The sustainability of gravel roads as depicted by sub Saharan Africa's standard specifications and manuals for road works: Tanzania case study

R. R. Mwaipungu & D. Allopi
Durban University of Technology, South Africa

Abstract

The sustainability of gravel roads depends, among other things, on the appropriate locally formulated manual and standard specification. These regulating documents should not only address how best these roads could be brought into being but also address the environmental and climatic issues affecting or affected by gravel roads. To achieve that goal, these manuals and standard specifications have to ensure that during their design life, the gravel roads constructed are in harmony with the environment. In that period, the gravel roads should contribute less to the pollution and degradation of the environment and climatic changes. This can be achieved through properly documented mitigation procedures embedded during gravel roads design and construction and also during routine and periodic maintenance.

This paper reviews what is specified in the Tanzania's Pavements and Materials Design Manual (PMDM) and the Standard Specification for Road Works (SSRWs), in particular on environmental and climatic issues associated with the gravel roads construction and maintenance activities and mitigation measures adopted.

The review results show that the Tanzania PMDM and SSRWs do not adequately address environment and climate issues affecting or being affected by gravel roads performance. This paper concludes by listing the appropriate measures expected to achieve gravel roads sustainability.
Keywords: atmosphere, climate change, environment, global warming, gravel loss, gravel roads, mitigation, Pavements and Materials Design Manual, Standard Specification for Road Works, sustainability.

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1 Introduction

For a long time into the future, gravel roads will continue to dominate as the most widely used modes of travel for traffic and as an affordable means of road network in most of sub Sahara African countries. Gravel roads constitute more than 70% of the road networks in Sub Sahara Africa. In Tanzania they make up 93 per cent of the total road network and most probably 100 per cent of the rural roads network.

It is a matter of fact that during gravel road operation, fine particles are lost as dust. At the same time the finer and coarser particles eroded from the gravel roads usually find their way into the water course, where together with detritus from vehicles combine to form siltation and pollution.

Looking back at the history of road evolvement [1], it is convincing that gravel roads are sustainable and Ferry [2] argues that for reasons related to intergenerational equity, gravel roads are the better choice, providing that appropriate techniques are applied in their design, construction and maintenance. It is a logical conclusion that sealed and unsealed roads have to coexist for the major reason of conserving non-renewable resources used for constructing and maintaining sealed roads.

This paper reviews what has been documented in Tanzania's PMDM and SSRWs in achieving the sustainability of gravel roads and to address the shortfalls.

1.1 Background

The Tanzania Pavement and Materials Design manual (PMDM) [3] and the Standard Specification for Road Works (SSRWs) [4] were prepared as a component under the institutional cooperation between the Ministry of Works (MoW) and the Central Materials Laboratory (CML) as one part and the Norwegian Public Roads Administration (NPRA) as the other part.

The main purpose of preparing the PMDM and SSRWs is to ensure that a formal procedure is being carried out in pavement design (elements and structural), construction and maintenance.

The manual and specifications are a reflection of the MoW experience gained in the road sector over the past 30 years, from the year PMDM and SSRWs were published.

The PMDM is divided into two sections; the first is the design elements and the second is structural design. The first section contains details pertaining to the environment, cross section, shoulders and drainage, traffic, subgrade, problem soils and pavement materials, while the second section contains details on the pavement design for new roads, pavement rehabilitation, bituminous surfacing and gravel roads.

The SSRWs is divided into seven series, which are: (1000) general, (2000) drainage, (3000) earthworks and pavement layers of gravel or crushed stones, (4000) bituminous layers and seals, (5000) ancillary road works, (6000) structures and (7000) tolerances, testing and quality control (using SSRWs numbering system). It is in section 1700 of the series 1000, where environmental protection and waste disposal is discussed.

The PMDM and SSRWs have been in existence for 13 years, it is high time now that their contents are revisited and edited where necessary.

This paper compares what is being stated in the PMDM and SSRWs regarding environment and climatic issues and what is implemented at site during the construction and maintenance of gravel roads. This paper attempts to address the shortfalls to avert the changes we see in the climate and further the sustainability of gravel roads.

1.2 Sustainability of gravel roads

The decision to seal a road is a matter of trade-offs. Sealing a road helps to seal the road from climatic elements and thus protects unbound materials used in the construction of the base course, the sub base layers and road formation. It eliminates dust problems and has high traffic acceptance because of its increased smoothness.

In spite of the benefits of sealed roads, well maintained gravel roads are an effective alternative to sealed roads. Gravel roads have the advantage of lower construction and maintenance costs. They are easier to maintain, requiring less equipment and labouring experience, hence contributing less to global warming.

Gravel roads are comparatively safer than sealed surfaces as they normally generate lower speeds.

Another advantage of gravel roads is its forgiveness to external forces. For example a vehicle with a ten ton load would damage a lightly sealed road so as to require re-sealing, or even reconstruction. The damage on a gravel road would be much easier and less expensive to correct.

Gravel roads produce less waste during construction and subsequent maintenance activities than sealed roads, which require more operations to be accomplished. In fact some local agencies in USA are reverting to gravel roads [5]. Properly managed gravel roads can serve generated traffic adequately for years.

The climates of sub Sahara Africa are less "prone" to the performance of gravel roads than in those regions of the world where damp, cold and frosty condition prevails. In most of sub Saharan African countries there is an abundance in many areas of good unsealed road surfacing materials, derived from the weathering of surface rocks [6]. With adequate funding and staff to carry out effective gravel road management and appropriate research to improve the performance of gravel roads the environmental footprints will diminish gradually and come to a halt.

2 Literature review

At this juncture we shall look at the literature review to learn what the atmosphere, environment and climate change refers to.

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2.1 Atmosphere

According to the Longman dictionary [7], the word atmosphere has four different uses; one of these is related to the theme of this paper, which is the mixture of gases that surrounds the Earth or a Planet. The composition of the atmosphere has changed throughout Earth's history. However many people believe human activities are changing both the atmosphere composition and climate very quickly indeed with potentially harmful effects for all life on Earth [8].

2.2 Environment

The term environment, apart from denoting 'surrounding', can be extended to objects, individuals or processes, which interact in some way with whatever is being surrounded.

2.3 Climate

Longman dictionary [7] define climate as the typical weather conditions in a particular area. The climate affects almost all environmental systems and aspects of human society [9].

According to Letete *et al.* [10], climate change is the shift of weather conditions over time or a permanent change in weather conditions.

For the purpose of gravel road design, Tanzania has been divided into three climatic zones, namely a dry zone in the interior, a large moderate zone and several wet zones, mainly at high altitudes [3]. These zones are demarcated on the basis of the number of months in a year with surplus of rainfall over potential evaporation as shown in table 1.

Table 1: Climatic zones (source: [2]).

Climatic zone	Number of months per year with higher rainfall than evaporation
Dry	Less than one month
Moderate	1-3 month
Wet	More than three months

As a result of climatic changes, these demarcations of climatic zones, as shown in Figure 1, will not reflect the realities in the near future if global warming continues to escalate unchecked.

Confronting climate change requires new and increased capacities. According to Zahadi [11], these capacities are to; i) monitor and assess the changing climate and its potential impacts on people and ecosystems, ii) plan for and to integrate climate change into development strategies and plans, iii) increase capacity to take advantage of and remove barriers to invest in climate resilience, clean technologies and low-carbon growth and iv) learn quickly from it all.

In gravel roads design, the construction and maintenance of these capacities can be translated into the increasing capacity of the individual pavement engineer to monitor the performance of gravel roads and understand its interaction with traffic, environment and climatic changes.

Figure 1: Climatic zones (source: [2]).

3 The status of Tanzania's pavement and materials design manual and standard specification for road works on gravel roads

3.1 Pavement and materials design manual (PMDM)

The PMDM mainly addresses environmental impact assessment and lightly touches on the climate effects on granular materials, which are the surfacing materials for unsealed roads. Environment Impact Assessment (EIA) is a management tool that attempts to put environmental factors on an equal footing with economic ones [8]. According to MoW, CML, and NPRA [3], the purpose of EIA is to ensure the sustainability of gravel roads as a whole.

EIA is aimed at discovering the unintended consequences of a project on; i) cultural heritage, ii) society, iii) the local economy and iv) natural resources now or in the future [3].

3.1.1 EIA

The conduct of EIA is a mandatory requirement in Tanzania for new roads and road up-grading, as for other substantial developments.

The MoW, CML and NPRA [3] state that EIA is not required for regravelling and similar periodic maintenance projects, without going into detail. It should be noted that during regravelling there is a requirement for new gravel materials from existing or new borrow pits and hence the EIA should be mandatory before one starts using gravel materials from borrow pits.

3.1.2 Environment impact mitigation measures applied on gravel roads

Usually, the Environmental Impact statement directed to gravel roads includes a set of mitigation measures to bring potentially adverse impacts within tolerable limits. This may be achieved by; i) the realignment of the gravel road to avoid vulnerable ecosystem or land use, ii) stipulating conditions to be observed during construction and maintenance and iii) compensating those who will be affected by the envisaged project.

MoW, CML, and NPRA [3] state that very rarely will an EIA conclude that a project should be halted, which categorically implies that those conducting EIA must strive to find the solution in favour of the continuation of the project.

3.1.3 Climatic and environmental factors influencing gravel road performance

The climatic and environmental factors having the greatest effect on gravel road performance are; i) moisture regime, ii) changes in temperature and iii) unfavourable subgrade conditions related to the environment (swamp areas, subsurface wells, localised areas with high moisture content, and cavities made by burrowing animals). Moisture regime and changes in temperature will be briefly discussed below:

a) *Moisture regime:* The moisture regime has a major influence on a gravel road's performance as the stiffness and strength of subgrade soils and granular materials vary with their moisture content.
b) *Changes in temperature:* The movement of moisture within soils and granular layers caused by changes in temperature, brought about by global warming, can indirectly affect the strength of the granular layers. Currently the PMDM does not address the global warming influence on moisture movement within granular materials, as the issue is of recent occurrence.

3.1.4 Design moisture content

According to PMDM the design moisture content for the purpose of gravel road design is determined by the estimation of likely future equilibrium moisture contents of the subgrade and within the existing gravel road structure. This equilibrium moisture content can be greatly disturbed by effect of climatic changes, and influence the nominal strength of CBR_{design}.

For new roads, nominal CBR_{design} values of subgrade, sub base, base course and gravel wearing course materials shall be specified at the specimen moisture content as presented in table 2.

Table 2: Design moisture content (source: [2]).

Climatic zone	Layers CBR_{design} Moisture			
	Sub grade	Sub base	Base course	Gravel Wearing Course
Dry	OMC	OMC	OMC	Soaked
	Additional requirements are given for minimum CBR after 4 days soaking. Both CBR requirements, soaked and un-soaked shall be met.			
Moderate	Soaked	Soaked	Soaked	Soaked
Wet	Soaked	Soaked	Soaked	Soaked

It can be noted that apart from specifying the required designed CBR moisture content for each climatic zone, the PMDM do not address the consequence on environment issues at site during the exercise of drawing water to satisfy the requirements of OMC from the local sources.

3.2 Standard specification for road works (SSRWs)

SSRWs mainly target environmental protection and waste disposal, which is under section 1700 [4]. The section covers the environmental protection and waste disposal activities to be exercised by the contractor during the execution of the contract.

Byrne [8] defines waste as material that has no direct value to the producer and so must be disposed of. Gravel road construction and maintenance activities produce negligible waste products.

The following gives a brief discussion on Sections 1703, 1704, 1705, 1706, 1707 and 1708 of SSRWs.

3.2.1 Landscape preservation (1703)

To preserve the landscape, all those structures which were constructed temporarily to assist with road construction have to be removed and the area restored to the original contour. According to MoW, CML and NPRA [4] the surface shall be scarified to provide a condition which will facilitate natural vegetation, provide for proper drainage and prevent erosion.

Precautions should be exercised when using explosives to prevent scattering of rocks, stumps, or other debris outside the work area and to prevent damage to the surrounding trees, shrubbery and vegetation.

MoW, CML, and NPRA [4] further states that when quarry sites, borrow pits and areas used for the disposal or storage of surplus materials are no longer required, it shall be reinstated by landscaping. Lacking are the actions at the construction site, as none of the measures stated herein are being implemented, as during the tendering process they are not listed for pricing.

3.2.2 Temporary soil erosion control (1704)

Temporary soil erosion control are activities to control erosion and water pollution, by use of berms, dykes, silt fences, brush barriers, dams, sediment basins, filter mats, netting, gravel, mulches, grasses, and slope drains.

Although MoW, CML, and NPRA [4] insist that a schedule of proposed temporary or permanent soil erosion control measures be developed by the Contractor at the commencement of the contract in consultation with the Engineer, few gravel road construction sites use these measures due to the costs involved in establishing them, as few or none of them are covered in the bill of quantities.

3.2.3 Preservation of trees and shrubbery (1705)

The layout of the Contractor's construction facilities such as workshops, warehouses, storage areas and parking areas, the location of access and haul routes and operation in borrow and spoil areas shall be planned and conducted in such a manner that all trees and shrubbery not interfering with the construction work are adequately preserved and protected from either direct or indirect damage by the contractor's construction operations or equipment. The preservation of trees and shrubbery also involve treatment or replacement of injured or destroyed trees or shrubbery.

No tree shall be used as anchorage, and when such use has been approved, the trunk shall be wrapped with a sufficient thickness of approved protective material before any rope, cable or wire is placed.

MoW, CML, and NPRA [4] fell short in specifying the measures required to preserve and protect trees and shrubbery. The protective barrier recommended to be used comes in different shapes, materials and construction technique. All these involve money and sometimes special knowledge on how to construct them without damaging those natural trees and shrubbery that were intended to be protected in the first place.

Currently no measure is being observed to be taken on site to preserve trees and shrubbery.

3.2.4 Prevention of water pollution (1706)

Waste water from aggregate processing, concrete batching or other construction operations shall not enter streams, water courses or other surface waters without the use of turbidity control methods such as settling ponds and gravel-filter entrapment dikes.

The contractor is tasked with the job of compensating for any polluted source of water and for providing the consumers with clean drinking water transported through pipes from an unpolluted source if required by the Engineer.

It is to be noted that the turbidity methods listed under section 1706(a) are not used at site.

3.2.5 Abatement of air pollution and dust (1707 & 1708)

i. *Air pollution abatement:* MoW, CML, and PRA [4] section 1707 states that the contractor shall utilize such practicable methods and devices as are reasonably available to control, prevent, and otherwise minimize atmospheric emissions or discharge of air contaminants. The SSRWs ask the contractor to use methods and equipment which are capable of preventing dust during the excavation, loading, spreading and compacting gravel materials.

ii. *Dust abatement:* According to MoW, CML and NPRA [4] section 1708, the contractor shall furnish all the labour, equipment, materials and means required and shall carry out proper and efficient measures wherever and as often as necessary to reduce the dust nuisance during the execution of the project. The contractor is further required to prevent dust that has originated from their operations from damaging crops, orchards, cultivated fields and dwelling or causing nuisance to persons. Based on current the Tanzania economic and political situation and the prevalence of dust and air pollution producing sources, the attainment of these clauses are not realistic.

4 Trucks and plants used at site

Emission from construction plants, trucks and supervision vehicles used at sites are harmful to the environment MoW, CML, and NPRA [3] and MoW, CML and NPRA [4] are silent on the contribution of these plants and vehicles to the greenhouse effect.

The trucks and plants at construction sites mostly use diesel to power their engines and the amount of fossil fuels used during the gravel roads construction and maintenance is in terms of hundreds to thousands of litres per day depending on the scope of the project.

There is a need to encourage the use of solar power to generate electricity for the camp use and also the need to improve the efficiency of trucks and construction plants. The numbers of supervision vehicles have to be scaled down and common pool method optimized. Vehicles and plants that emit excessive exhaust gases due to malfunction engine or other inefficient operating conditions have to be stopped until corrective repairs or adjustments are made.

5 Gravel loss and associated defects

The MoW, CML and NPRA [3] noted the importance of gravel loss (GL) during the maintenance of gravel roads. The manual suggests that the gravel wearing course needs to be regularly shaped and also replaced periodically throughout the service life of the road at a rate depending on the gravel loss. The manual suggests that an annual loss of 10 to 30 mm of gravel wearing course material at an AADT of 100 is common, without specifying the climatic condition or the gravel types and its characteristics. According to PIARC, TRL and Interch Associates [12], gravel loss is due to the action of rain, traffic wear and dry season dust loss. Typically annual gravel loss rates are 10–50 mm. It should be mentioned here that alignment gradient, surface cross fall, road width, material quality, compaction, and maintenance practices significantly influence the rates of gravel loss. The poorer the compaction and maintenance practice is, the higher the rate of gravel loss regardless of quality of gravel materials. The gravel loss contributes in one way or another to environmental degradation, as those gravel material lost has to be replaced by regravelling.

Gravel loss is very specific to the type of gravel material, defects and location and there is some variation between the results of trials and relationships derived in different regions and conditions. Hence it is vital to understand the defects associated with the contractor and to address them as fast as it is economically feasible.

Typical gravel road surface defects associated with GL are dust, loose gravel, erosion, ravelling and the loss of surfacing materials [13].

The remedial action can start from selecting gravel materials that are not susceptible to erosion, ravelling and dust. Figure 2 can assist in selecting appropriate materials for gravel wearing course. It should be stressed here that there is no substitute for local experience and research, which should enable more accurate predictions of gravel loss to be developed.

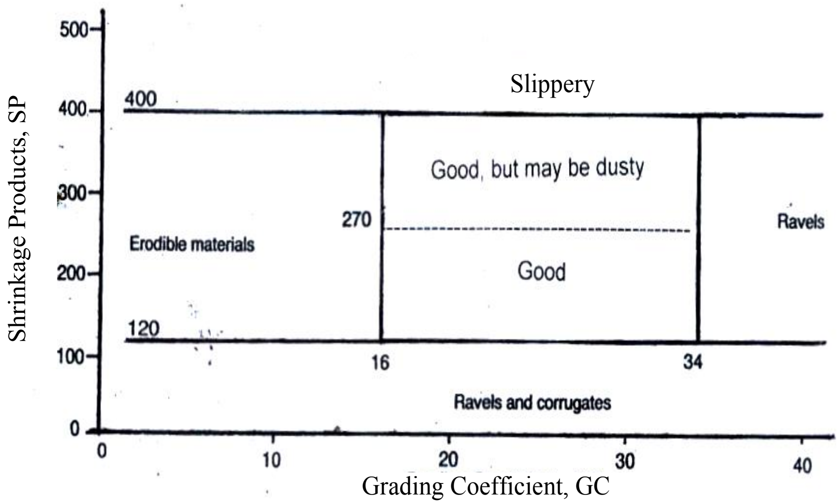

Figure 2: Performance specification for gravel wearing course (source: [2]).

5.1 Dust abatement

New Zealand is one of the countries in the developed world which is spearing the research on gravel roads dust abatement measures. According to McDougall [14], trials in Western Bay undertaken by council with a variety of clay bound gravel base courses, compared dust generation, wearing rates and application and construction practicality issues. These were ranked and prioritized, which then led to a material specification that was achievable and most favourable when strengthening gravel roads. The quantum of dust generated on these roads using the specified control material was set as the standard required on all gravel roads, regardless of gravel material used. The Key Performance Measure for dust in New Zealand is set at 3.5 milligram/m^3/hour as maximum dust to be generated by vehicles using the gravel road in question and shall not be exceeded at any time.

6 Conclusions and recommendations

In conclusion it can be generally mentioned that with appropriate gravel material selection specified in a locally formulated PMDM and construction and maintenance procedures stipulated in appropriately documented SSRWs, based on performance, the sustainability of gravel roads will be enhanced. For that concluding remark to succeed, the current PMDM and SSRWs used in Tanzania as well as those used in Sub Sahara Africa should be reviewed now and then to reflect the current practice. The following recommendations attempt to address the current Tanzania's PMDM and SSRWs shortfalls and focus on the effects of gravel roads performance on environmental and climatic changes and vice versa.
i) The engineered gravel road performance can be significantly improved through extensive empirical study of existing gravel roads and the results documented in SSRWs for the covered local area. ii) Those sections in the current Tanzania's PMDM and SSRWs addressing environment and climatic changes mitigation measures which are not economic, bearing in mind the country's economic strength and level of technology, have to be revisited and edited accordingly. iii) The extents of global warming affecting local areas or national at large have to be established for its effects to be addressed during design period. iv) The science of managing gravel materials borrow pits has to be put in place in PMDM, so as to guide users to use them efficiently and effectively to avoid environment degradation. v) Dust control measures on gravel wearing course should be listed in SSRWs and applied on all gravel roads with heavy traffic regardless of its category.

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