduced the annual erosion control work programme and in 2000 effects from cyclone Eline caused substantial additional damages to the roads that increased the requirements for emergency works. Following 2002 financial constraints further slowed and eventually stopped the erosion control programme.

During its implementation some 4,250 erosion sites were worked on by the Erosion Control Units for which . The activities ranged from planting grass for smaller sites to multi gabion structures, landscaping and grass planting for bigger structures. Vetiver grass nurseries were established in 82 main nurseries, 178 maintenance base camps and 274 pull in camps giving countrywide access to vetiver plants within close proximity of the erosion sites.

The control measures substantially reduced the number of damage threats to the roads and reduced repair costs for damage repairs as indicated above. The serviceability of the roads was improved through reduction in disruption to traffic. The measures also improved the resilience of the roads with reduction in recurring damages on sections prone to flooding.

The effectiveness of this type of approach to achieve a long-term solution to the problem was demonstrated from recent follow-up inspections/assessments of erosion control structures where visits have been made of the sites worked on in the late 1990s and have confirmed that the erosion control measures still remain effective after 15+ years.

The need for erosion control measures for rural roads is indicated in the increasing number of "Emergency Repairs" which are required on various rural networks. Extreme events resulting from climate change are increasing and causing damages to the road infrastructure. In the current economic climate it is not feasible, especially on rural roads, to design and construct a road that will cope with the future anticipated effects of climate change and increased problems of erosion damages. A flexible approach is required to the problem, where cost effective and appropriate measures can be taken to deal with erosion through both controlling existing erosion damages and stopping them from getting worse and by improving resilience of the roads in erosion prone areas by taking measures to reinforce the existing infrastructure with measures such as gabions and vetiver grass. These erosion control measures should be seen as complimentary to normal the normal road maintenance activities, but there is a need for long-term commitment to establish and work the process.

On the following pages some of the measures that were used on the erosion control programme are presented in a series of photographs. They show photographs of before, during and after the measures were implemented.

Fig. 6 on page 11 shows installation of a Gabion Bolster in a typical larger gully, which was tackled using a series of gabion bolsters constructed across the gully as shown in the plan for the control measures in fig. 6 page 8. The photographs were taken from the start of construction, during construction and then in October 2016. As can be seen by 2016 the gulley has stabilised, vegetation is growing back strongly within the gulley and on the banks and the erosion has been halted.

Fig. 7 on page 12 shows the use of a gabion retaining wall with vetiver grass. Water coming from the left side of the drainage channel resulted in severe erosion where it met the channel. The retaining wall and vetiver grass stabilised the area allowing natural growth of vegetation over the area by 2016.

Fig. 8 on page 13 shows the repair of a damaged culvert outlet using gabion bolsters. The culvert is situated on a road in Mutare District, which is a very dry area with sandy soils and subject to severe erosion. The culvert was damaged in 1997 and was repaired under the erosion control programme in 1998. As can be seen in 2016 the outlet remains in a stable condition in spite of the very sandy outlet channel.

Fig 7: Installation of Gabion Bolster in Erosion Channel in Murehwa District (see page 10).

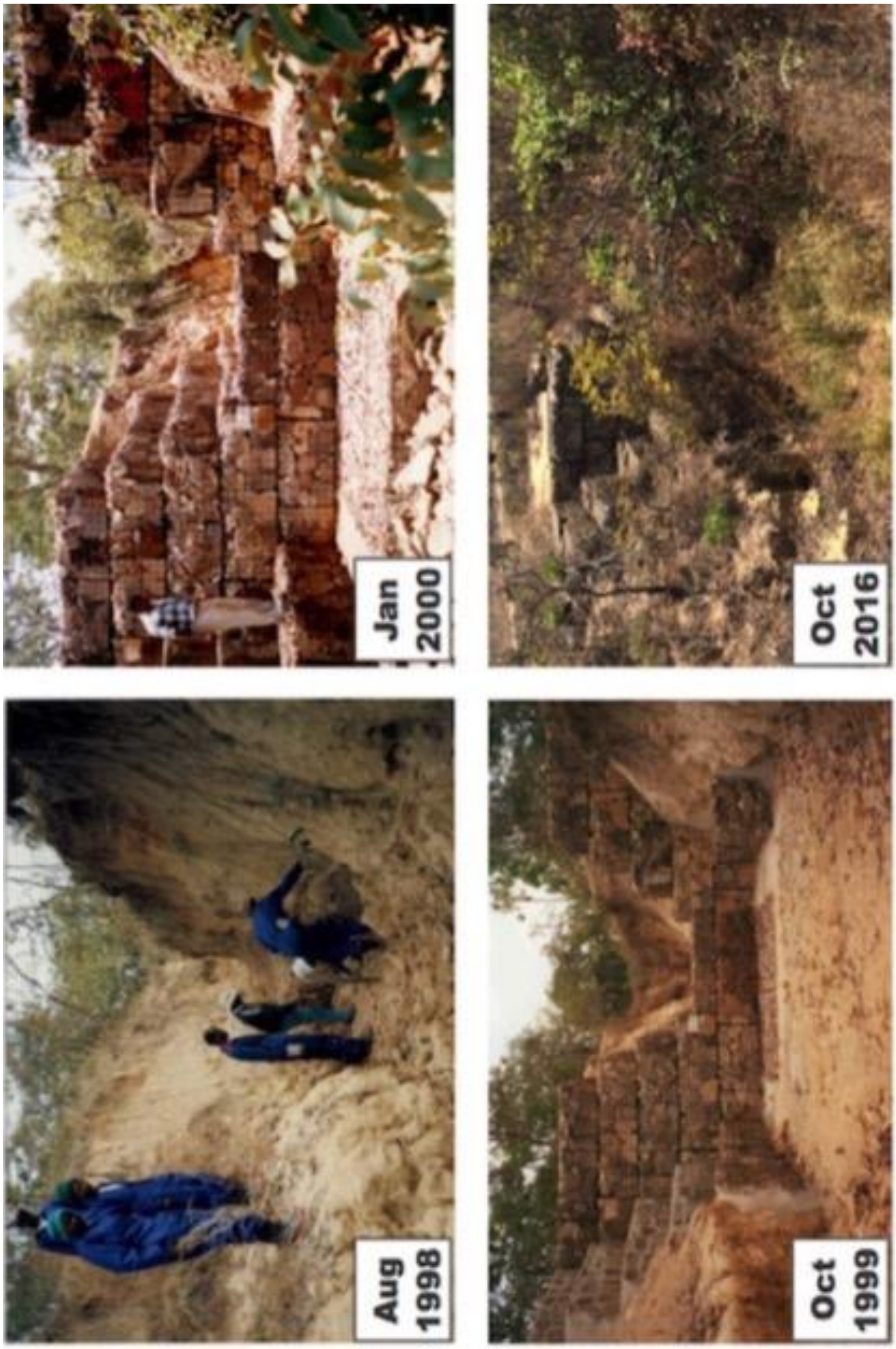
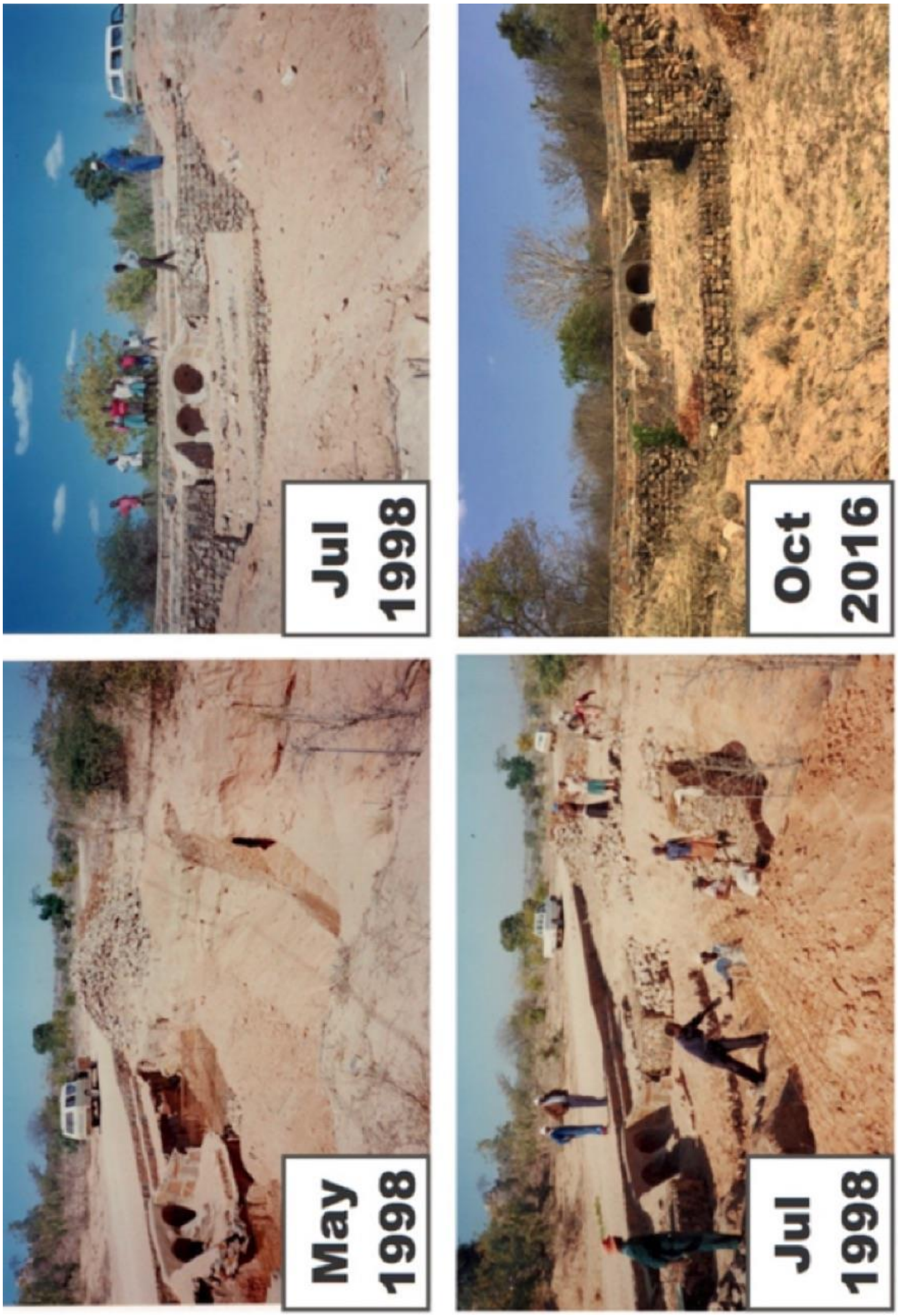


Fig 8: Construction of Gabion Retaining Wall with planting of Vetiver Grass to stop inlet erosion on drainage channel (see page 10).

Fig 9: Use of Gabion Bolster to stabilise outlet channel in very sandy soils in Mutare District (see page 10).



F. Recommendations

Erosion Control measures can make an important contribution towards the security of the road networks by providing a cost effective mechanism to deal with existing erosion damages affecting the roads and also improving resilience of road drainage systems for future effects.

However the technologies need to be properly applied and while they are technically relatively simple processes they requires a high level of coordination and management due to the extent, widespread nature and the variations in type of problem. Also Erosion Control should be viewed as a long-term measure, and needs to be established as a routine operation within the road organisation. The methodologies used under the programme described above could be usefully adopted for other networks with adaptations to fit with the specific requirements of the networks. Further research or investigation into the Erosion Control would be of benefit in order to refine the approaches to be used.

Areas for further research could include improving monitoring of the occurrences of erosion and effectiveness and benefits of specific erosion control measures, specifically;

Monitoring:

- Improvement of Erosion Monitoring Techniques - preparing reporting and monitoring system using GIS type mapping to record location and extents of erosion, measures taken to control erosion and effectiveness of measures;
- Appraisal of what makes certain areas more susceptible to erosion and what the anticipated effects of climate change may be. Discussion of what measures may be taken to try and mitigate this vulnerability;
- The costs and benefits of the erosion control. (in terms of road assets) i.e. overall cost implications in road life cycle, financial and social benefits, community benefits etc. Assessment of effectiveness of road related erosion control on the overall erosion problem.

Integration with communities:

- How to benefit communities by incorporating erosion control with enhancement of community water supplies - i.e. water harvesting and storage for communities using road and erosion structures;
- Integration of erosion control roads into national programme – erosion problems need to be dealt with at all levels – improving co-ordination at with communities – erosion damages may be from other sources.

Methodologies:

- The technologies shown in the Zimbabwe example have worked very well, but they were appropriate for the specific areas selected. Coastal region of Mozambique where sources of aggregate is scarce make gabions less suitable due to cost of sourcing the aggregate. Investigations should be made into other areas providing alternative solutions for mechanical soil stabilisation and also look at alternative bio-engineering methods which may be used.

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