# THE FORMULATION AND APPLICATION OF A GRAVEL LOSS MODEL IN MANAGEMENT OF GRAVEL ROADS IN IRINGA REGION, TANZANIA

**By**

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# DECLARATION

I, Richard Robert Mwaipungu, hereby declare that this thesis, except where indicated in the text, is the candidate's own work and has not been submitted in part, or in whole, at any other University or University of Technology, and that it's only prior publication was in the form of conference papers and journal articles which are listed in Appendix 13.

This research on the formulation and application of a gravel loss model in management of gravel roads was conducted in Iringa region, Tanzania, and registered at the Durban University of Technology under the supervision of Professor Dhiren Allopi.

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# ABSTRACT

Among various gravel roads distress prediction models in existence, a gravel loss prediction model is considered critical in selecting the optimal re-gravelling schedule for effective maintenance management of gravel roads. However, due to the number of variables contributing to deterioration of gravel roads and hence gravel loss, gravel loss prediction models are not readily transferable from one geographical location to another, particularly if the locations in question differ in climatic condition, gravel material characteristics, quality of construction and maintenance, terrain, traffic characteristics and driver behaviours. Addressing the aforementioned local characteristics pose a challenge to existing international gravel loss prediction models when employed locally, resulting in inaccurate prediction of gravel loss. Hence the need for a gravel loss prediction model to be formulated locally so as to address local characteristics influencing gravel roads deterioration.

The main objective of this study was to formulate locally, a statistically accurate gravel loss prediction model for marginal gravel materials employed to surface gravel roads in Iringa region. The intention was to address local characteristics influencing gravel roads deterioration in the region. To promote research on gravel roads management, the author has published seven papers and presented ten papers in established journals and conferences respectively, as indicated in the Appendix 13. It is author expectation that, given the right impetus, locally formulated gravel loss prediction models can be incorporated, as one of a tool, in gravel roads management systems (GRMS).

The literature review focused on the gravel road condition surveys, modelling exercises, gravel loss, and a review of existing gravel loss prediction models. The literature review also examined the version of GRMS currently practiced in Tanzania by its road organizations.

The study used factorial experimental design. Parameters which are deemed to influence the gravel loss were collected and studied. A questionnaire was used to study the status of gravel road MMS in Tanzania. The data obtained from the questionnaire responses were analysed with the aid of Statistical Package for Social Sciences (SPSS) and Microsoft Excel. A detailed gravel road condition survey of each 300 m long test section was carried out during site visits. The measurement of gravel loss through the change in average height loss formed a crucial part of the study. The modelling of a gravel loss prediction model was performed using pavemetric principles, the term coined by this study, which is principally based on econometric principles.

From the analysis of questionnaire responses, it was evident that each Tanzania Roads Agency (TANROADS) regional office and district council works department needs to have a unique MMS and GRMS which reflect their operating capacity. The results of the condition survey led to the formulation of a new range of grading coefficient (GC) to suit the local marginal materials. The gravel loss survey results assisted in establishing gravel loss thresholds. The thresholds were based on the rate of gravel loss noted in the study. These thresholds can be employed to enhance the quality control of gravel roads construction and maintenance practices.

The study formulated a gravel loss prediction model for Iringa region. The process utilized average daily traffic, climate, and derivatives of sieve analysis and Atterberg limits. The model is statistically significant at 1 % level. The model gives a constant gravel loss of 0.1 mm per annum regardless the state of the six variables in the model. This was attributed to autonomous loss that is the amount of gravel material lost through mechanical and chemical weathering.

Recommendations include the need for gravel loss prediction models to reflect local characteristics influencing the deterioration of the gravel roads in question and the modelling capacity of local road agencies. Areas for further studies are highlighted.

# DEDICATION

To

My late grandfather, Weston Mwaipungu, his late wife Ndinagwe Mafupa, my late father Robert, my late sisters, Mary, Tabu, and Salama, my late young brother Michael, and

my late daughters Ndinagwe, and Sarah.

My relationship with each of them was of understanding, mutual respect, and love until their last moments.

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Secondly, I wish to express my sincere appreciation to the Research and Postgraduate directorate of the Durban University of Technology for their financial support, without which this study would not been possible. This appreciation extends to the staff members of Alan Pittendrigh Library, Steve Biko campus and Department of Civil Engineering and Survey for physical and mental support.

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I express my appreciation to the Iringa TANROADS Regional Manager and members of staff for allowing me to use gravel roads under their jurisdiction as a case study and a materials laboratory for testing samples collected from test sites. My appreciation extends to the Prime Minister`s Office for Regional Authority and Local Government and TANROADS Headquarters for allowing me to contact all their offices in Tanzania mainland who availed to me the necessary information on the management of their gravel roads. In addition, I would like to express my sincere gratitude to universities and colleges named hereunder for their assistance during data analysis. These are the University of Dar es Salaam, Ruaha University College, the University of Iringa, the University of Dodoma, and Arusha Technical College.
Last but not least I should thank my wife, Veronica E.R. Mwaipungu and my extended family for their advice and support over the years that has brought me this far.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| AADT | Annual Average Daily Traffic |
| ADRICS | Annual District Road Inventory and Condition Survey |
| ADT | Average Daily Traffic |
| ARRB | Australia Road Research Board |
| ASIST | Advisory Support, Information Services and Training |
| AUSTROADS | National Association of State, Territory and Federal Road and Traffic Authorities in Australia |
| BSM | Budget Split Module |
| BTPA (GEIPOT) | Brazilian Transportation Planning Agency |
| CBR | California Bearing Ratio |
| CE | Civil Engineers |
| CI | Coarseness Index |
| CML | Central Materials Laboratory |
| CMM | Contract Monitoring Module |
| DFID | Department for International Development |
| DR | Dust Ratio |
| DRs | District Roads |
| DROMAS | District Roads Management System |
| EE | Engineered Earth Road |
| EG | Engineered Gravel Road |
| GC | Grading Coefficient |
| GM | Grading Modulus |
| GL | Gravel Loss |
| GRs | Gravel Roads |
| GRMS | Gravel Road Management System |
| GST | Geological Survey of Tanzania |
| HDM-4 | Highway Development and Management-4 |
| ILO | International Labour Organization |
| IMC | Iringa Municipal Council |
| IRI | International Roughness Index |

| | |
|---|---|
| LL | Liquid Limit |
| MCI | Maintenance Condition Index |
| MoTC | Ministry of Transport and Communication (Kenya) |
| MoW | Ministry of Works (Tanzania) |
| MMP | Mean Monthly Precipitation |
| NEE | Non Engineered Earth Road |
| NEG | Non Engineered Gravel Road |
| NITRR | National Institute for Transport and Road Research |
| NPRA | Norwegian Public Roads Administration |
| PCI | Pavement Condition Index |
| PF | Plasticity Factor |
| PI | Plasticity Index |
| PIARC | Permanent International Association of Road Congresses |
| PL | Plastic Limit |
| PM | Plasticity Modulus |
| PMM | Periodic Maintenance Module |
| PP | Plasticity Product |
| PRO-RALG | Prime Minister Office Regional Administration and Local Government |
| RH | Relative Humidity |
| RI | Road Inspectors |
| RMMS | Road Maintenance Management System |
| RRM | Routine/Recurrent Maintenance Module |
| SL | Shrinkage Limit |
| SP | Shrinkage Product |
| SPSS | Statistical Package for Social Science |
| TANROADS | Tanzania Road Agency |
| TBI | Towed Bump Integrator |
| TBM | Temporary Bench Mark |
| TMA | Tanzania Meteorological Agency |
| TRH | Technical Recommendation for Highways |
| TRL | Transport Research Laboratory |

| | |
|---|---|
| TRRL | Transport and Road Research Laboratory |
| UNDP | United Nations Development Programme |
| USA | United States of America |
| VC | Vehicle Classification |
| VMBI | Vehicle Mounted Bump Integrator |

# LIST OF SYMBOLS

| | |
|---|---|
| D | Time period considered since last blading (days/100) |
| Delta GL | Annual change in surface thickness |
| G | Absolute value of grade of road |
| GL | Average gravel thickness loss (mm) or gravel loss |
| $GL_e$ | Gravel loss due to environment |
| HC | Average horizontal curvature of the road (deg/km) |
| IRI | International Roughness Index (m/km) |
| Kgl | Material loss calibration factor |
| Kkt | Traffic induced material whip-off calibration factor |
| km | Kilometer |
| KT | Traffic induced material whip-off coefficient |
| m | Metre |
| MLA | Predicted annual material loss (mm/year) |
| mm | Millimeter |
| N | Weinert N-value (Weinert, 1985) |
| % | Percent |
| P075/<0.075 | Percent passing the 0.075 mm sieve |
| P26/<26.5 | Percent passing the 26.5 mm sieve |
| Rf | Average rise and fall of the road (deg/km) |
| $R_L$ | Annual rainfall measured in metres |
| $T_A$ | Annual traffic in both directions measured in thousands of vehicles |
| TLB | Number of days since last blading |
| Vc | The percentage gradient in metre/km |

# CHAPTER 1
# INTRODUCTION

## 1.1 Research background

Two years of empirical research on the performance of gravel roads surfaced with marginal materials formed the beginning of the author`s interest in studying unsealed road performance. That study, which was part of the requirements for a degree of Master of Science in Highway Engineering at the University of Dar-es-Salaam, took place from 1997 to 1999 (Mwaipungu 1999:1-82). The study focused on the effective use of pavement longitudinal roughness data as a tool for unsealed road maintenance management in Tanzania. Three gravel roads - two from Kilimanjaro region, and one from Coastal region- were randomly selected for the study.

The equipments employed for the longitudinal roughness data collection were the vehicle, vehicle-mounted bump integrator (VMBI), and Merlin, which was used to calibrate the VMBI. The field work involved: randomly selecting test sections of 200 m length; calibration of the VMBI; road condition surveys; conducting classified traffic volume counts manually; and; laboratory testing physical characteristics of marginal gravel materials employed in surfacing the test sections.

The specific objectives of the study were to develop: i) a system of locating physical and structural changes in the condition of gravel roads, and ii) a basis for allocation of maintenance resources (Mwaipungu 1999:4). The key outcome was establishment of the range of longitudinal roughness values in terms of the International Roughness Index (IRI), which could be used to trigger maintenance on the gravel roads under study (Mwaipungu 1999:73-74). The threshold values were based on the interrelationship between longitudinal roughness, traffic, climate and local marginal gravel material physical characteristics. The study recommended further research to establish the relationship between the weathering of marginal gravel materials, climate, and traffic on gravel roads performance (Mwaipungu 1999:82). This research on the formulation and application of a gravel loss prediction model in management of gravel roads in Iringa `region can be viewed at as an extension of that study.

### 1.2 Unsealed roads

An unsealed road can either be a track which has fallen out of use over a number of years, or it can be a purposely built road that has a properly designed and engineered alignment, cross section and drainage facility (PIARC 1994:II-xiv). These roads have a roadbed and surfacing layers that comprise unbound materials. The surfacing materials are either in-situ soil or gravel materials. Extensive networks of unsealed roads form the majority of roads in the world (Pearson 2012:34)

#### 1.2.1 Types and threats of unsealed road surfaces

Basically, there are three types of unsealed road surfaces differentiated by their design and construction methods used (TANROADS 2010a:8). These categories are:

i. An Engineered Gravel (EG) road, which has a controlled horizontal and vertical alignment, and a consistent cross-section with appropriate camber and side ditches. The surfacing material is normally imported gravel. This enables the road to be passable in all weathers.
ii. An Engineered Earth (EE) road which has a controlled horizontal and vertical alignment, and a consistent cross-section with appropriate camber and side ditches. The surfacing material is in-situ soil, and the road may be impassable for some period in the rainy seasons.
iii. A non-engineered earth or gravel (NEE/NEG) road which has neither controlled horizontal and vertical alignment, nor a consistent cross-section with appropriate camber and side ditches. Typically, the camber for this type of road will be flat, rutted or concave, and retain surface water in some

places. Also, this type of road may not have side ditches or possibly have inadequate ones and has variations in road width. The surfacing material is in-situ soil or gravel, and the road may be impassable for some periods during the rainy season.

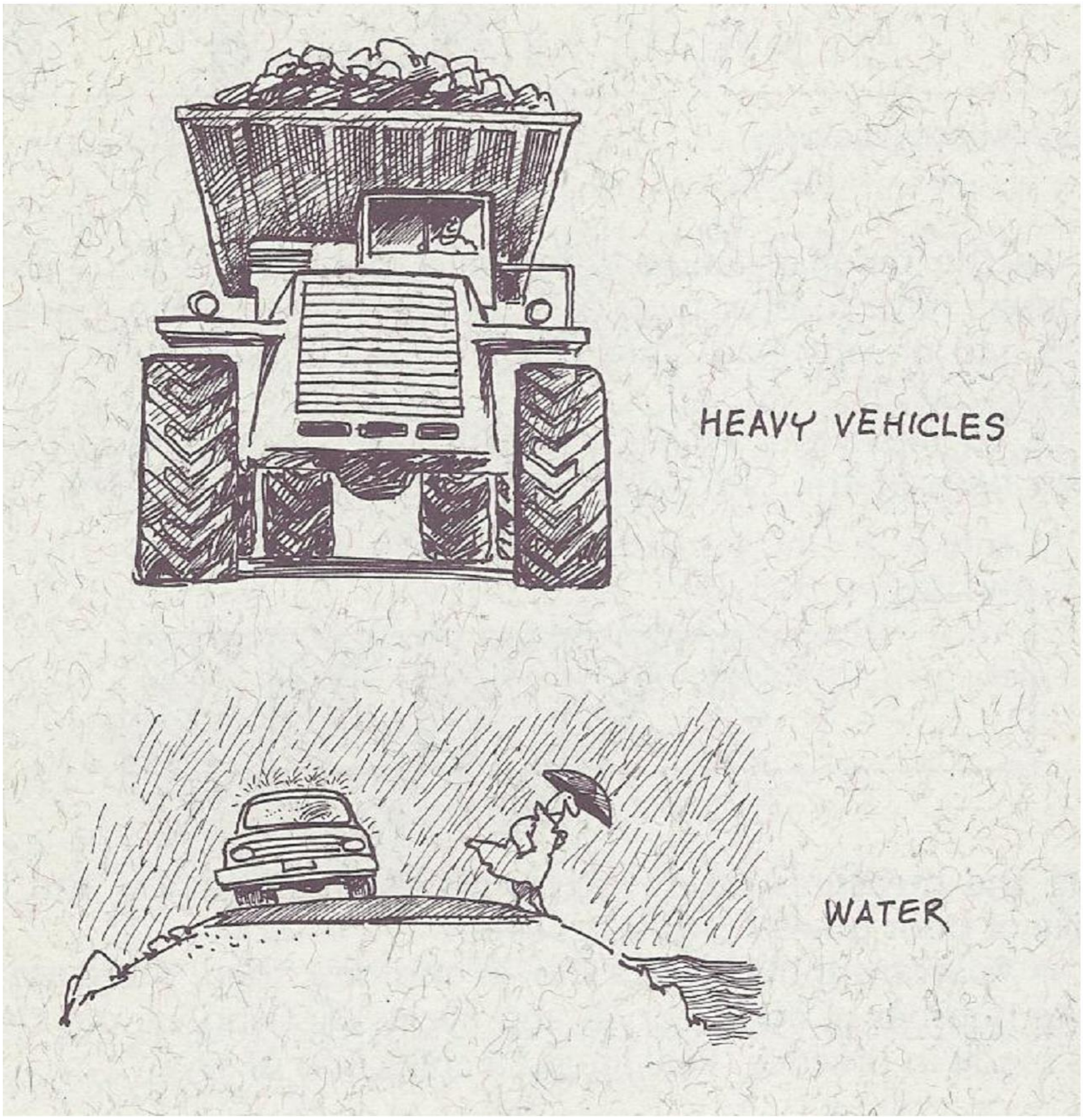


**Figure 1: The threats of unsealed road pavement**
**(Source: Schliessler and Bull 1993:48)**

Rainwater and heavy vehicles, as depicted in Figure 1, are the threats of unsealed road pavement performance (Pearson 2012:1). Surfacing unsealed roads with gravel materials provides a riding surface which can better withstand, with an effective maintenance regime, the detrimental effects of restricted heavy vehicles and rainwater. Appropriate gravelling materials permit all weather usage (Morris 1990:193; Anderson, Beusch, and Miles 1996:4-7).

This study concentrates on the performance of both engineered and non-engineered gravel surfaced unsealed roads, which are prevalent in Tanzania and the rest of sub-Sahara Africa.

## 1.3 Gravel roads

Gravel roads are common worldwide (Dawson 2011:395, Visser and Hudson 1983:143). A gravel road is surfaced with a layer of gravel material which is stronger than the natural in-situ soil. According to Pearson (2012:203), gravel roads have a designed layer of imported material, which is typically constructed to a specified standard and width providing an all-weather surface. The performance of a gravel surface is based on material quality, the location of the road and the traffic volume using the road TZ-MoW (1999:11.2).

As depicted in Figure 2, the most important function of a gravel road`s pavement is to withstand the traffic loading, without deforming excessively (Mallick and El-Korchi 2009:1). In addition, the layered structure of the pavement is meant to ensure that the load is spread out below the tyre, such that the resultant stress at the subgrade is low enough not to cause damage. Although this type of pavement is frequently employed for low traffic and fairly low loads, some have major industrial significance. It should be stressed that successful performance of gravel roads is critical to the economic operation of the industries concerned (Dawson 2011:395).

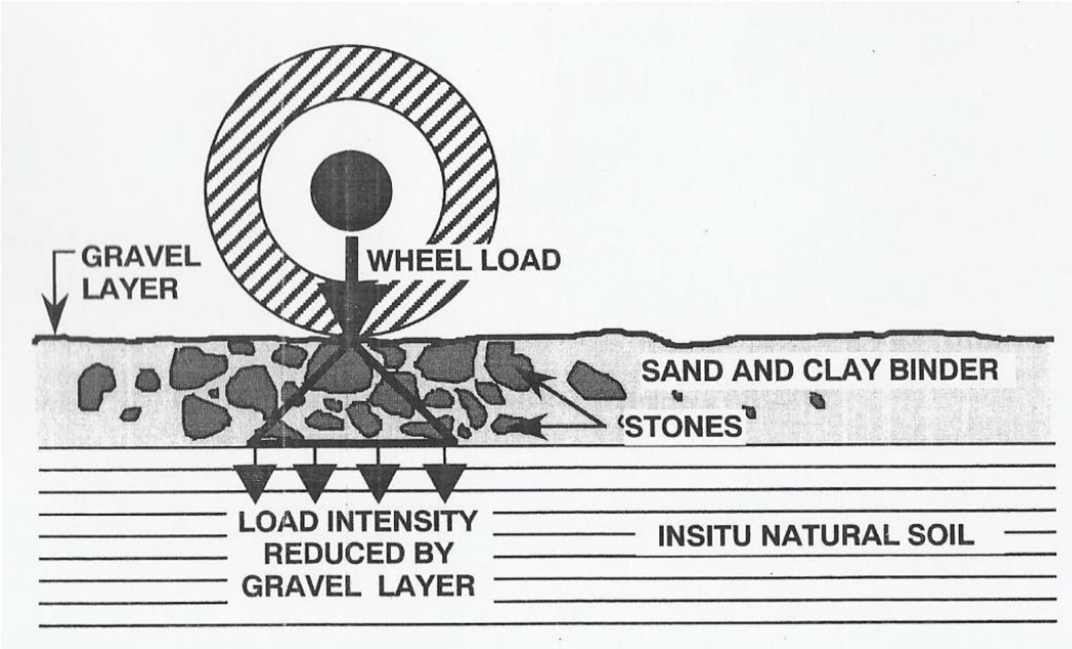


**Figure 2: Function of engineered gravel layer (Source: Anderson, Beusch, and Miles 1996:8)**

A gravel road can provide a good level of service for traffic volumes up to several hundred vehicles per day with adequate preventive maintenance (PIARC, 1994:II-xiv). Harral and Faiz (1988:2) put this traffic volume between 150-400 vehicles per day.

The two main distresses which characterise the deteriorations of a gravel road`s pavement are gravel loss and roughness. The initial gravel loss and the roughness will normally increase through shear, mechanical disintegration, and erosion of the surfacing materials caused by traffic, wind and rain water runoff (Mwaipungu and Allopi 2011). Pearson (2012:51) is of the same opinion, that there are three fundamental mechanisms of deterioration affecting gravel roads. These are:

- Wear and abrasion of the surface material under traffic;
- Deformation of the surface and roadbed material under the stresses induced by traffic loading and moisture condition; and
- Erosion of the surface by traffic, water and wind.

Inadequate funding for gravel road maintenance is one of the major challenges currently hindering the effective management of gravel roads in sub-Saharan Africa.


**Figure 3: Sources of budget inadequacy for maintenance works on gravel roads (Source: Schliessler and Bull 1993:52)**

On one hand, the resources for adequate maintenance of existing gravel roads are dwindling; that is, the resources available are often much less than what is required to keep the gravel roads network in desirable and serviceable conditions as depicted in Figure 3 (Shliessler and Bull 1993:52). At the same time, there is strong pressure to expand the existing unsealed road network to access and integrate rural areas that are severely marginalised. Inadequate maintenance is largerly the results of misallocated funds, unsound maintenance strategies and inefficient implementation (Harral and Faiz 1988:9).

To address the challenges of inadequate funds and maintenance for gravel road maintenance, road agencies have turned to gravel road management systems (GRMS) (Mallick and El-Korchi 2009:4, Visser and Hudson 1983:141).

### 1.3.1 Gravel Road Management System

A gravel road management system (GRMS) is a coordinated and systematic process for carrying out all activities related to providing and maintaining pavements (Garber and Hoel 2014:1134). The primary goal of a GRMS is to survey and predict the pavement condition and determine costs associated with its maintenance and rehabilitation over a given time frame and aid in the planning and programming of maintenance works.

According to Fay, Spofford and Thorndike (2009:5) the development of the GRMS is a logical approach road officials use to prepare a cost effective road budget. With a properly developed and implemented GRMS it is possible to make good, well-informed and consistent decisions on maintenance and rehabilitation of pavements.

GRMS can assist engineers to identify the most appropriate treatment of selected sections of the road network through the use of economic analysis, predictive models and time series information (Aggarwal, Jain and Parida 2003:273). The theory behind pavement management is based on accurately predicting the rate of roadway deterioration (Fay, Spofford and Thorndike 2009:5)

### 1.3.2 Functions and inputs of GRMS

A GRMS mostly assists with strategic and tactical planning of gravel road networks (Jones and Paige-Green 2011:10). The function of a GRMS is to:

i. Define the current gravel road condition,
ii. Establish trends of deterioration and backlog, which is a relative measure of outstanding repair work,
iii. Identify and prioritise periodic maintenance projects,
iv. Identify and prioritise "upgrading to surfaced standard" projects,
v. Provide general guidance regarding optimal grading frequencies, and
vi. Determine optimal budget requirements and impact of funding constraints at a strategic level (Fay, Spofford and Thorndike 2009:16).

The input data for GRMS are traffic volume and type, gravel material characteristics, climatic conditions, subgrade materials characteristic, and time-series data on gravel road performance. These data are used for design purpose; improving construction and maintenance techniques and establishing deterioration prediction models.

## 1.4 Road condition survey

Road condition survey or visual assessment of the condition and performance of gravel roads can be used as a whole in GRMS, maintenance programming and the monitoring of experiments (Jones and Paige-Green 2011:1). Road condition survey is most applicable for determining the following: re-gravelling requirements; whether the current grading frequencies are sufficient; and whether the gravel materials on the road is suitable for the prevailing traffic and environment and what type of distress is typical of the road/gravel combination. Furthermore, Garber and Hoel (2014:1133) stress that pavement distress condition data can be used to establish project priorities, forecasting performance and establishing options. This implies that data on the gravel road`s pavement distress condition, in terms of type, extent and severity are tools to determine which available routine or periodic maintenance options could be effective and hence selected.

### 1.5 The need for formulating gravel road's deterioration prediction models

The maintenance of gravel roads is imperative and unavoidable as it contributes to the overall safety of road users, vehicles, and cargo. To achieve an optimum maintenance level of the gravel road network, there is a need for continuing to study, improve, and increase the knowledge of how various parameters of gravel roads interact. According to Ellis (1979:5), there is growing interest among highway planners and engineers in quantifying, for a particular climate zone, the relationships between traffic volume, construction standards, the rate of deterioration, and maintenance. He further suggests that knowledge of these relationships is required if cost-effective decisions are to be made about the construction of gravel roads, or economic maintenance strategies are to be devised. Pavement deterioration models are a critical component in any pavement management system, and accurate models are essential in order to better manage roads for both strategic and maintenance works and to gain greater value from the funding available (Giummarra, Martin and Choummanivong 2004:1). In order for a gravel wearing course to be predictable it has to undergo a known design and construction procedures, which have been followed exactly (McKinlay 1988:263-348). Harral and Faiz (1988:7) are of opinion that the maintenance needs of a road network can be predicted fairly accurate from a set of structural characteristics, such as age, climate, materials characterisitics, traffic, design standards, construction standards, and subsequent maintenance.

Due to variation in the environments surrounding gravel road pavements, the gravel road networks, after construction or receiving maintenance treatments, do not deteriorate at the same rate (Mallick and El-Korchi 2009:3). To capture this deterioration rate statistically there is a need to perform regression analysis between various parameters contributing to this phenomenon.

Furthermore, the performance of the gravel road system is complex. The condition of a gravel road pavement at any time reflects the interrelationships between economic, environment, quality, quantity, structural and management variables (Veeraragavan 1995:483-492). Effective progressive monitoring of the nature of the deterioration of gravel roads will reveal a state of performance leading to appropriate action. This type of monitoring may also provide a warning of impending behaviour which threatens to shorten the life span of gravel road pavements in time for preventive maintenance action to be taken (Lay2009:286-287). Anastasopoulos, Mannering and Haddock (2009) are of opinion that given the important role that pavement maintenance treatments play, understanding the performance of these treatments has the potential to provide improved resource allocation and more effective use of maintenance funds.

In the light of the above discussion, it is appropriate to conclude that gravel road pavement performance studies, which will result in formulation of a performance model to predict its gradual deterioration, are necessary (Paige-Green 1995). Giummarra, Martin and Choummanivoug (2004:10) stress that the formulation of suitable deterioration prediction models for local roads are much-needed worldwide if local roads are to be better managed in the future. According to the United States of America Department of Transportation; Federal Highway Administration (2000) performance prediction model is a critical tool in effective pavement design and management.

### 1.6 Gravel loss prediction models

The principal maintenance activities of gravel roads are grading and reshaping. The frequencies at which grading and reshaping should be applied depend on the economic trade-off between the costs of the grading/reshaping and the benefit to be gained from reducing road-user costs (Paterson 1991:143). According to the Brazilian Transportation Planning Agency (BTPA) (GEIPOT) and UNDP (1981:3) gravel loss prediction models are an essential technological tool for economic analysis of gravel road infrastructure.

The loss of gravel material is caused by both natural weathering and by friction and whip-off from vehicles (Paige-Green 1989:6.1). As far back as 1929, Strahan (cited in Paige-Green 1989:6.1) noted that an average gravel loss of 15 mm per year occurred. He concluded that up to half of that loss was due to "weather influences, grade conditions and machining", regardless of traffic density. Gravel loss is one of gravel roads distress modes which makes gravel roads susceptible to rutting under traffic and raises the risk of losing passability in wet conditions (Paterson 1991:143). Gravel loss is of primary relevance to the quantification of the amount of gravel materials needed to replenish that which is lost. Furthermore it is a primary determinant of the timing of re-gravelling operations.

Gravel loss prediction models are employed to quantify the progression rates of gravel loss as a function of traffic, road geometry, material properties, and climate. The prediction of the expected gravel loss from a gravel road is of utmost importance for both unsealed road design and maintenance planning as gravelling and re-gravelling operations are the most costly construction and maintenance procedures (Paige-Green 1989: 6.1). The models of predicting gravel losses are critical in selecting the optimal re-gravelling schedule for effective maintenance management of gravel roads.

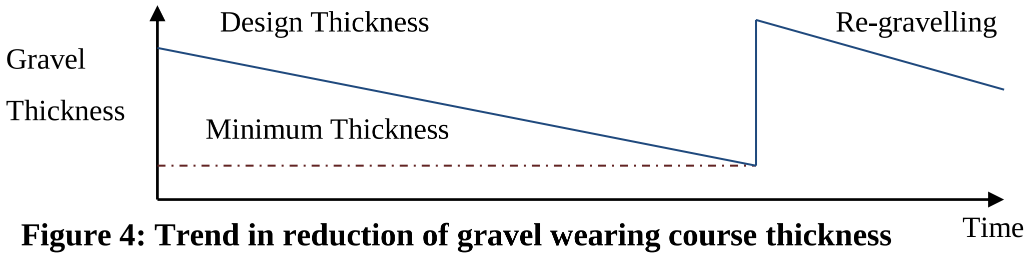


**Figure 4: Trend in reduction of gravel wearing course thickness (Source: Paterson 1991:144)**

For a management model, the life-cycle of gravel roads deterioration and maintenance can be depicted by the measurements of the trends of material loss over time, as shown in Figure 4 (Paterson 1991:143-144).

The mean gravel surfacing material design thickness tends to be reduced progressively under the action of traffic and climate-related deterioration. This reduction in thickness, by keeping other variables constant, may vary with material characteristics, and the effectiveness of maintenance practice, until it reaches the minimum depth which shall trigger re-gravelling, and then the cycle repeats itself (Paterson 1991:143).

Although it has limitations, the gravel loss measurement is among the tools available for implementing maintenance management goals in terms of depleation rate of gravel loss. Knowing a gravel roads unique rate of gravel loss is the key to a correct and optimum decision on its re-gravelling cycle (Mwaipungu 1999: 2).

### 1.7 Problem statement

Based on the above discussion, it is justifiable to say that for effective management of gravel roads, one need, among other tools, the output of visual assessment of the condition and performance of a gravel road and a gravel loss prediction model. However, due to the number of parameters which contribute to the performance of unsealed roads and gravel loss, both cannot be readily transferable from one geographical location to the other without affecting their relevance. The parameters which limit such transferability vary within themselves and location. The parameters in question are: climatic condition; terrain; gravel material characteristics and weathering; road user behaviour; quality of construction and maintenance; and traffic type and volume.

Various authors on gravel roads performance, agrees that most existing international gravel loss prediction models are unable to capture the intangible characteristics of the locality, and cope with variability in materials and climates in predicting gravel loss. One of these is Uys (2008:1), who pointed out that gravel loss predictions models which were used in South Africa by then, were neither accurate nor transferable due to their local influences. Using international predictions models result in a poor estimation of gravel loss, and consequently, inaccurate estimation of the amount required for re-gravelling and unreliable design input for gravel layer thickness requirements. This goes against the theory of pavement management, which is based on accurately predicting the rate of roadway deterioration (Fay, Spofford and Thorndike 2009:5).

In a set of simulation experiments conducted at Purdue University in the USA, it was noted that the minimum expected life cycle costs of pavement sections were found to vary with the extent of the deterioration model prediction error.

Figure 5 shows that using a deterioration model with prediction error of about 7.5 pavement condition index (PCI) instead of the 12.5, USA models would save transportation agencies about 0.90 US $ per square metre of a road (Madanat 1987: 2).

The limitation of the existing international gravel loss prediction models in addressing local condition can be attributed, but not limited to:

- The challenge faced by these models to capture the quality of work during the construction stage and subsequent maintenance operation.
- Failure of models to adequately address the climatic factors which have more of a role to play in gravel road deterioration than do either traffic or material properties alone (Paige-Green 1999:163-171).
- Models becoming obsolete.
- Models being limited by the data that feed them.

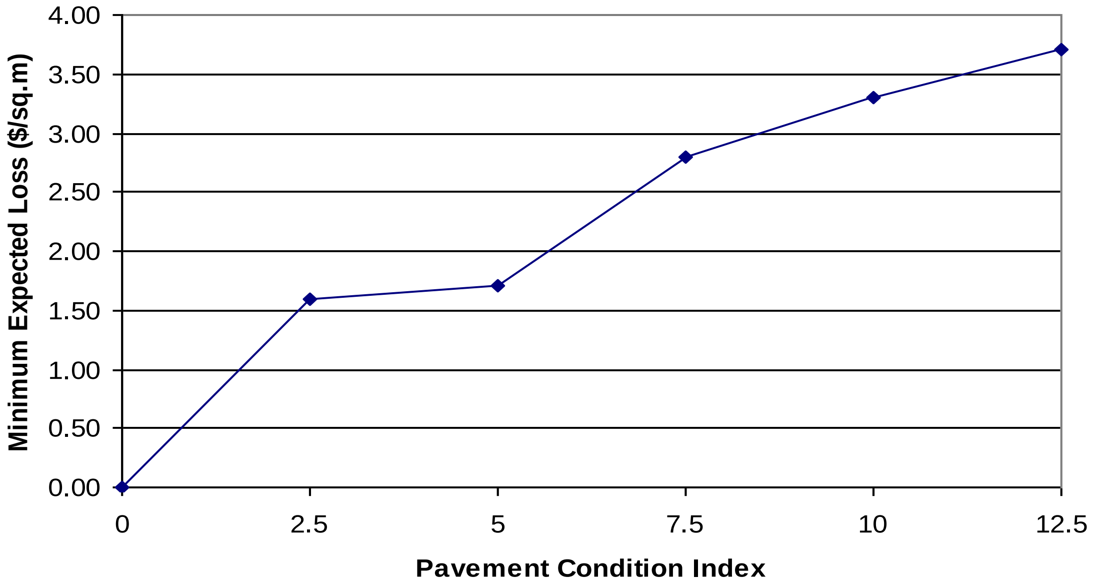


**Figure 5: The effect of PCI error in pavement performance forecasting (Source: Madanat 1987:2)**

- Failure of some models to address the characteristic variation within the same type of local gravel material.
- Advances in vehicle technology which increases vehicles ability to travel faster. These increases in speeds increase the rate of gravel loss, which may not have been accounted for and which cannot be calibrated due to its uniqueness.

Findings from research studies carried out in the Western Cape in South Africa have highlighted the failure of internationally accepted gravel road deterioration prediction models to predict change in the deterioration of the gravel roads. The failure is due to the effect of improved construction techniques, where more emphasis on better material selection and more stringent quality control measures have been put into place. These measures, among others, have slowed down the rate of gravel loss (van Zyl, Henderson and Uys 2007:217).

It should be stressed that parameters such as traffic volume and type, and climatic conditions vary throughout the day, month, and year. Road geometry, material properties, construction standards, and maintenance practice vary from one location to the other, and the list goes on, thus creating a cyclic nature of gravel road performance, which implies that for gravel loss prediction models to be effective, they have to be dynamic and local.

According to Paige-Green (1989:6.3) the variability of materials properties within any one material group will influence the gravel loss. He further points out that plasticity and grading tests results for gravel materials of the same geological classification vary considerably depending on the condition and stage of weathering. In addition quality and testing procedures vary between individuals, from one materials laboratory to the other, and from one country to another.

PIARC, TRL and Intech Associates (2002:1) support the idea that gravel loss is very specific to material and location, and there is some variation between the results of the trial and relationships derived in different regions and conditions. Giummarra, Martin and Choummanivong (2004:10) on the other hand, state that pavement deterioration prediction models, which were used in Australia before formulating the local ones, were based on the performance of overseas pavements, and therefore were not accurately predicting pavement performance under Australian condition. These caused local government authorities across Australia to have difficulties with their PMS package. In this regard, they have emphasized the importance of having gravel road performance prediction models that reflect the local characteristics.

Furthermore, the results of work carried out by Paige-Green and Visser (1991:142) showed the danger of using performance prediction models developed in a different environments. PIARC, TRL and Intech Associates (2002:1) argue that the accurate gravel loss prediction models can only be achieved through local experience and research. GEIPOT and UNDP (1981:3) further stress that performance prediction models must reflect the conditions to which they are applied and must either be developed from local data or modified and verified based on such data.

Iringa region has somehow different climatic conditions, heterogeneous subgrade soils, terrain, and marginal gravel materials behaviour from other regions in Tanzania and the world at large, which affect gravel road performance. As a result, this necessitates the parameters identified above to be reflected in any gravel loss prediction model for it to be applicable in the region.

## 1.8 Research justifications

This study on the formulation and application of a gravel loss prediction model for management of gravel roads was conducted in Iringa region, Tanzania. The followings are the justifications for this study.

### 1.8.1 Variability of natural materials used and environmental conditions

In general the performance of gravel roads surfaced with marginal materials depends much on material physical characterisitics, the location of the road, and the traffic volume using the road. The material's behaviour and natural characteristics, road location and traffic volume characteristics, are not transferable to other geographically different areas due to the inherent variability incorporated within each one of them.

The properties of all marginal gravel materials used to surface unsealed roads change over time with use and exposure to environmental condition. These changes can be noted during routine visual assessment of the condition and performance of gravel roads. Furthermore, use and exposure to environmental conditions are the variables unique to the locality where the gravel roads are located; and hence need to be studied to be captured in the development of a local gravel loss predicting model or for calibrating the existing one.

### 1.8.2 Influence of climatic changes on pavement performance

Regardless of the similarities in climatic condition, the finding on gravel road performance from one county cannot be translated directly to another country due to differences in properties of marginal materials used as gravel wearing course, seasonal climatic changes, and construction techniques (Visser and Hudson 1983:147). Study of the effects of seasonal climatic changes in performance of marginal gravel materials used for surfacing unsealed roads in the host country's climatic conditions is therefore, important to road organizations for assessment of current design, construction and maintenance or rehabilitation practices (Watson and Rajakapse 2000:45). Tanzania has been demarcated into three climatic zones, namely dry, wet and moderate. Iringa region enjoys all three climatic zones, and the gravel roads under study are located in all three zones.

### 1.8.3 The need to study the behavioural changes of marginal gravel materials under the impact of traffic and climatic elements

For the sake of protecting the environment, it can be deduced that the economical use of gravel surfaced materials should to be advocated through deployment of marginal gravel materials. This can be achieved through studying and incorporating into unsealed road performance prediction models the impact of climatic elements and traffic volumes on marginal gravel materials. Study has to be extended to visual assessment of the condition and performance of gravel roads surfaced with marginal materials. Ellis (1979:6) argues that an empirical relationship has to be devised to link frequency of grading necessary to maintain an acceptable level of service to the volume of traffic, climatic and the type of gravel materials. Such studies will aid in optimum structural design, construction and maintenance of gravel road network in question. This study is focused on the performance of marginal gravel materials deployed to surface unsealed roads in Iringa region.

### 1.8.4 Advocate further scientific research study on gravel road performance

The fact that gravel surfaced roads are the type of flexible pavements which were not given enough research attention in the past (Ellis 1979:3) is in itself a good reason to start reversing the trend. In spite of accumulated experience in the expected performance of unsealed roads, still the design of these roads is based on recipe methods. For this trend to change, empirical research is required to provide consistent and scientifically sound policy regarding the structural design, construction and maintenance of unsealed roads in sub-Sahara African countries and beyond. Empirical research broadens understanding of the physical process of road deterioration (Harral and Faiz 1988:2).

It should be stressed that the gravel roads are sustainable; hence the scientific research on gravel roads should be geared towards improving their structural capacity. Such studies shall aid in slowing down the rate of gravel loss caused by the adverse impact of climatic elements and traffic loading and volumes. Furthermore, it will lengthen their design life with appropriate design, construction, and maintenance methods.

### 1.8.5 Improve the gravel road maintenance management systems

Eventually the construction of unsealed road networks needed by the sub-Saharan countries for accessing rural areas shall come to completion. The need to preserve existing gravel road networks as a national asset is becoming apparent to governments and their road organizations (Mwaipungu and Allopi 2012a). Furthermore, many of the unsealed roads constructed or rehabilitated in 2000 and 2005 have come to the end of their design lives, and some have deteriorated very badly. As a result, it is now clear that the gravel road maintenance management is going to become one of the most rapidly developing areas of highway engineering in the next decade and beyond (Mwaipungu and Allopi 2012a). Hence, any study dedicated to improve the tools for managing the maintenance of gravel roads has to be encouraged.

### 1.8.6 Gravel loss prediction models have to reflect the condition of the host country

The study of gravel loss on gravel roads is the focal point of this research on the formulation and application of a gravel loss model in management of gravel roads in the Iringa region. The aim of this study is to formulate a gravel loss prediction model which is appropriate for marginal gravel materials in Iringa region conditions. Also the model needs to reflect gravel road design, construction, and maintenance techniques prevalent in Tanzania. Gravel loss phenomenon is specific to gravel material type and location (Mwaipungu and Allopi 2014:590). Studies conducted worldwide on gravel loss, have indicated that there is a variation between the results of trials and relationship derived in different regions and conditions. Hence it suffices to conclude that there is no substitute for local experience and research, which shall enable more accurate prediction models to be developed through application of pavemetrics principles. These principles are similar in methodology but different in objectives with econometrics principles.

Furthermore, there is less quantitative information on the engineering performance and modes of deterioration of gravel roads in Tanzania; hence this study will add to existing knowledge of how marginal gravel materials available in Iringa region perform under prevailing traffic and climatic conditions.

### 1.8.7 Statistical legitimacy

Having one specific performance predicting model applied either across an individual country or across countries has been proved by various authors to lack statistical legitimacy. The variability between various parameters in play during the gravel road deterioration cycle, and the variability in the interaction between these parameters dictates the form of the performance prediction model to be used in the sphere of this influence. This study which is the basis for formulating a performance model is composed of a number of elements, such as but not limited to: a) natural marginal material characteristics and composition, b) vehicle movements, volume, composition, and loading, c) terrain and location of roads, d) climatic condition, and e) skills and experience of personnel conducting the exercise.

## 1.9 Justification of the research methodology

### 1.9.1 General

A variety of literature was consulted in search of a methodology that best suits this research. The *Advanced Learner`s Dictionary of Current English* (2000:999) defines research as “a careful study of a subject in order to discover new facts or information”. The *Dictionary of Contemporary English for Advanced Learners* (2009:1100) defines methodology as “the set of methods and principles that one uses when studying a particular subject or doing a particular kind of work”, while Fellows and Liu (2008:57) define methodology as the principles of the methods by which research can be carried out.

Leedy and Ormoud (2014:9) list two functions of research methodology which are: (i) to control and dictate the acquisition of data, and (ii) to correlate the data after their acquisition and extract meaning from them. Different approaches are available to classify research activities depending on the methodology employed to generate knowledge, or the nature of the data required for the research or on the method employed to generate the data. The following classification methods are considered in this chapter: a) deductive and inductive; b) qualitative and quantitative; and c) opinion, empirical, archival and analytical.

### 1.9.2 Deductive and inductive method

The essential feature of research for a doctoral degree is that it should lead to the discovery of new facts and information that makes an original contribution to knowledge (Phillips and Pugh 2010:38). In order to contribute to knowledge, research may aim to generate a new theory, in which case it is inductive; or it may aim to test an existing theory, and is therefore, deductive. According to Buckley, Buckley, and Chiang (1976) deductive research is guided by hypotheses that are either accepted or rejected during the course of research. The use of deductive research requires some prior knowledge upon which to construct the hypotheses.

Inductive research is guided by a scientific inquiry, and the researcher's efforts are concentrated on the procedures to obtain and analyse data and focus the analysis for the purpose of generation of a new theory. However, some research consists of both modes. The application of inductive research method can result in a hypothesis that may require testing through deduction. Similarly, deductive research method may raise a need for a detailed inquiry into a certain aspect of a problem, in which induction is applicable.

A study of the formulation and application of a gravel loss model in gravel road management has never been undertaken in the Iringa region, which is in the southern part of Tanzania. The data collected on changes of gravel road elevation, and data associated with this change will produce a gravel loss prediction model for marginal gravel materials used for surfacing gravel roads in Iringa. This study is unique to the area under study. The researcher employed existing knowledge on how to collect data on gravel loss and related data. The researcher used existing statistical data analysis in order to generate the gravel loss prediction model appropriate to the Iringa region. In this regard, the study has employed both deductive and inductive methods.

### 1.9.3 Qualitative and quantitative methods

An array of qualitative and quantitative methods exists for carrying out research, and these have an impact on the way the data are collected, analysed, interpreted and presented.

According to Holt (1998:83), a qualitative approach means to "utilize subjective methods very often based on a personal opinion, perception or feeling." Qualitative research methods include process observation, opinion or expressions, unstructured interviews and open question surveys.

Kerlinger (2007) defines a quantitative research methodology as "the systematic, controlled, empirical and critical investigation of natural phenomena guided by theory and hypothesis about the presumed relations among such phenomena." The quantitative approach involves gathering of factual data and studying relationships between facts and how such facts and relationships agree with the theories and findings of previous research. This could be achieved by using structured interviews, structured surveys, symbolic models and physical experimentation (Holt 1998:83).

Quantitative and qualitative methods have been customarily associated with research in the natural sciences and social sciences respectively.

According to Fellows and Liu (2008:27) there is an increasing recognition of the potential of qualitative studies in what may be primarily a quantitative study. More than one research methodology can be used to study the research problem, and when one employs such an approach, this is referred to as triangulation.

Fellows and Liu (2008:28) define triangulation as the “use of two or more research methods to investigate the same thing." Triangulation is employed to complement the advantages while minimizing the disadvantages of the individual approaches.

This study on “The formulation and application of a gravel loss model in management of gravel roads” used both strategies, qualitative and quantitative. A quantitative approach (pavemetrics), based on the empirical study, was used to formulate the gravel loss prediction model. On the other hand, a qualitative approach was used to generate an understanding of the challenge faced by Tanzania Road Agency (TANROADS), and Local government district /municipal engineer offices in dealing with maintenance management of gravel roads.

### 1.9.4 Opinion, empirical, archival and analytical methods

According to Buckely, Buckley, and Chiang (1976), there are four research strategies depending on whether the research is deductive or inductive. The authors define ‘strategy’ as being the” essential nature of the data and the process by which it is found and analysed." The said four strategies are:

- **Opinion research**: seeks views, judgement or appraisals of other persons with respect to a research problem. This is usually achieved through interviews, opinion polls and questionnaires.
- **Empirical research:** based on observation or experience by the researcher through experimentation or fieldwork. This approach calls for the researcher to actively participate in the observation, instead of relying on the experience of others. Empirical research, unlike opinion research, “examines what actually happens as opposed to what people say has happened, is happening or may happen."

- **Archival research**: concerned with the examination of recorded facts either in their primary, secondary or physical form. Primary data consists of original documents or official files and records, while secondary data consists of published data gathered by other investigators based on summaries or analyses of primary data. Both primary and secondary archives can be obtained through written records, tapes and other forms of documentation. This distinguishes them from empirical data, which is based on physical observation.
- **Analytical research**: entails the use of internal logic by the researcher to solve the research problem. The problem is usually broken down into its component parts to discover its true nature and causal relationships among its variables. With analytical research, there is no necessity for the explicit reference to external data. The problem is solved "logically or philosophically."

This study was conducted by using archival, empirical and opinion strategies. The opinion strategy was carried out by means of mailed questionnaires.

## 1.10 Contribution to knowledge

According to McKinlay (1988:265) not all research on engineering problems lead to an immediate or comprehensive solution to those problems. He stresses that these researches may yield a better understanding of the nature of problems, which will help in the amelioration of those problems. According to Fellow and Liu (2008:4) research is a voyage of discovery regardless of its outcome. They further explain that discovery is a process divided into two parts: i) process of formulating the investigation topic, and ii) process of investigating the topic. According to them even if no new knowledge is added, the investigation may lend further support for extant theory.

### 1.10.1 General

The following section evaluates the extent to which this study contributes to solving a practical problem, or improves on traditional thinking, which is an essential feature of an applied research for a doctoral degree in technology (Bless and Smith, 2013:3; Fellows and Liu 2008:8; Leedy and Ormoud 2014:5; Holt 1998:11; Walker 1997). According to Philips and Pugh (2010:61) doctoral degree research can be regarded as making an original contribution to knowledge if the research:

a) Carries out empirical work that has not been done before;
b) Makes a new synthesis that has not been tried before;
c) Makes a new interpretation of existing material;
d) Carries out an activity in a geographical area, such as a country, that has previously not been carried out in that area before;
e) Applies a particular technique in a novel way;
f) Introduces substantial new evidence to an old issue;
g) Is cross-disciplinary and uses different methodologies; and
h) Adds to knowledge in a way that has not been tried before.

This study is empirical and aims to formulate a gravel loss prediction model for marginal gravel materials used in surfacing gravel roads in Iringa region. The model shall be used in gravel road management. In ascertaining the current practice of gravel road management in Tanzania, the study used a questionnaire. The study is the first of its kind in that area and in Iringa region. Hence ‘a’, ‘d’, and ‘e’ applies.

There is a gap in the knowledge of how marginal gravel materials, which are used as wearing course on unsealed roads, behave under climatic and environmental conditions and the traffic pattern prevailing in Iringa region. Not only is it the case that gravel loss prediction models have never been used in Tanzania, but it is also the case that no data on gravel loss has been collected in Iringa region for the purpose of gravel road management. Hence this study adds knowledge using a methodology that has not previously applied in Iringa region, Tanzania.

DUT post graduate student guide (2014:4) has listed eight criteria which must be shown by a candidate of Doctor of Technology through his/her thesis. Among this eight the last three are: “a) intellectual independence and research leadership through managing advanced research and development in a field professionally and ethically; b) the capacity to evaluate one`s own and others` work critically on the basis of independent criteria; and c) the capacity to make a new contribution to the existing knowledge base with a specific field/discipline.” The author is of opinion that he has fulfilled all eight criteria as listed in the DUT post graduate student guide.

### 1.10.2 Bias in the research process

Leedy and Ormoud (2014) define bias as “any influence, condition, or set of conditions that singly or together distort the data from what may have been obtained under the conditions of pure chance. Furthermore, bias is any influence that may have disturbed the randomness by which the choice of a sample population has been selected."

The following are some of the forms of bias possible in an empirical study using a questionnaire:

a) Randomness bias in the selection of government institutions specifically targeted for interview by using a questionnaire (Leedy and Ormoud2014).
b) Researcher bias on the self-completed responses in the questionnaires. “Responses given in the closed questionnaire sometimes represent the researcher’s response and may not necessarily represent the respondent’s answer or opinions in the absence of leading questions” (Fellows and Liu 2008).
c) Researcher bias in the research design, data collection and analysis. This could be attributed to human error or misinterpretation (Leedy and Ormoud2014).

d) Respondents bias resulting from respondents who gave false information due to “mistrust, fear, conformity, or social status” (Bless and Smith 2013).

## 1.11 Aim

The aim of this study is to improve Tanzania`s gravel road management system by:

- Formulating a statistically accurate gravel loss prediction model for Tanzania`s marginal gravel materials used for surfacing gravel roads; and
- Enhancing further gravel road management systems through the use of visual assessment of the condition and performance of gravel road and deterioration prediction models.

## 1.12 Objectives

The general objective of this study is an attempt to improve understanding of the intrinsic and diverse characteristics of gravel loss associated with the type of gravel materials in question. This study attempts to link these characteristics with parameters influencing gravel wearing course performance through the formulation of a gravel loss prediction model. The understanding gained might enable the relevant authorities to combat the annual rate of gravel loss, reducing it to the lowest level possible. The ultimate intention is to extend indefinitely a gravel road's life cycle through appropriate design, construction and maintenance procedures. The specific objectives of this study, which tally with the aims of the study, are to:

- Formulate for local application, a statistically accurate gravel loss prediction model through investigation of marginal gravel materials’ geotechnical properties and physical characteristics, and the interaction over time between these properties with prevailing traffic characteristics and climatic conditions of Iringa region;

- Determine a rational method of quantifying quality of gravel road construction and subsequent maintenance operation, based on visual assessment of the condition and performance of gravel roads and measured rate of gravel loss; and
- Stimulate the culture of formulating gravel loss prediction models locally.

## 1.13 Terminologies

Terminologies defined herein are those words or terms which have been used in this study with the purpose to elucidate the research's specific objectives and the thesis as a whole.

**Behaviour**

Behaviour is the response of a pavement to traffic load and environment. This response is usually a function of the mechanical state which occurs as a primary response to the input.

**Deformation**

Deformation is the change in a road surface profile from the constructed one. It is usually the result of disturbance of loosely bound materials. Much of deformation of unsealed roads can be attributed to wear and erosion of surface material.

**Distortion**

Distortion is the state of change of the pavement from its original shape condition.

**Distress modes**

Distress modes are those responses which lead to some form of distress when reaching a certain limit.

**Distress manifestations**

Distress manifestations are the visible consequences of various distress mechanisms that usually lead to a reduction in serviceability.

**Distress surveys**

Distress surveys are made for the purpose of determining the condition of a pavement at a given time, without evaluating the structural strength of that pavement.

**Efficiency**

Efficiency is the best use of resources by obtaining the best possible results with the limited resources available. Efficiency could be described as spending as little as possible to carry out certain tasks deemed necessary on the road network.

**Effectiveness**

Effectiveness is related to meeting targets. In this study effectiveness could mean being successful in keeping the road network in good condition and being able to rehabilitate roads, which have deteriorated beyond normal maintenance.

**Evaluation surveys**

The purpose of an evaluation survey is to determine the structural adequacy of a pavement and to establish the reasons why the pavement condition is as it is.

**Maintenance Management Systems (MMS)**

MMS is a process of coordinating and controlling a set of activities in order to maintain gravel roads so as to make the optimum use of resources available.

**Marginal gravel materials**

Marginal gravel materials are materials which do not comply with the ideal gravel material specification to be employed for surfacing unsealed roads with regard to their physical and mechanical characteristics.

**Pavement**

Pavement is a horizontal structure supported by *in situ* natural materials. Its purpose is to distribute the applied traffic and other loading to such levels that they can safely and reliably be carried in a sustainable manner by the supporting soil.

**Performance**

Performance is a measure of the accumulated service provided by a facility, i.e. the adequacy with which a pavement system fulfills its purpose.

**Present serviceability**

Present serviceability is the ability of a specific section of pavement to serve current traffic in its existing condition. The existing condition means the condition on the date of rating.

**Standard deviation**

Standard deviation is a uniform amount that each value in a distribution deviates from the distribution`s mean.

**System**

System can be described as a device or scheme, which behaves according to some description to accomplish an operational process.

**Variance**

Variance is an average of how the scores are dispersed from the centre of the scores.

## 1.14 Overview of chapters

The following is a brief overview of the structure of this study.

### Chapter 2–Literature review

Chapter 2 gives a brief explanation regarding visual assessment of the condition and performance of gravel roads, model formulation, a framework for guiding the choice of model, and areas in which models can be improved. The characteristics of gravel loss, and gravel loss models prediction error are expounded.

The importance of having dynamic gravel loss prediction models which reflect the local characteristics in terms of variability in gravel materials, climatic changes, gravel road design, construction and maintenance is given due consideration. The chapter insists on consistency of personnel, equipment and methodology employed in collection of the gravel loss data. For the sake of reliability, gravel loss empirical studies should cover areas with similarities in geographical features, climate and quality of work in construction and maintenance. Moreover reviews of the existing gravel loss prediction models are presented to give a picture of how various variables in these models have been treated. To improve the accuracy of gravel loss predicting models the chapter proposes the use of pavemetrics principles, which are similar with econometrics methodology principles.

### Chapter 3 – Overview of Tanzania's Gravel Road Management System

The chapter 3 discusses and points out factors affecting the efficiency and effectiveness of the pavement management system as practiced by Tanzania`s road organizations. Attention is paid particularly to gravel road management, and Tanzania`s practice is compared with those in the developed world. It is expected that ironing out those aspects of management affecting effective and efficient conservation of gravel roads will further improve their performance.

**Chapter 4 – Data collection and analysis methodologies**

Chapter 4 is on data collection and analysis methodologies. Twenty two test sections on four gravel roads were randomly selected for the study. Twenty one test sections were on three gravel roads managed by TANROADS Iringa region, classified as “regional roads”, and one was on the gravel road managed by Iringa Municipal Council (IMC). The road managed by IMC is in urban areas and is serving as a collector road. The site investigation methods used to collect data on these twenty two test sections for correlation with gravel loss data is presented.

Furthermore, a questionnaire which was used to gauge the level of the gravel road management system as practiced by Tanzania road authorities is presented. Data on the rainfall quantity on Iringa region, traffic volume, and laboratory tests conducted on gravel materials are presented and discussed. Further, visual assessment of the condition and performance of gravel roads aimed at recording the distress on the gravel road sections under study, and pavemetrics method (based on econometric-panel data) employed in formulating gravel loss prediction model, are discussed.

**Chapter 5 – Analysis and discussion of questionnaire responses**

Chapter 5 presents the analysis of responses obtained from the questionnaire posted to TANROADS region offices and district and municipal councils engineers’ offices. The objective of the questionnaire was to gauge the capacity of Tanzania road organizations to run gravel road maintenance management systems. The questionnaire responses are presented and analysed using SPSS, and Windows Excels software.

**Chapter 6 – Gravel materials test results, traffic and climatic data analysis**

The results obtained from the laboratory tests conducted on gravel materials sampled from borrow pits and road surface are presented in tabular form and discussed. The chapter further presents and discusses classified traffic volume data from test sites and climatic data in terms of temperature, relative humidity, and rainfall.

**Chapter 7 – Condition survey and gravel loss data analysis and modelling**

The summaries of data collected during gravel road test sections condition surveys and gravel loss surveys are presented and analysed. The process followed in formulating a gravel loss prediction model and the formulated gravel loss prediction model for Iringa region condition is presented and discussed.

**Chapter 8 – Summary of findings and conclusion and recommendations**

Summaries of findings and conclusion and recommendations drawn from the study are presented, specifically with respect to the economic, social and political consequences. Recommendation regarding further improvement of the gravel loss model as formulated is presented and future research work in the area of study based on the experience of this and similar studies are identified.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 Introduction

This chapter defines and explains road condition survey, prediction model formulation, framework for guiding the choice of the model, and areas in which models can be improved. The chapter moreover discusses the causes of gravel loss prediction error, and reviews existing gravel loss models.

The chapter further emphasizes the importance of having dynamic gravel loss prediction models which reflect the local characteristics in terms of: variability in gravel materials; traffic type, loading, volume, and composition; climatic changes; and the required level of services. The effects of gravel road design, construction and maintenance on the rate of gravel loss are addressed. The chapter highlights the importance of a consistent team in collecting the gravel loss data and analysis. Other recommendations put forward are that gravel loss empirical studies should cover areas with similarities in geographical features, climate and quality of work.

The chapter provides a brief discussion on pavemetrics (econometrics) and a review of existing gravel loss prediction models. The chapter ends with a conclusion and recommendations based on the chapter discussion.

## 2.2 Road condition survey

### 2.2.1 General

Various terms are employed by various authors in describing the exercise of determining visually the extent of defects on the pavement surface. Some of these terms are visual survey, visual inspection, road condition survey, or visual assessment of road condition and performance. In this study the term ‘road condition survey’ has been used.

### 2.2.2 The significance of the road condition survey

According to Oliver (2002:457) it is vital to know the condition of a road’s pavement surface and, just as important, changes in its condition over time. Furthermore, he stresses that the deterioration rates, even of similar road components, can be quite variable. This view is supported by Mallick and El-Korchi (2009:3). Morse and Green (2012:3.53) point out that for the determination of the remaining life of a pavement, or the amount of pavement repair required to extend a pavement’s life for another given time period, or the most appropriate time for pavement repair, the amount and type of deterioration in a pavement must be quantified.

Robinson and Thagesen (1996a:389) reckon that in order to assess the maintenance needs of a road network it is necessary to register the present defects, which is achieved through a condition survey. Underwood (1995:466) stresses that data on road condition provides the basis for identifying the following: road section/s with poor condition and or performance; selecting maintenance, rehabilitation, and reconstruction activities; and establishing priorities. According to Jones and Paige-Green (2011:1) visual assessment is most applicable for determining re-gravelling requirements, grading frequencies, suitability of gravel materials for the traffic and environment, and types of distress prevalent on the gravel roads in question.

### 2.2.3 Methods and frequency of conducting a road condition survey

Road condition survey data may be collected by visual survey or by a levelling instrument in the case of gravel loss. Road condition surveys should be carried out at suitable and fixed intervals to enable effective monitoring of changes in pavement condition.

The nature and extent of road condition data to be collected will depend on the importance of the road, the type of analysis to be carried out and the resources available. According to Underwood (1995:466) the simplest type of road condition survey involves inspecting each road section and noting its relative condition in terms of an overall rating score. Papagiannakis and Masad (2008:331) point out that a more detailed pavement condition survey would record measures of extent and severity. The resulting data needs to be sufficient to enable the existing condition and changes in it over time to be defined at both the section length and network levels (Underwood 1995:466). Change in pavement condition defines pavement performance (Papagiannakis and Masad 2008:251)

Jones and Paige-Green (2011:2) point out that the information required from a road condition survey dictates the structure and content of the form of assessment to be used. The following can be achieved by processing the visual assessment data (Jones and Paige-Green 2011:2):

a) Calculation of a visual condition index through the combination of a rating for the degree and extent for each distress type, together with a weighting factor based on the importance of the distress type. The visual condition index can be used to:
   - Give an indication of the condition of each segment of the road assessed;
   - Indicate changes in the overall condition of a road network or individual segments overall; and
   - Classify a road section into one of five condition categories for statistical or visual presentation as shown in Table 1.

b) Identification of required maintenance and/or improvement measures and priorities for uses as input for programming and budgeting

c) Identification of required maintenance or improvement measures for use at network or project level by maintenance teams.

**Table 1: Classification of road condition categories for statistical or visual presentation (Source: Jones and Paige-Green 2011:2)**

| **Descriptor** | Very good | Good | Fair/Average | Poor | Very poor |
|---|---|---|---|---|---|
| **Rank** | 1 | 2 | 3 | 4 | 5 |

### 2.3 Model – A variable entity

Simply put, variable is anything that is likely to change and synonyms including changeable, inconsistent and fluctuating. Thus a variable is anything that can take different values over a period of time. Variation relationship can be linear or otherwise. Thorne and Giesen (2000:12) maintain that it is only through observing the way things vary that one can capture relationship behind the phenomenon.

A model can be defined as a variable, a paradigm, a description or an explanation of the relationship of the parts of the problem or of the problem to its environment (Austin and Burns 1985:1), or as Gichaga and Parker (1988:17) put it, a simplified representation of reality. The *Advanced Learner's Dictionary of Current English* (2000: 755) defines a model as a "simple description of a system, used for explaining how something works or calculating what might happen". Models assist in helping one to understand the problem, enabling one to evaluate the courses of action one could take in any given decision situation, and reflecting the structure of the system or decision it is intended to represent (Austin and Burns 1985:1). A model is simply a set of mathematical equations (Gujarati 2014:5). The modelling decision is a creative exercise and an economic investment, which must itself be economically and financially justifiable.

#### 2.3.1 Model building

There are a number of ways in which one can choose to build a model. According to Austin and Burns (1985:9) there are eleven steps for model building, namely:

i. Statement of purpose:

ii. Clarification of the values;
iii. Determination of the system;
iv. Identification of the problem;
v. Collection of data;
vi. Formulation of the model structure,
vii. Validation of the model,
viii. Selection of the algorithm;
ix. Derivation of feasible policies;
x. Determination of the most appropriate policy; and
xi. Implementation of the policy.

Amongst the eleven steps identified above steps (v) to (vii) are relevant for the improvement of the existing pavement management models.

### 2.3.2 The art and science of modelling

Conceptualisation and modelling of engineering problems are as much an art as a science (Austin and Burns 1985:8; Gichaga and Parker 1988:21). In the first place, concept and modelling is an art as they attempt to develop a simplified abstract representation of real-world situations while capturing the essential aspects of the problem under investigation. The concept has to be relevant to the questions of interest and yield valid results when quantified. In the second-place, conceptualisation and modelling is a science as they attempt to quantify the conceptual relationship. Considerable effort is required to (i) gather data, (ii) develop statistical relationships, and (iii) calibrate curves to ensure that the results are accurate as far as it is statically acceptable (Gichaga and Parker 1988:21).

### 2.3.3 Model types and classification

Models can be grouped into two types, namely empirical and theoretical models also known as probabilistic and deterministic models respectively (Garber and Hoel

2009:1151-1152). Probabilistic modelling is any form of modelling that utilizes presumed probability distribution of certain input assumptions to calculate the implied probability distribution for choosing output metrics, whereas the deterministic model is a mathematical model in which the outcomes are precisely determined through known relationships among states and events, without any room for random variation (Mwaipungu and Allopi 2012b).

There are different criteria that rule, classification of models; among them are purpose, perspective, degree of abstraction, and content. Classification according to purpose takes into consideration the uses to which models can be put. Models can be used for (i) planning, (ii) predicting, (iii) training and, (iv) behavioural research, to mention but a few. Planning and prediction models improve the decision-making acumen of managers and represent the two most widely employed purposes to which models can be put by road agencies (Austin and Burns 1985).

### 2.3.4 Characteristics and requirements of an ideal model

The fact that a model contains less information than is contained within the real system makes the exercise of selecting a specific model for use as challenging as formulating one. In the model all aspects of the real situation irrelevant to the purpose of the model are ignored in order to maximize the viability of the selected model.

**Table 2: Characteristics and requirements of a good model**

| Characteristics | Requirements |
|---|---|
| **Relevance** | Responds to the questions and concerns of the day and of the foreseeable future. |
| **Validity** | Exhibits trends in the dependent variable that is consistent with pavement engineering judgement and expectations. |
| **Accuracy** | Confidence that the model estimate is within a certain percentage of the true value. |
| **Testability** | Results should be verified in the real world and be feasible to use in the environment of the application. |
| **Feasibility** | Time, effort and resources required to run the model have to be optimal. |

According to Gichaga and Parker (1988:25), in conceptualising problems one must be careful to ensure that the concept meets the characteristics of an ideal model, namely; relevance, validity, accuracy, testability, and feasibility, as briefly explained in Table 2 under the sub-heading 'Requirements'

### 2.3.5 Areas in which models can be improved

The two areas of modelling which can be improved are: (i) data collecting procedure, and (ii) modelling tools.

**i. Data collecting procedure**

Data to be used for modelling can be improved in quality and quantity to be more representative of the question in hand. Appropriate measuring instruments maximise accuracy and repeatability of the data. The quality of the data also can be improved by reducing the element of human error through the use of a consistent method of data collection and automation, and suitable training

**ii. Modelling tools**

Modelling tools come in different types and varieties and each has its special characteristics and limitations. The flexibility of modelling tools can be improved so that the model is able to capture the nature and extent of deterioration of gravel roads. The tool's accuracy and the duration of gravel road deterioration prediction models can be extended to cover the life expectancy of the pavement in question. Furthermore modelling tools can be improved to capture improved local technology in gravel road management. The level of uncertainty in a model can be reduced, and hence increase the confidence level. To improve gravel loss modelling tools one should start looking at variables that need to be captured and their characteristics. The foremost of these variables is the gravel materials used in surfacing unsealed roads.

## 2.4 Gravel material essence contributing to its characteristics and gravel loss

According to McKinlay (1988:265) gravel materials exist in many types and varieties, and are the accumulated results of many separate factors and processes. Their characteristics depend on the: (i) parent rocks from which they are derived; (ii) weathering of these rocks and the weathering of the gravel material itself at its various stages of formation; (iii) means of transport bringing the gravel soil to its present location; (iv) manner of deposition of the soil; and (v) history of loading, drainage, wetting and drying. These modes of gravel materials formation influence to a great extent, the characteristics and the performance of gravel roads and hence the gravel loss. In addition, the nature of relationship within and between modes of gravel materials formation is too complex to be described by linear association.

### 2.4.1 Gravel loss

Gravel loss (GL) refers to the amount of gravel wearing course that has been swept away which needs to be replaced in order to restore the original designed thickness. The thickness of a gravel wearing course varies between 150-250 mm depending on the strength characteristics of the road bed. This implies that gravel loss should be measured in average millimetres reduction of gravel layer thickness (Gichaga and Parker 1988:33).

Gravel loss can be defined as a time-dependent reduction of the thickness of a gravel layer by the mechanical removal of gravel material from the road prism to the immediate surroundings of the road (Dierks 1992:81). It is a change in average gravel thickness over a period of time (Paterson 1991; Visser and Queiroz 1979:79). Visser and Queiroz further stress that on a well compacted sub grade, the change in gravel level is the change in gravel thickness. Gravel materials are lost by the actions of scouring, kick off, dust, attrition, stones breaking down through the passage of heavy vehicles and by traffic pushing gravels into the weak sub grade (Henning, Giummara, and Roux 2008: 15).

The rate of gravel loss depends on the intensity and duration of rainfall, wind forces and traffic characteristics; also on gradient alignment, natural weathering (mechanical and chemical) of gravel materials, surface cross-fall, road width, material quality and characteristics, compaction achieved on respective layers of the road structure and maintenance practices (PIARC, TRL, and Intech Associates 2002:1; Dierks 1992: 81; Jones 1984:6-9). According to Visser and Queiroz (1979:79) three major influences affecting gravel loss are weathering, traffic, and maintenance in the form of grading. They further stress that material properties, road alignment and width influence the gravel loss generated by each of the three listed influences.

**Table 3: Variables employed in the modelling gravel loss**

| Variables | Study | | | | | | |
|---|---|---|---|---|---|---|---|
| | HDM-4 | TRH 20 | Kenya | A-T | NZS | NM | UR |
| **Material Characteristics** | | | | | | | |
| Material type (f) | | | √ | | | √ | |
| Plasticity Index (PI) | √ | | | √ | √ | √ | √ |
| Passing 0.075 mm sieve(P075) | √ | √ | | √ | √ | | |
| Passing 26.0 mm sieve (P26) | | √ | | | | | |
| Plastic Limit (PL) | | √ | | | | | |
| **Traffic Volume** | | | | | | | |
| Annual average daily traffic (AADT) | √ | | √ | | | | |
| Average daily traffic (ADT) | | √ | | √ | √ | √ | √ |
| **Climate** | | | | | | | |
| Mean monthly precipitation (MMP) | √ | | | √ | | | |
| Weinert N-value | | √ | | | | | |
| Annual rainfall (m) (RI) | | | √ | | | | |
| **Geometry** | | | | | | | |
| Average rise + fall (m/km) (RF)/Road Width | √/NA | | | | NA/√ | | |
| Gradient (%) for uniform road length | | | √ | | | √ | |

**Table 3: Continued**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Average curvature (degrees/km) (C) | √ | | | | | | |
| **Calibration factors** | | | | | | | |
| Kgl/Kkt | √/√ | | | | | | √/NA |
| **Maintenance** | | | | | | | |
| Number of days since last blading | | | | | √ | | |

**Note:** NM = Namibia; UR = Uganda; A-T = Australia-Tasmania;
NZS = New Zealand; NA = Not Applicable

The general GL model as presented by Visser and Quiroz (1979:79-80) is as given in Equation 1.

**Equation 1:** $\mathbf{GL = (time)f_1 + (time)\ (average\ daily\ traffic)f_2 + (grading)f_3}$

Where $f_1$, $f_2$, and $f_3$ are: linear combinations of material properties, road alignment and width.

Paige-Green (2007b) points out that gravel loss is the function of time, traffic, materials and climate. Table 3 shows various factors used by different studies in modelling gravel loss.

Table 3 shows that, GL independent variables vary to certain extent with the study. For example, the New Zealand and Namibian models did not use climate. New Zealand used grading frequencies, while the rest did not use grading frequencies. Soil erodibility (Wischmeir and Mannering 1968 cited in Jones 1984:6-9), which is the characteristic of soil explaining why erosion takes place at different rates, irrespective of usage, when other factors are constant, have not been taken into consideration by the studies in Table 3. Hence it can be said that 'Equation 1' reflects just one type of GL prediction model.

Prediction of gravel materials behaviour when used as a wearing course material for unsealed roads is a tool which can provide a solution for gravel road management problems (McKinlay 1988:287). Gravel wearing course's behaviour changes with time and can only be captured through empirical study. McKinlay (1988:263-348) stresses that for the gravel wearing course to be predictable, it has to undergo known design and construction procedures, which have been followed in every detail to detect consistent and inconsistent behaviour.

### 2.4.2 Significance of gravel loss prediction models

A gravel loss prediction model is a distress specific performance model that can be used to reliably predict gravelling materials performance. 'Performance' is related to the interaction between traffic, the environment and material properties. According to Paige-Green (1989:6.1) the prediction of the expected material loss from a gravel road`s wearing course is of utmost importance for: gravel road design, addressing construction short falls and maintenance planning. Timely prediction of when gravel roads are likely to need re-gravelling is precious information during gravel roads maintenance budgeting. Dierks (1992:82) insists that the importance of gravel loss prediction models is in establishing an economically defendable re-gravelling cycle and setting trigger values for gravel road maintenance or improvement to sealed standard. Without deterioration relationships for gravel roads, derived from gravel loss prediction models, among others, it is difficult to set appropriate standards or to know the effect of applied standards on performance (Greening *et al*. 2006:1) so as to address the shortfall. According to The United Republic of Tanzania, Ministry of Works (TZ-MoW) (1999:11.3) the gravel wearing course needs to be replaced periodically throughout the service life of a gravel road at a rate dependent on the gravel loss. This should not be looked at as a shortfall, but as one of the characteristics of gravel roads (Morris 1990:196).

Furthermore, Henning, Giummarra and Roux (2008:14) and Ellis (1979:3) assert that the importance of gravel loss prediction models is in:

i. Facilitation of the understanding of the interaction between the environment, traffic and local materials, which can assist in better planning of maintenance activities for the short, medium and long-term period;
ii. Attaining appropriate standards and specifications for local condition, and improving the same;
iii. Assisting in predicting the expenditure on gravel roads routines and the periodic maintenance the road in question will receive throughout its design life; and
iv. Providing a better understanding of the behaviour of material within a region so that a number of activities or measures can be applied to reduce or delay the deterioration of the gravel roads.

Taseni (2000:97) argues that local experience regarding the rate of gravel loss peculiar to the type of gravel materials in question should be used as an input to the design procedure of gravel roads in the local area concerned.

### 2.4.3 Attributes to the failure of international gravel loss predicting models deployed locally

Rates for gravel loss are influenced by a number of factors, such as road geometry, material quality, traffic volume and type, climatic conditions, construction standards and maintenance practices (Henning, Giummarra and Roux 2008:16). These factors can vary from time to time contributing to the cyclical nature of the performance of gravel roads and to the failure of gravel loss prediction models. Other reasons why gravel loss models, which are used internationally, can fail are:

- Models becoming obsolete. Except for New Zealand's gravel loss model which was not put into use, and the Uganda study gravel loss model which was actually developed for the purpose of calibrating the HDM-4 model, the rest of the five models reviewed under 2.5 were developed between 1971 and 1998, based on construction standards and technology prevailing at the time.

It should be noted that performance prediction models cannot go beyond the limitations of the standards and technology that control the data that feed them (Schmidt 2005:19-20).

- Pavement behaviour, which is defined as the function of the condition of the pavement with time (NITRR 1984:1). According to the National Institute of Transport and Road Research (NITRR) (1984:1), there are a number of factors which influence pavement behaviour. These are: climate, drainage, subgrade conditions, geology, topography, changes in traffic pattern, geometry, gravel materials and construction and maintenance quality. Due to these factors, each pavement is unique and careful monitoring is needed to establish its behaviour patterns.
- Challenges in addressing the characteristic variation within the same type of gravel and sub grade material.
- The difference in the soil formation process affects the performance of the gravel materials in different regions. For example, laterites developed by chemical decomposition occurs predominantly in Brazil, and soils resulting mostly from physical disintegration or arid pedogenesis predominate in Southern Africa. These differences in soil formation may account to a large extent for the differences between gravel loss models formulated in different regions (Paige-Green 1995:219).
- Inconsistent periods and teams of data collection. For example, the study in Western Cape took five and a half years using different teams and methods. The data was collected five times only - twice in 2002, and once in 2003, 2005, and 2007 (Uys 2008:52). This was attributed to financial and time constraints which forced the researchers to adopt a phased approach method for the gathering of information. Data gathered in this fashion might miss a trend and provide misleading results regarding gravel loss, which is a time dependent phenomenon.
- Greater variability of marginal gravel materials' physical properties (Table 4), quality of construction and large fluctuations in traffic volume,

composition and vehicle loading that are typically encountered in sub-Saharan African countries (Ellis 1979:1).

According to TZ-MoW (1999:11.3), the materials for gravel wearing courses for gravel roads in Tanzania must comply with the requirements provided in Table 4.

**Table 4: Marginal material properties and requirements for gravel wearing course (Source TZ-MoW 1999: Table 11.1 and TZ-MoW 2000b: Table 3702/1)**

| Marginal material properties | Requirements | |
|---|---|---|
| | Climatic zones | |
| | Wet | Moderate and Dry |
| CBR (%) at 95% of MDD (BS-Heavy compaction) | Min 25 after 4 days soaked | Min 25 at OMC |
| % passing 37.5-mm sieve | Min 95 | |
| Shrinkage Product (SP) | 120 - 400 (In built up areas a maximum SP of 270 is desirable to reduce dust problems) | |
| Grading Coefficient (GC) | 16-34 | |
| Field dry density [% of MDD] (BS-Heavy compaction) | Min 95 | |

According to Table 4, the gravel materials used to surface unsealed roads in Tanzania are marginal, which implies they do not meet the quality requirements for gravel materials to be used for gravel wearing course. This is supported by Taseni (2000:1) who asserts that the majority of natural gravels available in Tanzania are marginal, as they do not meet the gravel wearing course specification with regard to particle size distribution and Atterberg limits. Hence imported gravel loss prediction models will not be able to predict the rate of gravel loss for such types of gravel materials. Robinson and Thagesen (1996a:399) argue that a system copied unchanged from another country is unlikely to be successful.

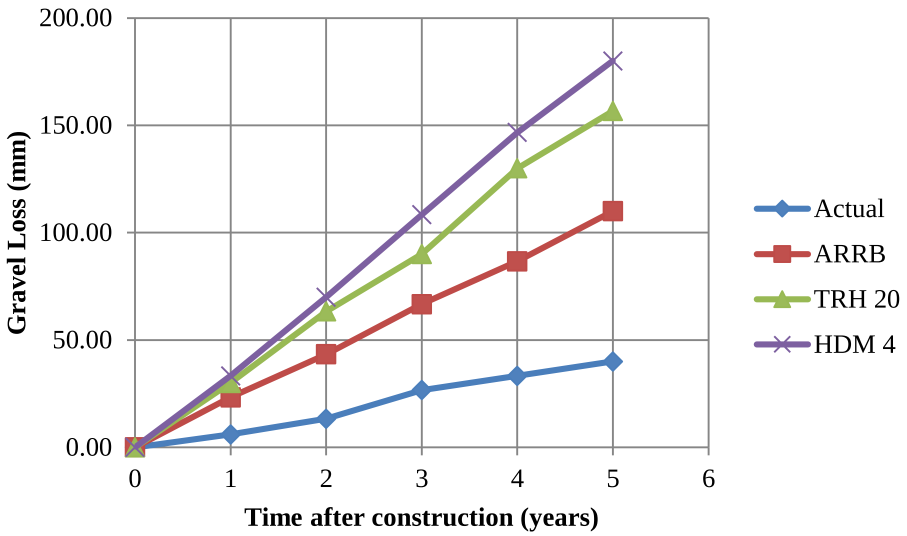


**Figure 6: The effect of improved quality in construction and the level of gravel loss prediction (Source: Van Zyl, Henderson & Uys 2007:207-225)**

Findings from recent studies in South Africa have highlighted the failure of internationally accepted models to predict change in gravel loss on the gravel roads surveyed. This is due to the effect of improved construction techniques, where more emphasis on better material selection and stringent quality control measure has been put into place (van Zyl, Henderson, and Uys 2007: 224) as depicted in Figure 6. This further validates the deployment of gravel loss survey as a quality assurance tool, as the quality of construction techniques deployed can be reflected in the rate of gravel loss experienced thereafter. According to Harral and Asif (1988:2), even the standard engineering practices on gravel road construction have different effect in different environments, hence performance. This stress further the needs of gravel loss prediction model to be tailored to the circumstance of individual countries.

### 2.4.4 Effect of deterioration model prediction error

Accurate prediction of future pavement performance is the most important element in the planning process. If the planning process is based on incorrect predictive models, actual conditions encountered will be different than expected, and planned actions may be inapplicable which, essentially, invalidates the planning process (Paterson, 1991:146). Model prediction error affects timing of re-gravelling and strategic planning of material sources, and has an adverse effect on pavement life-cycle costs.

In order to address the issue of statistically accurate prediction model, the uses of econometric (pavemetric) modelling principles was adopted for the present study. The characteristics of this modelling principle which addresses gravel loss behaviour follows.

## 2.5 Economic

Robinson, Danielson and Snaith (1998:4) are of opinion that road transport is a key component of the economic and social development process often absorbing a high proportion of national budget. They further point out that effective and efficient road transport lowers input prices, and hence production costs, and can lead to greater economic well-being. From the above it can be noted that there is an intrinsic relationship between gravel road management and economics. A number of authors, namely Anastasopoulos, Mannering and Haddock (2009) in the one hand and Veeraragavan (1995:483-492) and Paterson (1991:143) on the other hand have repeatedly insisted on optimum uses of maintenance resources.

Gravel loss modelling decisions are a creative exercise and an economic investment, which must itself be economically and financially justifiable**.** According to GEIPOT and UNDP (1981:3) pavement performance prediction models are an essential technological tool for economic analysis of road infrastructure**.** Pavement deterioration models are economic models. Pavement deterioration models are part and parcel of gravel road pavement management systems (Robinson and Thagesen 1996a:396). Prediction models for gravel loss form the basis for establishment of economically defendable re-gravelling cycles, based on cost optimized arguments (Dierks 1992:82). Paterson (1987:143) is of opinion that the model of gravel loss is suitable for use in economic analysis models intended to evaluate the trade-off between different maintenance and construction policy.

## 2.6 Pavemetrics

### 2.6.1 General

In general no gravel loss prediction model can capture all independent variables contributing to gravel loss; however, thoroughly study on the performance of different types of gravel surfacing materials will enable key variables or theory behind gravelling to be captured. This is the major reason why this study opted to use econometric principles, hereby called pavemetric principles to tally with the discipline under study, which attempt to capture economic theories through statistics methods. This study attempted to use pavemetric to reflect to a certain extent the characteristics of gravel loss statistically.

### 2.6.2 Pavemetrics as econometrics

Econometrics methodology apply mathematics, statistical methods, and, more recently, computer science, to economic data and is described as the branch of economics that aims to give empirical content to economic relations (Pesaran 1987:8). More precisely, it is "the quantitative analysis of actual economic phenomena based on the concurrent development of theory and observation, related by appropriate methods of inference". Econometrics is the intersection of economics, mathematics, and statistics. Econometrics adds empirical content to economic theory allowing theories to be tested and used for forecasting and policy evaluation (Geweke, Horowitz and Pesaran 2008:1-38). The same can be said about Pavemetrics in regards to gravel loss theory or gravel road pavements at large.

In econometrics, linear regression is most frequently used as the starting point for statistical analysis (Green 2012).

### 2.7 Econometric theory

Econometrics is largely concerned with quantifying the relationship between one or more variables ‘y’, called the response variables or the dependent variables and one or more variables ‘x’, called regressors, independent variables or covariates (Greenberg 2013:3). In addition to covariates, it is assumed that unobservable random variables affect ‘y’, so that ‘y’ itself is a random variable.

Econometric theory uses statistical theory to evaluate and develop econometric methods. Econometricians try to find estimators that have desirable statistical properties, including unbiasedness, efficiency, and consistency. An estimator is unbiased if its expected value is the true value of the parameter; it is consistent if it converges to the true value as the sample size gets larger, and it is efficient if the estimator has a lower standard error than other unbiased estimators for a given sample size. Ordinary least squares (OLS) is often used for estimation since it provides the "best linear unbiased estimator" (where "best" means most efficient, unbiased estimator) through assumptions given by the Gauss-Markov Theorem (Samwelson, Kopmens and Stone 1954). When these assumptions are violated or other statistical properties are desired, other estimation techniques such as maximum likelihood estimation, generalized method of moments, or generalized least squares are used (Geweke, Horowitz and Pesaran 2008:1-38).

Data sets to which econometric analyses are applied can be classified as time-series, cross-sectional, panel, and multidimensional panel data. Time-series data sets contain observations over time; for example, gravel loss over the course of several years. Cross-section data sets contain observations at a single point in time; for example, traffic volume passing a point in a given year. Panel data sets contain both time-series and cross-section observations. Multi-dimensional panel data sets contain observations across time, cross-sectional, and across some third dimension (Geweke, Horowitz and Pesaran 2008:1-38). This study expects that the deployment of econometric modelling principle to gravel roads performance through pavemetric will result in a relatively accurate gravel loss prediction model.

## 2.8 Review of existing gravel loss prediction models

### 2.8.1 Kenyan study

Between 1971 and 1974, the World Bank, Transport Research Laboratory (TRL) Limited, the then British unit of the Transport and Road Research Laboratory (TRRL), and the Kenyan Ministry of Transport and Communication (MoTC) made a joint study of the interrelationships between construction, maintenance and vehicle operating costs for both sealed and unsealed roads in Kenya. The study developed what can be termed the first model for predicting gravel loss on unsealed roads, among other models. The model was a multivariate equation relating the annual gravel loss at any point in time with annual traffic, annual rainfall, percentage gradient, and material constant "f" for each different type of gravel material used.

In 1979, the TRRL in collaboration with the Kenya MoTC conducted a two-year study on the effect of various maintenance inputs on the deterioration rates of unsealed roads; data were collected in three-month intervals. The results of this study modified the results of the earlier study made in 1974 by multiplying the former constants with 1.375 to account for the effect of under-predicting gravel loss (Jones 1984:8). The gravel loss prediction model as given by the Equation 2 remains as formulated in 1974.

**Equation 2:** $GL_A = [(T_A^2/(T_A^2+50)]\ (4.2+0.092T_A+3.5R_L^2+1.88V_C)\ f$

Where GLA is the annual gravel loss in millimeters; $T_A$ is the annual traffic in both directions measured in thousands of vehicles; $R_L$ is the annual rainfall measured in metres; $V_C$ is the percentage gradient (metres/km); and “f” is a material constant based on the type of materials. Materials employed for study were lateritic, quartzitic, volcanic, coral and sandstone gravels.

However, the studies did not consider the variability of the material properties within any one material group, such as plasticity, particle size distribution, particle strength, and clay mineralogy, which would also influence the gravel loss (Paige-Green 1989:6.2).

No factor was introduced in the later study to address the effect of maintenance on gravel loss, although the study included the maintenance input as a parameter affecting the rate of gravel loss (Jones 1984:7). The study also noted that the parameters of soil erodibility, ground slope and rainfall intensity affect the rate of soil loss, irrespective of whether it is on agricultural land or on unsealed roads (Jones 1984:7), although it did not take into consideration soil erodibility. The study showed a very strong rainfall effect on gravel loss, which was not realistic. It was noted that an increase of rainfall from 1000 to 2000 mm per annum caused a 200-400 % increase in gravel loss rate, which was purely due to the analysis method used (Paterson 1991:45)

The differences between the gravel losses predicted by the two TRRL studies (Jones 1984: 8-9) were attributed to:

- Variation in the methods of collecting and quantifying the rainfall data. The former study used a theoretical approach, while the latter used an empirical study.
- Variation in the thickness of the wearing course of the gravel test sections. In the former study, the thickness varied from 28 mm to 224 mm while in the

latter study the variations were contained within a band of 121 mm to 165 mm.

- Technological advancement in terms of road construction and vehicle manufacturing. In the latter study, not only the roads were capable of carrying traffic at higher speeds because of improved alignments, but also vehicles had the ability to travel faster. These advancements increased the speed and therefore increased the rate of gravel loss.
- Behaviour changes in road users associated with the introduction of new vehicles, in particular, aggressive road users' behaviour. The product of overloading, spreading and irregular manoeuvres results in shearing movements, which damage road surfaces.

The aforementioned attributes of the difference between the gravel losses predicted by the two TRRL studies warrant further calibration of the Kenyan model for it to be realistic.

### 2.8.2 Highway Development and Management-4 (HDM-4)

A wide range of material types, traffic volumes, and road geometry for unsealed roads was monitored for six years from 1976 to 1981 inclusive. The study was sponsored by the Brazilian government, United Nations Development Programme (UNDP), and the World Bank.

The study developed the relationship for predicting the annual quantity of material loss as a function of monthly rainfall, traffic volume, road geometry and surfacing material characteristics, known as Highways Development and Management (HDM)-4. The HDM-4 unsealed road material loss model for gravel or soil materials is shown in Equation 3. The Equation 3 is based on the HDM-III model with minor modifications to facilitate local calibration and adaptation (World Bank [HDM-4] 2000; Uys 2008:10).

**Equation 3: MLA = Kgl*3.65 (3.46+2.46*MMP*RF*$10^{-4}$+KT*AADT)**

Where KT = Kkt*MAX [0, 0.022 + 0.969(HC/57300) + 0.00342(MMP/1000) (P075) - 0.0092(MMP/1000) (PIj) - 0.101(MMP/1000)]

($r^2$ = 0.313; the standard error was 49 mm/year; the sample consisted of 456 observation; and the t-statistics were 3.1 and 2.6 for the coefficients of MLA and 3.7, 1.1, 3.9, 3.0 and 2.8 for the coefficients of KT). MLA is the predicted annual material loss (mm/year); RF is the average rise and fall of the road (deg/km); MMP is the mean monthly precipitation (mm/month); AADT is the annual average daily traffic (veh/day); KT is the traffic induced material whip-off coefficient; and Kgl is the material loss calibration factor.

KT is expressed as a function of rainfall, road geometry, and material characteristics, where HC is the average horizontal curvature of the road (deg/km), PIj is the plasticity index of material; P075 is the amount of materials passing the 0.075 mm sieve, and Kkt is the traffic induced material whip-off calibration factor.

The model predicts material loss by using AADT, and the material properties (particle size distribution and soil plasticity) of the surfacing layer, whether gravel or subgrade, to facilitate local calibration and adaptation.

The prediction of annual material loss transforms the average monthly rainfall into an annual average rainfall and thus makes no specific distinction between uniform and seasonal rainfall climates. Cross-section elements, including the width of traffic lanes, shoulders, camber, and super elevation, were not measured in the study. The gravel roads surveyed had no special compaction, and the influence of grading maintenance on the loss rate could not be identified (Paterson 1991:147).

### 2.8.3 Southern Africa study

Between 1983 and 1989, an extensive study was carried out in the then Transvaal Province in South Africa and in Namibia, to investigate the performance of local geologic materials used in wearing courses for unsealed roads in terms of their specification and rates of deterioration under a range of traffic and climatic influences. This study resulted in the development of a number of gravel road deterioration models; among them was a model to predict the rate of gravel loss as presented in Equation 4, which is incorporated into the National Institute of Transport and Road Research (Technical Recommendations for Highways Manual (TRH) 20 2009:93; Paige-Green 1989:6.9).

**Equation 4:** $$GL = 3.65[ADT\ (0.059+0.0027N-0.0006P26)-0.36N-0.001PF+0.0474P26]$$

Where GL is the average gravel thickness loss (mm); ADT is the average daily traffic in both directions; N represents climate in terms of Weinert N-value, which range from 1 in wet areas to more than 10 in arid areas and incorporate annual rainfall; P26 is the percentage of gravel materials passing through a 26.5 mm sieve; and plasticity factor (PF) is the product of plastic limit and the percentage passing through a 0.075 mm sieve.

The model did not incorporate road geometry, and maintenance practices. According to Paige-Green (2014, pers. comm. 10 March) the former was a variable in the analysis, but showed no statistical significance in the data set analysed.

The study was faced with a number of challenges, one being lack of timely routine maintenance on some test sections (in an e-mail communication on 10 March 2014, Paige-Green explained that this was planned in order to obtain the long-term effects), which allowed accumulation of loose material and growth of grass to narrow the trafficked part of the road (Paige-Green 1989:6.5). Although it was mentioned that this growth did not affect the monitoring exercise, the impact of narrowing the road width was to force the traffic to move to a reduced load width, and this might have influenced the rate of gravel loss. According to Paige-Green (2014, pers. Comm. 10 March) in very few cases, did it become a single lane. The impact should be minimal as the loss would just increase in the reduced lane area proportionally.

Implementing improved methods for material selection, drainage, compaction and maintenance as recommended in TRH 20 has resulted in less gravel loss than predicted by the gravel loss model (TRH 20 2009: 93).

According to Paige-Green (2007a:10) the gravel loss prediction model formulated between 1983 and 1989 for South African conditions is currently over-predicting gravel loss significantly. This can be attributed to the fact that the said model was developed with poorly constructed roads with little control on material selection and compaction. This stresses the point that any formulation of gravel road performance prediction models carries with it the design, construction, and maintenance standards prevailing at the time. Figure 6 shows the effects of improved quality in gravel roads construction on predicted gravel loss. It can be noted that all three models that are HDM 4, TRH 20 and ARRB over predict gravel loss in comparison to reality as studied by Van Zyl, Henderson, and Uys (2007:217-225).

Apart from noted short falls, the model is simple as it incorporates a few parameters, namely daily traffic, climate in terms of Weinert N-Value, Atterberg limits, and sieve analysis. According to Paige-Green and Visser (1991:138), the listed parameters can be easily collected by relatively unskilled staff in unsophisticated laboratories, which is the reality in most of materials laboratories in Tanzania with only a few exceptions.

The gravel loss model to be developed from this study shall be based on similar premises. In an e-mail communication on 10 March 2014, Paige-Green indicates that such models are quite broad as a result of variation in traffic, rainfall, and even material properties along a road and any additional sophistication will actually be of little benefit. Paige-Green (2014, pers. comm. 10 March) insist that such a model does, however, allow a relatively better assessment of average gravel loss among a number of roads in a network such that the annual gravel replacement needs, costs and equipment requirements can be more accurately assessed.

### 2.8.4 New Zealand study

The New Zealand study commenced in 2002, and included cooperation of 51 local authorities. The objective was to derive a gravel loss model for application in New Zealand conditions. The gravel loss measurement site was 60 m long, and measurements were taken at 10 m interval along the road, which resulted in measuring a total of seven cross sections. Each cross section consisted of a height measurement interval of 0. 5 m. The study was carried out for five years, and data were collected twice a year. A total of seven surveys were conducted.

The study resulted in two prediction models namely: a shape loss prediction model; and a gravel loss prediction model, which is shown in Equation 5.

**Equation 5:** $$DeltaGL = 2*[25.6-F_1*Width-F_2*PI+F_3*P265-F_4*TLB+F_5*ADT]$$

Where DeltaGL is the annual change in surface thickness; Width is the road width; PI is the plasticity index; P265 is a percentage of gravel materials passing the 26.5 mm sieve; TLB is the number of days since last grading; ADT is average daily traffic; and $F_1$ to $F_5$ are model coefficients.

The New Zealand study was affected by low frequency of data collection (twice per year), limited survey points, inconsistent survey team (51 councils were involved), and there was no data collected before and after maintenance execution. Climatic effects on gravel loss were indirectly implied through studying gravel road performance under four climatic conditions prevailing in New Zealand. The data set was not always complete, thus limiting the amount of effective data on which the analysis was undertaken (Henning, Giummarra and Roux 2008: 76). Based on those limitations, a site specific model, which was the ultimate aim of the researchers, could not be developed because the experimental data did not include site specific information such as maintenance effects and full grading cycle data.

During the regression analysis, the general model developed from the studies had a regression coefficient of 0.34, and model significance of 0.196 (Henning, Giummarra and Roux 2008: 78).

### 2.8.5 Namibian study

In 1986, studies were conducted to developed unsealed road performance models so as to establish a maintenance design system (MDS) for Namibian condition (Dierk 1992:78). The studies were conducted on established 19 test sections of 300 m in length in the districts of Windhoek and Gobabis. The studies resulted in a number of models; among them was the gravel loss model as shown in Equation 6.

**Equation 6: GL=D [-0.0346G–0.1288PI+0.0242ADT+0.39T7+0.548] mm**

Where GL is average gravel thickness loss (mm); D is the time period considered (days/100); G is the absolute value of grade of road (%); PI is the plasticity index of surfacing material (%); ADT is the average daily traffic in both directions (evu); and T7 is material properties (for a calcareous mix T7 =1, else T7 = 0).

The sample size was 112 (Dierk 1992:81). The model excluded the following variables, namely compaction, climate and sizes of materials. Reasons given for exclusion of a compaction were that: the traffic compaction is difficult to quantify, and the correlations between proper compaction and gravel loss were not available. Regarding the climatic variable which was left out in the Namibian study, Dierk (1992:81) points out that climatic conditions do not have a very distinct influence on the performance of the prediction model because most parts of Namibia are situated in regions with a Weinert value N greater than 10 in the average with minimal climatic influence on road building materials. This contradicts what Greening *et al.* (2006: 1-24) observed during their Uganda study that climatic and environmental influences can be the dominant factors in the deterioration of unsealed roads. The lifetime performance of gravel roads is also influenced to a certain extent by factors such as terrain, construction materials, construction quality and traffic. The Namibian gravel loss prediction formula gives lower values than the Brazil formula (Dierk 1992:81).

The Namibian gravel loss prediction model incorporates as few variables as the South Africa one, but it does not consider the climatic factor which is significant for Tanzania conditions.

### 2.8.6 Australian – Tasmanian study

The Australian-Tasmania study was conducted in 1997. The study objective was to evaluate the performance of four different gravel surfacing materials as a function of maintaining the hard crust, minimizing wear, ravelling and dust. A single road of 2.7 km was divided into nine sections of 300 m long in order to study different treatment options. A single traffic volume was used for the full experiment (ADT = 83). The study area had a temperate climate, and experienced a rainfall between 1,400 – 1,600 mm/year. The gravel loss model which resulted from the study is presented in Equation 7.

**Equation 7:** $GL=D*(F_1*ADT+F_2*MMP+F_3PF)$

Where GL is the average gravel thickness loss (mm) across roadway; D is the time period in hundreds of days (days/100); ADT is average daily vehicular traffic in both direction's (veh/day); MMP is the mean monthly precipitation (mm/month); PF is plasticity factor (PI *P075); P075 is the amount of material passing the 0. 075 mm sieve, in percentage by mass; PI is a plasticity index; and $F_1$ to $F_3$ are model coefficients.

Although the study achieved its objectives, which were to demonstrate the different performance outcomes of gravel wearing course for each gravel material used in the trials in terms of roughness, gravel loss and loss of shape, the models developed were purely for an academic purpose. There is also a question of homogeneity of the sub grade materials which was not addressed in the study.

### 2.8.7 Uganda country report

The work described in the report was funded by the Department for International Development (DFID) of the UK. The work was carried out by TRL Limited in partnership with the International Labour Organization/Advisory Support, Information, Services, and Training (ILO/ASIST).

The purpose of the report was to reduce the lifetime costs of unsealed rural roads by promoting appropriate engineering standards, planning tools and works procedure for labour-based construction and maintenance (Greening *et al* 2006: 1-24).

Extensive desk and field studies were carried out to select gravel roads sites that covered the range of factors typically found in Uganda related to gravel loss and longitudinal roughness. The sites were monitored for a period of $2^1/_2$ years from April 2002.

Samples of the gravel wearing course and the sub grade were taken for material testing from the centre of the carriageway at locations that were immediately next to each of the 200 m long sites. Tests carried out on the samples included grading analysis, and consistency.

The main conclusions of the study concerning gravel loss were:

- Different rates of gravel loss relating to material plasticity and traffic were observed;
- The average gravel loss for all the sections was 20% higher than the predicted values of HDM-4; and
- A wider grading envelope could be adopted for the gravel wearing course materials with grading modulus in the range 1.56<GM<2.40.

The Uganda study did not produce a gravel loss model, but did produce a formula to adjust gravel loss due to environment as shown in Equation 8.

**Equation 8: Adjusted GL = (GL –GLE)(100/ADT) + GLE**

Where GL refers to average gravel thickness loss (mm); $GL_E$ refers to average gravel thickness loss (mm) due to environment; and ADT refers to average daily traffic.

According to the study, the observation on the sites indicated that 6 mm/year of gravel was lost due to environmental effects. The study came out with gravel road performance criteria based on adjusted gravel loss as shown in Table 5.

**Table 5: Gravel road performance criteria based on adjusted gravel loss**

| Performance | Adjusted GL (mm/year/100 vpd) |
|---|---|
| Good | ≤ 25 |
| Moderate | 25 – 60 |
| Poor | > 60 |

These criteria, in terms of the rate of gravel loss in mm per annum per 100 vehicles per day reflected in performance, is a tool of measuring not only the quality of construction technique employed, but also the quality of gravel materials used as wearing course.

**Table 6: Calibration factors for gravel loss based on material plasticity**

| Sites | Material loss calibration factor (Kgl) |
|---|---|
| Low plasticity | 1.4 |
| High plasticity | 0.8 |
| All | 1.2 |

The Ugandan study calibrated the HDM-4 gravel loss model to suit local materials' plasticity characteristics, using the calibration factors for material loss (Kgl) as summarized in Table 6.

One could have expected the study to come out with its own gravel loss model for labour-based unsealed roads, as these roads are a likely to be inferior compared to equipment based unsealed roads, in terms of degree of site compaction achieved.

## 2.9 Conclusions and recommendations

### 2.9.1 Conclusions

This review of gravel loss prediction models has highlighted the influence of the level of technical know-how, the power of funding organization, and the objectives of the study as well as inconsistent methods of data collection, variation in study duration, data collection, modelling equations, and methods of material testing. One should note that, gravel loss prediction models are not cast in stone; rather they are subject to continuous monitoring and improvement as more experience is gained during their implementation.

A gravel loss prediction model is effective when accompanied by an effective gravel road maintenance management system; otherwise as the gravel wearing course is progressively reduced in thickness, other defect developments such as the formation of ruts and erosion gullies will accelerate the gravel loss beyond the model's predictive capacity.

The variables in a gravel loss prediction model do not necessarily reflect those known to influence its start and progression, but are those which were proved to be significant during a modelling exercise, as has been noted in Table 3.

A gravel loss prediction model as a tool for gravel road management system has its limitations as it has to tally with local road organisations' capacity and societal economic power. Furthermore, there is a need for political will before a gravel loss prediction model can be used as an effective tool in determining appropriate maintenance associated with the reached stage of gravel road performance.

It should be stressed here that the uses of a gravel loss prediction model developed in the context of different environments economically and politically will not address the local condition. Local conditions contain a long list of things unique to that area, namely climate, economic status, local maintenance traditional, types and volume of predominant vehicles and road worthiness of vehicles, and political influence on local matters pertaining to road design, construction and maintenance.

The rates of gravel loss experienced on any particular gravel road reflect, to a certain extent, the quality of construction techniques and materials selected as wearing course. From the variation of factors influencing the rate of gravel loss, as noted under 2.4.1, the relationship between and within each factor associated with gravel loss is either linear or nonlinear. Furthermore, their relationship can be characterized by the combination of direct and inverse proportions.

The changing nature of gravel roads performance affects the predictability of the defects significantly. It is thus expected that gravel loss models will have a significant variability and consequently relatively low regression coefficients. This was the case with Brazilian and New Zealand gravel loss models which had a very low square of the correlation coefficient ($r^2$).

Pavemetric should relate statistics methods to pavements theories as it is being used by economists through econometric. This can be achieved by studying and taking into account the characteristics of pavement materials, pavement behaviour, cyclic nature of maintenance and performance of pavement under the influence of natural and human made variables, and capture the unique characteristics of each phenomenon aforementioned through statistics principles. This paper expect by so doing the prediction of pavement deterioration will be statistically accurate.

### 2.9.2 Recommendations

- Traffic volume, loading, and type, together with climatic conditions vary throughout the day, month, and year. Road geometry, material properties, construction standards and maintenance practice vary from one location to the other. These factors point to the cyclical nature of unsealed road performance. Hence, for a gravel loss prediction model to become an effective and efficient tool in maintenance management of gravel roads, it has to be dynamic and reflect local material characteristics, climatic changes, and changes in gravel road design, construction, and maintenance technology.

- It is imperative that the survey team, equipment, frequency of surveys, and methods of collecting and analysing data to be used for formulating a gravel loss prediction model must be consistent.

- Gravel loss modelling exercises should reflect as far as it is practical the variability within the same local materials used in surfacing the unsealed roads. This is achieved through empirical studies and exhaustive laboratory testing of gravel materials physical characteristics.

- Gravel loss empirical studies have to cover areas of similar geographical features and climatic nature to address the characteristic variation within the gravel and sub grade materials.

- The quality of work during the construction stage and subsequent maintenance operations has to be standardized as will be reflected in the gravel loss models through the rate of gravel loss.

- The rate of gravel loss reflects the quality of construction/maintenance and gravel materials employed as wearing course, hence it can be employed as a quality assessment and auditing tool.

- Changes in road user behaviour associated with the vehicles' technological innovation and the effect of vehicles' manoeuvres resulting in shearing movements of granular wearing course materials have to be independently studied to be incorporated in gravel loss models, or to be noted during the condition survey.

- The effects of errors arising from deterioration prediction models affects timing of re-gravelling cycles and strategic planning of materials sources, hence it is imperative that the accuracy of the formulated prediction models be verified periodically.

- Gravel loss models reflect the period in which the data were collected. The period is characterised by the economic situation, political situation, and technology prevailing.  Predictions will be valid as long as these conditions persist, changes in any one of these condition affecting gravel road performance will necessitate new model. Hence the view that such model has to be dynamic.

- The definition of symbols employed in gravel loss prediction models equations should be consistent worldwide.

# CHAPTER 3
# OVERVIEW OF TANZANIAN GRAVEL ROADS MANAGEMENT SYSTEMS

## 3.1 Introduction

In an attempt to establish the extent of gravel roads management systems (GRMS) operating in sub-Saharan African countries, the study looked at the version of GRMS practiced by Tanzanian road organisations as part of the literature review. It should be mentioned that, looking at one`s road organization`s GRMS is at the same time looking at its MMS, as there is a thin line dividing between the two systems' functions.

### 3.1.1 Background

Management of gravel road networks in an optimal manner remains a technically complex task, particularly in countries of lesser economies where there are competing demands for limited resources. This experience is true of many existing gravel roads constructed or rehabilitated between 2005 and 2008 (Mwaipungu and Allopi 2012a). These roads have, at the time of this research, come to the end of their design lives, which could have been prolonged with adequate and timely maintenance. What is becoming apparent to the governments and road agencies of sub-Saharan African countries is the urgency of conserving, as national assets, the gravel road networks, through the use of operational road management systems (Mwaipungu and Allopi 2012a).

In regard to these needs, sub-Saharan African countries, including Tanzania, are exploring ways of strengthening the management of their road infrastructure assets. Fortunately, this task is greatly simplified by establishing road agencies and employing gravel road management systems. Towards this end, Tanzania formed –in the late eighties – two road organizations responsible for managing its road networks namely Tanzania Road Agencies (TANROADS), and Local Government Authority (LGA) district and municipal engineers' offices (Mwaipungu and Allopi 2012a). TANROADS is responsible for the management of national roads, while LGAs are responsible for the management of district roads.

Each one of these road organisations uses their own brand of a road management system. TANROADS uses Road Maintenance Management Systems (RMMS), and LGAs use District Roads Management Systems (DROMAS). Both systems have been developed with sponsorship and experts from foreign countries. The involvement of local experts was at ministerial or top management level.

This chapter discusses and points out the factors affecting the efficiency and effectiveness of GRMS deployed by Tanzania's road organizations in comparison with those in developed countries. The study believes that addressing those areas of management affecting effective and efficient conservation of gravel roads will improve further their performance.

### 3.2 Fundamentals of GRMS

According to Oliver (2002:456), fundamentals of GRMS and MMS are: inventory data, condition data, maintenance standards, economic analysis, budgetary analysis, programming and work control and feedback. In the view of Underwood (1995:468) GRMS has three modules, namely: a database; an analysis; and a reporting module. The analysis and reporting modules are covered during the explanation of the applicability of Tanzania`s GRMS, while the database module is briefly discussed below.

### 3.2.1 GRMS database module

The gravel road database module includes: reference system; inventory; condition; and treatment types and costs. Treatment types and costs are not within the scope of this study, and thus only the first three are briefly described below:

i. **Gravel road reference system**: The gravel road reference system is required to tie all the information stored in the database to a fixed point in the road system. It comprises a set of links, described on a map by start and finish nodes. The nodes are permanent physical features in the road network, such as culverts, bridge abutments, and intersections.

ii. **Gravel road inventory**: The gravel road inventory is a collection of information generated on the basis of data obtained on the roads that make up a network. According to The United Republic of Tanzania; Prime Minister's office Regional Administration and Local Government (PRO-RALG) (2004:2), data collected shall include: the particular specification and characteristics of a gravel road; its condition; its volume of traffic; and the climatic condition in the area where it is located. Oliver, (2002:468), asserts that the information gathered should be limited to the location, nature, age, purpose and service provider of each gravel road component. The quality and quantity of information collected during the gravel road inventory differ according to the organisation doing the exercise.

iii. **Condition survey**: A condition survey is usually based on visual inspection to register all conspicuous defects of wearing course, shoulders, ditches, culverts, slopes and road furniture (Schliessler and Bull 1993:191).

### 3.2.2 Characteristics and deployment of road condition survey

Data on gravel road conditions provides the basis for: identifying road sections with poor condition and/or performance; selecting maintenance, rehabilitation and reconstruction actions; and establishing priorities. The process of keeping an inventory of road conditions and selecting pavements for rehabilitation and reconstruction is what is termed pavement management (Mallick and El-Korchi 2009:4). The nature and extent of gravel road condition data to be collected will depend on the importance of the road, the type of analysis to be carried out and the resources available.

A condition survey in developed countries is mostly mechanised; the philosophy behind the exercise is to minimise disruption to the travelling public. From European experience, the road condition has to be assessed by experienced engineers and reported on a standard form to ensure, as far as possible, uniformity of approach and reliable results which are above suspicion.

(a) **Rating of gravel road condition**: PRO-RALG (2004:10) uses three to four ratings, namely: good, fair, bad and poor conditions. Where three criteria are used, the 'bad condition' is dropped. TANROAD`s road mentor uses five criteria (TANROADS 2010a). A typical rating system for a gravel road wearing course that uses five criteria is shown in Table 7 (Underwood 1995:468; Schliessler and Bull 1993:34).

**Table 7: Typical rating system for unsealed road's distress**

| Rating | Descriptor | Degree of distress and remedial measures |
|---|---|---|
| 1 | Very good | No signs of distress |
| 2 | Good | Some minor signs and a need to identify sources of distress |
| 3 | Fair/Regular | Moderate distress, indicating the need for grading |
| 4 | Poor/Bad | More severe distress, indicating the need for re-gravelling |
| 5 | Very poor/<br>Very bad | Failed surface, requiring full reconstruction |

(b) **Frequency of the condition survey**: Condition surveys for gravel roads should be based on the knowledge that its components deteriorate rapidly and that the frequency selected should reflect the dynamic changes on the gravel roads in question. In general, the gravel road condition survey has to be conducted twice a year to enable effective monitoring of changes in gravel road condition. Deng and Henning (2013 cited in Tapper, Henning and Dunn 2013:17) strongly urge that regardless of the frequency of survey, timing of surveys is one of the factors that contribute most to variation in survey outcomes. Their recommendation was that condition surveys should take place within a specified period of the year. In tropical countries, the exercise can be done at the end of wet and dry seasons.

### 3.3 Categories of road network in Tanzania

According to the Tanzania Road Classification Act of 2007 (The United Republic of Tanzania 2007:359-360), roads are classified into categories A and B as shown in Table 8. Category A is national roads, and category B is district roads. Category A can be further classified into trunk and regional roads, while category B is district, feeder, and urban roads.

From Table 8, it is noted that Tanzania has a total road network of 91,049 km. The percentage of sealed roads is 7.3%, while that of unsealed roads is 92.7%.

**Table 8: Categories of road network in Tanzania**

| **Category** | | **Sealed (km)** | **Unsealed (km)** | **Total (km)** |
|---|---|---|---|---|
| A:National Roads | Trunk Roads | 5,150 | 7,636 | 12,786 |
| | Regional Roads | 722 | 19,504 | 20,226 |
| B: District Roads | District Roads | 0 | 29,337 | 29,337 |
| | Feeder Roads | 0 | 22,703 | 22,703 |
| | Urban Roads | 790 | 5,207 | 5,997 |
| Total | | 6,662 | 84,387 | 91,049 |

**Source: TANROADS 3rd Quarter Progress report 2009/2010 and PRO-RALG's Operational plan for 2010/2011**

National roads fall under the jurisdiction of TANROADS, while district roads fall under the jurisdiction of the Local Government, under the umbrella of the Prime Minister`s Office Regional Administration and Local Government (PRO-RALG).

### 3.4 PRO-RALG

The PRO-RALG has a general responsibility of coordinating the management of all road networks classified as district roads, feeder roads and urban roads. The last two are also known as community roads.

District roads (DRs) and community roads fall under the responsibility of the district engineer's office, who works under the district executive director.

#### 3.4.1 PRO-RALG road management system

The PRO-RALG has a system in place for managing the road network under the Local Government Authority known as District Roads Management System (DROMAS). DROMAS is a computer operated software package, which has been developed to prioritise district roads, identify the core network and determine the resource requirements necessary for its conservation. DROMAS is designed to facilitate effective planning of rehabilitation and maintenance work on district roads throughout the country. The planning process, which includes inventory data and condition surveys of district roads, is accomplished through a system known as ADRICS.

#### 3.4.2 Annual District Road Inventory and Condition Survey (ADRICS)

Annual District Road Inventory and Condition Survey (ADRICS) is a system of collecting data manually to be used in running DROMAS. The system guides the district engineer in collecting inventory and gravel road condition data. The inventory data required are: the location and geometry of the gravel road, drainage condition and drainage structures, type of soils, climate, traffic, population served, maintenance history of gravel wearing course, and proximity to suitable gravel materials.

A condition survey is conducted in order to capture the current condition of the gravel road in terms of wearing course surface, shoulder and drainage systems. ADRICS information is recorded on site on pre-printed forms.

#### 3.4.2.1 ADRICS pre-printed data collecting forms

ADRICS uses three specially formatted forms to collect gravel road inventory and condition data. These forms are coded A, B and C. Form A, which is used to collect gravel road section inventory and conditions, is mainly an assessment form. Form B is used to assess and update the district road structures inventory and condition, and form C is used for ward road inventory. Form C provides a known population number in a particular ward as an indicator of the population which is being served by the gravel road in question. The form provides preferences and priorities of the ward in accessing the district roads, and community access road links, feeding into the district roads. Hence the forms contribute to identifying the core district road network.

#### 3.4.2.2 The ADRICS procedure

Conducting an annual survey for road inventory and condition is a procedural activity. It needs the Civil Engineers (CE) and Road Inspectors (RI) in the District Engineer's office to make a survey trip throughout the entire district road network taking data regarding the road condition in forms A and B. In such a trip the CE and RI arrange meetings with all ward administrations in order to complete form C.

### 3.4.3 DROMAS output

By the aid of data collected on form A, DROMAS can classify the individual sections of a distinct road link as part of the core or non-core network. The software can also identify their level of maintainability and whether or not a bottleneck exists.

In the case of a bottle neck, the software identifies and prioritises a particular spot in high need of improvement and/or rehabilitation. DROMAS uses data from form C to calculate the population served per road link, to determine the level of prioritisation of each of the district roads.

### 3.4.4 Maintenance Condition Index (MCI)

The maintenance condition index (MCI) is calculated by DROMAS from the data of the current condition of the gravel road. The output enables the civil engineers to take decisions of which roads should be or should not be maintained.

The MCI uses values ranging from 1 which indicates that the road condition is good, to 4 which indicate bad/poor condition. A cut off standard of MCI is 2.5, whereby any roads with a value less than 2.5 are considered to be routinely maintainable and above a value of 2.5, are considered to be not routinely maintainable. The road automatically reverts to the list of non-maintainable roads requiring interventions, including spot repairs and/or rehabilitation.

#### 3.4.4.1 Rehabilitation

DROMAS identifies those DRs determined to be not maintainable with MCI greater than 2.5 and creates a separate list of such roads. DROMAS determines the priority of those roads taking into account, the traffic levels and composition; the population served, and the cost of spot repairs and/or rehabilitation works. Priority is given to those roads, demonstrating the best cost-effectiveness.

### 3.4.5 Costs of rehabilitation and maintenance works

For all relevant district roads maintenance, spot repairs and rehabilitation work are itemised. Global unit rates have been established, which reflect current work practice and costs of inputs. Following the inputs of ADRICS data and the Global unit rate cost defaults, DROMAS automatically provides budget requirement reports for district roads maintenance and spot repair/rehabilitation work. These reports are dis-aggregated to detail individual funding needs with the time frame selected as required.

These reports allow district Civil Engineers and their staff to prepare: annual district road maintenance and rehabilitation programmes and work plans; three years rolling plan for all district road conservation and development works; and longer-term work plans, including District Road Development Plans (DRDPs).

## 3.5 TANROADS Road Maintenance Management System (RMMS)

### 3.5.1 Background

The Ministry of Works sought to develop an RMMS in the early 1990s with assistance from the United Kingdom’s Department for International Development (DFID). This was achieved by utilising and adapting the Road Mentor System originally developed by Jonathan Kemp Consultants and now owned by the Transport Research Laboratory (TRL) (Katula and Toole 2000).

### 3.5.2 RMMS scope and models

The RMMS is a database system which provides a repository for information on the road network administered and managed by TANROADS and provides TANROADS with a series of modules which can support the decision making within road maintenance (TANROADS 2010b). The RRMS is based on Road Mentor 5.

The core part of the RMMS is a database which stores information on the road network. The system includes features for manual and digital input of fresh inventory and condition data into the database. When the database has been updated, the data can be used to estimate maintenance needs, including needs for routine and recurrent maintenance, spot improvement, and periodic maintenance.

The data in the database can be viewed and presented in the integrated geographical information system (GIS). Whereas GeoGis (software for the collection of position data for GIS update and maintenance) is used for data viewing on the screen, while ArcView (a GIS software solution that allows one to visualize, manage and analyse GIS data) is used for map printouts and specialised maps. The RMMS comprises four modules, namely routine/recurrent maintenance, periodic maintenance, budget split and contract monitoring modules, which are briefly described below.

#### 3.5.2.1 Routine/Recurrent Maintenance Module (RRM)

The objectives of RRM module are to: (i) estimate the needs of RRM works for one year, and (ii) prioritise the estimated needs under budget constraints.

The RRM model estimates the needs over one year for routine and recurrent maintenance of sealed and unsealed pavements. The model estimates the routine and recurrent maintenance needs using a series of frequency and quantity tables, which link the information in the road database with maintenance needs. These needs are estimated for each sub-link, but aggregated for each link.

The RRM includes a model for prioritising the needs under budget constraints. This model is based on road element priorities, maintenance levels and traffic. The model ensures that most roads would receive maintenance even under severe budget constraints, though not to full standard (TANROADS 2010b).

#### 3.5.2.2 Periodic Maintenance Module (PM)

The objectives of PM module are to: (i) estimate needs for periodic maintenance and spot improvements for a period of one year, and (ii) prioritise the work considering budget constraints. The road network is divided into homogenous section based on variation in traffic, inventory, and condition. For each homogeneous section, the need for periodic maintenance and spot improvements are estimated using treatment matrices. Different matrices are applied for unconstrained and constrained budgets scenarios respectively. This is to ensure that under budget constraints not only are the lists of projects shortened, but also the type of work is scaled down. The PM includes a model for prioritising needs considering budget constraints. The prioritisation is based on a multi-criteria analysis (MCA) approach using the following parameters: AADT/unit costs (as a surrogate for economic feasibility); access to social services; network connectivity; population along the link; access to production centres; road classification; and access to tourist centres. An MCA score is given for each maintenance project (TANROADS 2010b).

#### 3.5.2.3 Budget Split Module (BSM)

The objectives of the BSM are to: accumulate the maintenance needs and types across all regions; and analyse the consequences of budget allocations in terms of distributions between the regions and types of maintenance.

The model accumulates all the needs for routine and recurrent maintenance, spot improvements and periodic maintenance across all regions and road classes. This can be used to report on the distribution needs between regions and work types. When given a budget, the BSM will prioritise needs to meet the given budget constraints (TANROADS 2010b).

#### 3.5.2.4 Contract Monitoring Module (CMM)

The objectives of the CMM are to enter contract packages into the system; monitor and report the implementation of contracts; and provide simple statistics on the contracts implemented.

### 3.5.3 HDM-4 Analysis

According to TANROADS (2010b) RRM prepared input files – road network matrixes based on the outcome of the homogenous sectioning process – are uploaded to the HDM-4 (version 2) for analysis.

The model produces multi-year maintenance programmes and strategic expenditure maintenance plan. Under budget constraints, the HDM-4 system can prepare a maintenance programme meeting the given budget level using different objective functions.

Using the model strategic analysis can be run under a range of alternative budget scenarios, and the consequences of the road network can be analysed.

## 3.6 Discussions on the PRO-RALG, TANROADS and developed world's RMS

The PRORALG method of prioritising road works is partly influenced by ward leaders and partly by district engineers' office staff opinions. The method is purely subjective regardless of the form used to collect the data. The criteria considered during the road condition assessment are as shown in Table 9.

**Table 9: Road condition assessment criteria**

| S/No. | Criteria | Assessment factors | | | |
|---|---|---|---|---|---|
| 1 | Surface type | Surfaced within 5 years ( Gravel Road) | | Not surfaced within 5 years ( Earth Road) | |
| 2 | Surface Materials Rates of Wearing | Good (wears slowly) | Fair (wears steadily) | Poor (damage quickly) | |
| 3 | Materials Proximity | Near (haul distance between 0-5km) | Average (haul distance between 5-10km) | Far (haul distance greater than 10 km) | |
| 4 | Traffic Group | Very light (< 15 vpd) | Light (15-30 vpd) | Medium (30-50 vpd) | Heavy (> 50 vpd) |
| 5 | Drainage condition | Good (rain does not stand on the road ) | Fair (some water on the road during rain) | Poor (much water on the road during rain) | Severe (no functioning drainage system) |
| 6 | Shoulder condition | Good (good shape) | Fair (uneven shape) | Poor (poor shape) | Bad (does not exist) |
| 7 | Surface condition | Good (< 8 m/km IRI) | Fair (9-14 m/km IRI) | Poor (15-18 m/km IRI) | Bad (>18 m/km IRI) |

These criteria differ with those assessed in the USA, which, according to Shahin (2005:20), also total seven and can be assessed visually, namely: improper cross section, inadequate roadside drainage, corrugation, dust, potholes, ruts, and loose aggregate.

Of the seven criteria listed in Table 9, only road surface type, material proximity, traffic group, drainage condition, and shoulder condition can be visually observed with certain accuracy, but surface material rates of wearing (gravel loss) and surface condition roughness in terms of IRI are difficult to ascertain visually without special measuring instruments. Among the seven criteria, only four are distress, the remaining three, which are traffic, surface type, and materials proximity, are more or less part of gravel road inventory.

The calculation of MCI is done by DROMAS, while that of PCI can be performed manually, by PCI computer program, or by entering distress data on Micro PAVER.

Currently, DROMAS is not functioning; one of the reasons is that it cannot address roads which have deteriorated beyond normal routine maintenance, which is the case of most gravel roads under local government management.

The TANROADS RMMS is mainly centralised at headquarters, with regional offices providing data to run it. The multi-criteria analysis used by TANROADS in prioritising maintenance and rehabilitation works might in the long run favour certain regions favoured by tourists. The uses of HDM-4 needs calibration to suit local conditions, which if not done properly will end up providing unrealistic results. From the information obtained from TANROADS headquarters (2014, pers. comm. 22 September) the agency does not have enough engineers to manage 33,012 km of trunk and regional roads under its jurisdiction. The agency has 230 engineers; among them are 46 principal engineers, 69 senior engineers, and 115 junior engineers. Futhermore, the agency has 180 technicians; among them are 118 senior technicians, and 62 junior technicians. In the opinion of Paige-Green and Visser (1991:139) the HDM-4 model requires significantly more input and is especially cumbersome to sub-Saharan African countries.

### 3.7 Conclusions and recommendations

The efficiency of DROMAS relies heavily on traditional approaches in financing, which as Pinard (1999:138) sees it, is managing roads through local government works departments and financing them through general budget allocation. This system has a lot of red-tape and is not appropriate for managing road works. The PMS software building process did not involve local experts at the grass root level, and hence displays shortcomings in its implementations. For PMS software to be successful at its implementation stage, it has to involve local experts during its formulation.

DROMAS does not address the issue of: a) quality of work and its effect on the performance of gravel roads, b) the adequacy of personnel vis-à-vis the length of the gravel road network each district has, c) the qualification of road inspectors in terms of education background and experience in civil works, and d) civil engineers' experience to conduct gravel road condition surveys.

The road condition has to be assessed by experienced engineers and reported on a standard form to ensure, as far as possible, uniformity of approach and reliable results which are above suspicion. In general, the gravel road condition survey has to be conducted twice a year to enable effective monitoring of changes in pavement condition.

Maintenance not conducted to full standard has a weakness of not addressing adequately the sources of defects, and hence in the long run creates a maintenance backlog.

None of the road organizations under discussion use gravel loss prediction model as one of the tools of GRMS or MMS. There is a need for this to be addressed, as the formulation of suitable gravel loss prediction models for local gravel roads is of paramount importance if they are to be better managed. Hence, the formulation and application of a gravel loss prediction model in management of gravel roads in Iringa region is the specific objective of this study.

# CHAPTER 4
# DATA COLLECTION AND ANALYSIS METHODOLOGIES

## 4.1 Introduction

The specific objectives of this study were to develop locally:

- A statistically accurate gravel loss prediction model through investigation of marginal gravel material's geotechnical properties and physical characteristics, and the interaction over time between these properties with prevailing traffic characteristics and climatic conditions for Iringa region;
- A rational method of quantifying quality of gravel road construction and subsequent maintenance operation, based on visual assessment of the condition and performance of gravel roads and measured rate of gravel loss; and
- The culture of formulating gravel loss prediction models through empirical studies.

Fossberg (1963 cited in Paige-Green 1989: 3.1) argued that there was a need for South Africa to conduct a survey of existing gravel roads, by relating performance of these roads to traffic, climate and soil conditions. The aforementioned statement has been carried out in detail not only in South Africa, but elsewhere in the world where these roads are dominant. This is evidenced by a number of such studies carried out in Australia, Brazil, Kenya, Namibia, and Tanzania as described in Chapter 2. The list is not exhaustive.

According to Paige-Green (1989:3.1) the best way of executing this type of study is by investigating a number of randomly selected in-service gravel road sections of predetermined length. Factors which influence gravel loss on the randomly selected gravel road sections should be studied. These variables are numerous, but the major ones as per Paige-Green (1989:3.1) include the material's geotechnical characteristics, climate, traffic volume and type, and geometric properties. Uys (2008:1) lists three variables, namely: the material's geotechnical characteristics, climate and traffic volume and composition. In regard to this study, the preferred independent variables are those enumerated by Paige-Green (1989:3.1).

This chapter describes not only the theory behind decisions for the experimental design and processes, the testing and monitoring carried out, but also the postal questionnaire which was used to gauge the current status of MMS and GRMS as practiced in Tanzania. The chapter moreover discusses the condition survey which was used to correlate the performance of the local gravel roads with the materials' characteristics and panel data employed in formulating a gravel loss prediction model. It should be noted in advance that there is a thin dividing line between MMS and GRMS.

## 4.2 Experimental design of study

In order to meet the objectives of this study the fieldwork was conducted in accordance with a detailed experimental design. The objective of the experimental design was to ensure that suitable data were collected, a systematic approach was followed, and the data could be used to formulate the gravel loss prediction model.

The study was conducted in Iringa region, which is located in the southern part of Tanzania. The study of the gravel loss survey was the first of its kind in the region. The study used factorial experimental design, which was also employed in Kenya, Brazil and South Africa studies (Paige-Green 1989:3.2). It was noted during the study that the results of a factorial experiment in Iringa region can be extrapolated to other southern regions of Tanzania which have similar climate, materials and traffic condition.

Figure 7 is typical selected test section at Muhunga. Each section was 300 metres long.

**Figure 7: Typical selected test section at Muhunga**

The sections were selected based on the following set of characteristics:

i. Start and end distance of the test section;
ii. Road width;
iii. Topography;
iv. Traffic characteristics;
v. Material properties;
vi. Drainage conditions; and
vii. Rainfall data.

In order to make realistic comparisons between the different test sections it was decided to select the monitoring sections based on the following geometric properties:

i. No steep longitudinal gradients (not more than 4%);
ii. No flat or steep cross gradients, acceptable cross section gradients shall be between 3.5% to 5%;
iii. No curves; and
iv. Acceptable drainage.

The following constraints were considered:

i. Inconsistency maintenance operation;
ii. Lack of control on the particle size distribution of marginal materials deployed for surfacing gravel roads;
iii. Duration and the nature of the study, which was part time;
iv. Data inaccuracy; and
v. Financial.

The effect of 'i' and 'ii' on the performance of gravel roads under study has been described in Chapter 7 in section 7.2. Items 'iii' and 'v' were dealt thorough conscientious planning of the steps required to conduct the study. Data inaccuracy is dealt with by means of the error term in the prediction model.

### 4.2.1 Homogenous sections

The literal meaning of homogeneous is "having the same origin" (Government of Western Australia 2008:6). According to Wright, Dixon and Meyer (2004:395) and Sargious (1975:57-58) one of the paramount facts regarding soils and soil deposits is their heterogeneous nature.

This study was mainly concerned with the rate of depletion of gravel materials used as wearing course for unsealed roads and not the designing part, and was not concerned with the subgrade materials. The study is based on local roads deriving their materials from local sources i.e. within the range of the preferred economic haul distance of zero to10 km between the gravel materials borrow pit and unsealed road being surfaced; under such a condition the question of homogeneous section, in terms of subgrade characteristics, does not apply.

It should further be noted that, the application of gravel loss prediction models derived from this type of study covers a wide geographical area, particular areas having similar material characteristics, prevailing traffic and climate. It is therefore sufficient to say that each section surveyed had gravel surfacing materials with uniform characteristics.

Table 10 shows the climate and gravel material's geological type of 22 test sections out of 25 selected for performance study. To simplify each test sites' identification, data processing and analysis, the test sites were numbered as shown under S/No in Table 10, where R stands for regional roads. Only one road came from Iringa municipal council.

The three climatic zones, namely dry, moderate and wet are demarcated according to the number of months in a year with surplus rainfall over potential evaporations.

**Table 10: Climate and soil geological type for road test sections selected for performance study**

| Road name | S/No | Test section | Climate | Soil geological type |
|---|---|---|---|---|
| Iringa-Pawaga | R621-1 | Kidete | Moderate | Brownish grey quartzitic |
| | R621-2 | Mapinduzi | Moderate | Brownish grey quartzitic |
| | R621-3 | Kilendu | Moderate | Brownish grey quartzitic |
| | R621-4 | Muhunga | Dry | Light blue ferruginous siltstone |
| | R621-5 | Kimalanogwa | Dry | Brownish red lateritic |
| | R621-6 | Mkwambilenge | Dry | Grey limestone with quartzitic |
| | R621-7 | Pawaga S.S. | Dry | Brownish quartzitic |

**Table 10: Continued**

| | | | | |
|---|---|---|---|---|
| Iringa-Msembe | R595-8 | Mwika A | Moderate | Brownish red quartzitic |
| | R595-9 | Mwika B | Moderate | Brownish red quartzitic |
| | R595-10 | Mangalali | Moderate | Brownish grey mudstone |
| | R595-11 | Muhimbili | Moderate | Quartzitic siltstone |
| | R595-12 | Nzihi | Moderate | Quartzitic siltstone |
| | R595-13 | Nyamihuu | Moderate | Brownish red lateritic |
| Iringa-Idete | R625-14 | Tagamenda | Moderate | Brownish grey quartzitic |
| | R625-15 | Kitayawa | Moderate | Brownish grey quartzitic |
| | R625-16 | Igula | Moderate | Brownish grey quartzitic |
| | R625-17 | Ndiwili | Wet | Brownish grey quartzitic |
| | R625-18 | Utengule | Wet | Brownish red quartzitic |
| | R625-19 | Itwanga | Wet | Brownish red quartzitic |
| | R625-20 | Amani | Wet | Brownish red quartzitic |
| | R625-21 | Ilamba | Wet | Redish quartzitic |
| Iringa Municipal | Urban 1 | Don Bosco | Moderate | Brownish grey quartzitic |

The descriptive statistics associated with the results presented in Table 10 are as follows:

- 13 out of 22 (59.09%) test sections falls in a moderate climate, followed by five (22.73%) test sections which are in a wet climate, and four (18.18%) test sections in a dry climate.
- The most common type of gravel material used for surfacing the test sections was quartzitic. Quartzitic was used to surface 18 (81.82%) test sections. Of those 18 test sections, eight sections were surfaced with brownish grey, five sections with brownish red , one section with reddish, one section with brownish, two sections with silt stone and one section with grey limestone. The remaining four sections were surfaced as follows; two sections with brownish red lateritic, one section with brownish grey mud stone, and one section with light blue ferruginous.

## 4.3 Questionnaire survey and design

The method of collecting information for gauging the status of MMS and GRMS as exercised by Tanzania`s road organizations was based on a postal survey questionnaire. The merits claimed in favour of this method in the view of Kothari (2013:100-101) are:

i. Low cost regardless of geographical location of respondents;
ii. Free from the bias if the questionnaire answers are in respondents' own words;
iii. Respondents have adequate time to give careful thought to answers;
iv. Respondents, who are not easily approachable, can also be reached conveniently; and
v. Helps to provide large samples and thus results can be more dependable and reliable.

On the other hand, there are certain demerits (Kothari 2013:101) such as:

i. Low rate of return of the dull, filled-in questionnaire;
ii. It can be used only when respondents can read and write and are willing to cooperate;
iii. Control over the questionnaire is limited once it has been sent out to the targeted populations;
iv. There is inbuilt inflexibility because of the difficulty of amending the approach once the questionnaire has been dispatched;
v. There is also the possibility of ambiguous replies or omission of replies altogether to certain questions, and interpretation of omissions is difficult;
vi. It is difficult to know whether willing respondents are truly representative; and
vii. The time taken until one receives responses cannot be controlled.

Nevertheless, the method of a structured questionnaire was favoured due to merit i, iii, iv, and v. Demerit 'ii' did not apply and demerits 'iii' and 'iv; were taken care of through well-prepared and tested questionnaires. Demerit 'vi' did not apply as the targeted respondents are Tanzanian road organizations.

The data obtained from the questionnaire response were analysed with the aid of the Statistical Package for Social Sciences (SPSS) and Microsoft Excel.

### 4.3.1 Targeted population

The targeted population for receipt of the questionnaire were Tanzania`s two formal road organizations which are responsible for the management of road infrastructures. These are TANROADS and local government councils. TANROADS has offices scattered throughout mainland Tanzania at regional level, whereas local government councils operate at the level of district and municipal councils.

These two road organizations use different software packages of data management for conserving the gravel road network under their jurisdiction as discussed in Chapter 3.

### 4.3.2 Contents of the questionnaire

Although there were two groups of respondents, the contents of questions in the questionnaire were the same. The questions in the questionnaires were intended to establish the capacity of the local management of unsealed road pavements. The questionnaire was divided into five distinct parts, namely: a) statistics of unsealed roads, b) experience of staff concerned with gravel road maintenance management, c) level of technical education of the management team, d) current status of maintenance operations, e) the operation of gravel roads management systems, f) the effectiveness of the gravel roads management software employed.

The content of the questionnaires are discussed hereunder in their respective sections.

**Part one: Size, training, experience and sustainability of personnel running gravel road MMS and GRMS**

The first part of the questionnaire had five questions, which sought to gather particulars of the profile of the responding organization staff. These questions sought to capture the size of the gravel roads management technical personnel and supporting staff, and the level of experience and technical education in the case of technical personnel. Furthermore, the questions wanted to establish whether there are schemes and funds in place for providing training, which is essential for sustainability of any operational MMS and GRMS.

**Part two: Local climatic conditions**

The second part of the questionnaire comprised of two questions. These questions sought to establish the local climatic conditions influencing the performance of unsealed road networks in the respondent's area of the jurisdiction. Furthermore it requested information on any unique climatic condition experienced by the respondent.

**Part three: Unsealed roads management practices**

The third part of the questionnaire had seven questions. These questions required the respondents to provide data on unsealed road networks in their domain. The questions intended to establish if they apply any gravel roads maintenance management practices. The questions looked at the following aspects: the existence of a gravel road inventory, the total length of gravel, earth and track road networks under the jurisdiction of the respondents. The questionnaire further touched on the frequency and type of data collected during the condition survey of unsealed roads. The questions also touched on the application of data obtained from the condition survey, which relates to the maintenance management of unsealed roads, and whether the road authorities have ever conducted gravel loss or roughness surveys.

**Part four: Availability, characteristics, and management of gravel materials deployed as wearing course**

The fourth part of the questionnaire had five questions seeking to get information on the availability, characteristics, and management of gravel materials used for surfacing unsealed roads. Furthermore, the questions intended to establish the existence of borrow pit management systems. The respondents were asked to quantify in number the active borrow pits in their area and type of materials found in these borrow pits. Also, they were asked to tell if there are any procedures to follow before opening new borrow pits. The questions were intended to establish the physical characteristics of borrow pit materials in terms of Atterberg limits, and gradation. In addition, the questions intended to establish if the compaction of gravel materials placed on the roadbed is a common phenomenon by seeking to know from respondents how they treat variation in the compaction results. Moreover the question wanted to enquire if there is a credited materials laboratory in the area for testing gravel materials' optimum moisture contents and maximum dry density, parameters which are used to ascertain the quality of compaction achieved at the site.

**Part five: Construction and maintenance operation of gravel roads**

The final part of the questionnaire comprised eight questions, which requested respondents to elucidate on the construction and maintenance operation of unsealed roads under their jurisdiction. In general the quality of construction and maintenance practice affects the rate of gravel loss. The higher the quality of the said operations at the optimum cost, the less will be the gravel loss. The respondents were requested to quantify the availability rate of compaction and grading equipment/plant in their area. The respondents were also requested to explain the type of maintenance techniques employed, that is if it is labour intensive, mixed or equipment based methods.

### 4.3.3 Correspondence addresses of respondents

For correspondence purposes, the list of postal addresses of all TANROADS regional offices in Tanzania was obtained from TANROADS Iringa regional office. The list of postal addresses of the district and municipal engineer offices was obtained from the PRO-RALG library located at its headquarter in Dodoma.

### 4.3.4 Questionnaire

Appropriate sets of the survey questionnaire were sent to TANROADS regional offices and local government district engineers' offices and municipal engineers' offices. The package mailed to each organization comprised a covering letter providing brief information on the researcher, research title and objectives, and the information intended to be collected by the questionnaire.

The covering letter is appended as Appendix 1 and the questionnaire is presented in Appendix 2. Other communications were letters requesting access to gravel roads under TANROADS management and clarification on tests to be performed at TANROADS materials laboratories, which are appended as Appendixes 3 and 5 respectively. Appendix 4 is a letter from TANROADS Iringa office, responding to the letter submitted by the researcher through his employer. Appendixes 9 and 10 are acceptance letters from TANROADS Mbeya on the researcher`s request to participate in the unsealed road condition survey, and a letter from PRO-RALG headquarter in Dodoma accepting the researcher's request to use their unsealed roads network for research work.

## 4.4 Data collection

### 4.4.1 Introduction

The researcher acknowledges up-front that there are new innovations in data monitoring/acquisition technologies, and data analysis/reduction. The use of a geographically based database to integrate vast amounts of GRMS data, and performance prediction models, is prevailing in developed and a few advanced emerging countries. For most emerging countries, particularly in sub-Sahara Africa, the economic situation dictates what type of technology is to be used to achieve the objectives of GRMS. However, the economic or technology gap between countries does not make one GRMS inferior to the other, as long as the objectives set in respective GRMS are being implemented accordingly.

### 4.4.2 Gravel roads selected

Apart from one urban road under the jurisdiction of the Iringa municipal engineer, the rest of the roads were under the jurisdiction of TANROADS Iringa regional manager. The study was conducted on gravel roads as indicated in Table 11 and Figure 8.

**Table 11: Regional roads selected for the study**

| Road Name | Road No. | Length (Km) | | Total (Km) |
|---|---|---|---|---|
| | | Sealed | Unsealed | |
| Iringa - Msembe | R 595 | 9.48 | 97.5 | 106.98 |
| Iringa - Pawaga | R 621 | 2.5 | 63.91 | 66.41 |
| Iringa - Idete | R 625 | 2.5 | 65.48 | 67.98 |

(Source: TANROADS - Iringa regional manager`s office 2009)

The total length of the three gravel roads (classified as regional roads) selected for the study is 226.89 km. The total length of test sections randomly selected is 6.6 km, which is 2.9% of the total length of gravel roads in question.

The selected sections represented the gravel roads in question. The selections of gravel road test sections for monitoring exercise were based on the geometrical properties, drainage, and material properties.


**Figure 8: TANROADS Iringa`s regional roads selected for the study are in red**

The geometrical considerations were: no steep longitudinal gradients (not more than 4%); and no curves. Drainage consideration was that a test section should be on acceptable drainage (roads located in the self drained parts of the terrain were selected). Test sections were also selected based on the type of gravel materials borrow pit used for surfacing them. Changes in gravel materials borrow pits necessitated selecting a new test section.

### 4.4.3 Measurement of gravel loss

There are a number of methods to describe the gravel loss quantity, including:

i. Each cross-section of the measurement can be expressed as a total area, thus allowing a total volume loss calculation,

ii. Taking the measurement at a point and calculating an average height loss.

The measurement of gravel loss by the average height loss formed a crucial part of the research. The measurement was conducted in three stages, namely: a) the identification of the monitoring section, b) the setting out of the monitoring section, and c) the measurement of change in elevation of gravel wearing course at predetermined intervals and periods.

#### 4.4.3.1 The identification of monitored test sections

Identification of the monitoring sections was made after a proper desktop study based on information obtained from the TANROADS Iringa office. This information included: re-gravelling or maintenance history; foundation conditions; in-situ material's properties; imported material properties; traffic characteristics; environmental conditions; and geometry. The monitored test sections were representative of the TANROADS Iringa regional road network, and were selected accordingly.

| | **Traffic (ADT)** | **< 200** | | | **200 – 400** | | | **> 400** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Climate* (Months per Year)** | GC / SP | < 16 | 16-34 | > 34 | < 16 | 16-34 | > 34 | < 16 | 16-34 | > 34 |
| **1** | < 120 | | | | | | | | | |
| | 120-400 | | | | | | | | | |
| | > 400 | | | | | | | | | |
| **2-3** | < 120 | | | | | | | | | |
| | 120-400 | | | | | | | | | |
| | > 400 | | | | | | | | | |
| **> 3** | < 120 | | | | | | | | | |
| | 120-400 | | | | | | | | | |
| | > 400 | | | | | | | | | |

**Note**: Climate* refers to months per year with higher rainfall than evaporation

**Figure 9: Typical experiment design matrix employed**

Different types of design matrices were drawn up to assist with the identification process, but tailor-made to suit the needs based on the available information or conditions.

The typical variables as stipulated in Figure 9 were used as an experiment design matrix. These variables were traffic volumes, rainfall data, terrain and the material properties.

The selection of the monitored test sections were made after considering the prevailing geometric and topographic conditions. Safety for the team responsible for setting out and measurement of the monitored sections was also considered. Access roads or junctions were avoided within the circumference of the monitored section, as traffic would influence gravel loss on part of the section and not all.

Road test sections were selected in a section with a uniform vertical and horizontal alignment. For the sake of gravel loss survey, only 100 metres long sections were set out.

#### 4.4.3.2 Setting out of the monitored test sections

Setting out of the monitored test sections was accomplished in two stages, namely the installation of the reference benchmarks, and the installation of the monitoring pegs.

Each monitored test section was based on a localized referencing system, where a height was allocated to the first reference benchmark, and the heights were determined for the rest of the reference benchmarks, and monitoring pegs. Three reference benchmarks were installed as a safeguard against missing or damaged pegs, so that they could be replaced effectively and accurately if needed. Twelve measurement pegs were installed per monitored test section at twenty metre intervals, six on each side of the road. All the localized heights were measured with a dumpy level and survey staff, in relation to the first reference benchmark (e.g. taken as 100 metres above sea level). All heights were well documented for monitoring and replacement purposes. Figure 10 shows the curing operation of an established monitoring peg.

**Figure 10: Curing operation of an established monitoring peg**

Table 12 provides an illustration of a typical survey form per monitored test section.

**Table 12: Typical gravel loss measurement form**

| **Road Name:** | | | | **From:** | | **To:** | | **Date:** | |
|---|---|---|---|---|---|---|---|---|---|
| **Section Name:** | | | | **Section Condition:** | | | | | |
| **Assessor Name:** | | | | | | **Weather:** | | | |
| Bench Mark | Back | Front | Offsets | 0 m | 20 m | 40 m | 60 m | 80 m | 100 m |
| TBM 1 | | | 3.50 | | | | | | |
| TBM 2 | | | 3.25 | | | | | | |
| TBM 3 | | | 3.00 | | | | | | |

The exact method for peg installation and gravel loss measurement is discussed in more detail in Appendix 6.

### 4.4.4 Traffic volume studies

#### 4.4.4.1 General

Traffic volume is defined as the number of vehicles that pass a point along a roadway or traffic lane per unit of time (Wright, Dixon and Meyer 2004:126). Traffic volume studies are carried out to collect data on the number of vehicles that pass on a particular point on a highway facility during a specified time period. According to Garber and Hoel (2014:115) time period varies from as little as 15 minutes to as much as a year, depending on the anticipated use of the data. The authors (2014:115) further noted that the data collected can be allocated to subclasses such as directional movement, occupancy rates, and vehicle classification. Traffic volume studies are usually conducted when certain volume characteristics are needed.

Since there is considerable variation in the volume of traffic, several types of measurements of volume are commonly adopted. This helps to average these variations into a single-volume count to be used for many design purposes. Those which were relevant to this study were Average Annual Daily Traffic (AADT), Average Daily Traffic (ADT) and Vehicle Classification (VC); the description of each of these volume counts follows.

The AADT is the average of 24 hour counts collected every day in the year, i.e. the total number of vehicles passing the site within a year divided by 365. AADTs are used in several traffic and transportation analyses for estimation of highway user revenues, establishment of traffic volume trends, evaluation of the economic feasibility of highway projects, development of freeway and major arterial street systems, and development of improvement and maintenance programs.

ADT is the average of 24 hour counts collected over a number of days greater than one but less than a year. It may be measured for six months, a season, a month, a week, or as little as two days. An ADT is a valid number only for the period over which it was measured. ADTs may be used for planning of highways activities, measurement of current demand, and evaluation of existing traffic flow.

VC records volume with respect to the type of vehicles; for example, passenger cars, two-axle trucks, three-axle trucks, and so forth. VC is used in the design of geometric characteristics, with particular reference to turning radii requirements, maximum grades, and lane widths; capacity analyses, with respect to the passenger car equivalent of trucks; adjustment of traffic counts obtained from machines; and structural design of highway pavements, and bridges.

**Table 13: Vehicle classification**

| Types of Vehicle | Description |
|---|---|
| Passenger cars | Cars seating not more than nine persons, |
| Lights goods | Goods vehicles less than 1500 kg un-laden weight or pay-load below 750 kg including minibuses and Land-Rover type vehicles |
| Medium goods | Two-axle vehicles with twin tyre rear axle not exceeding 10 tons gross vehicle weight |
| Heavy goods | Vehicles with more than two axles (trailers included as part of the vehicle) or exceeding 10 tons gross vehicle weight |
| Buses | All regular passenger service vehicles and coaches |

VC can be associated with ADTs or AADTs. Table 13 shows the vehicle classification system opted for in this study.

#### 4.4.4.2 Methods of conducting traffic volume counts

Traffic volume counts are conducted using two basic methods: manual and mechanical (Garber and Hoel 2014: 116). In this study the manual method was opted, as briefly described below.

The basic form of manual count involves a person recording each vehicle by making tally marks on a field sheet. Appendix 7 shows a typical field sheet form which was used to collect classified traffic volume data. The main disadvantages of the manual traffic count method are as follows (Garber and Hoel 2014: 116): a) it is labour intensive; b) it is subject to the limitations of human factors; and c) it cannot be used for long periods of counting. Apart from these shortcomings, the manual method is affordable particular in sub-Sahara African countries where labour is cheap. The method also is ideal for short-term studies.

The manual traffic count method was employed near, between or at test sections. A classified manual traffic counts to determine the composition of current traffic collected in terms of the number of light, medium, and heavy goods vehicles; buses; and cars were carried out. The counts were taken for seven consecutive days, for 12 hours from 0600 to 1800 hrs. The 12-hour counts were adjusted to 24 hour counts based on the estimate that a further 10% of traffic travelled during the period 1800 to 0600 hrs. (Greening *et al*. 2006:7).

### 4.4.5 Road condition survey

The condition of pavement constructed from gravel materials over subgrade is a function of the thickness of well compacted gravel layer, which is progressively reduced by attrition (AUSTROADS 1987:56). Many deformations of unsealed roads can be attributed to wear and erosion of wearing course materials. Gravel material's characteristics in terms of soil particle size and its moist behaviour affect its performance when used as gravelling materials (Paige-Green 1989:6.3).

A detailed description of the visual condition survey of each 300 m long test section was carried out during each site visit unless the section was wet or had recently been graded. For wet sections, which occurred during the rainy season, only drainage, slipperiness and trafficability were recorded. The performance information gathered was used to correlate with the material's characteristics. The surface condition of each test section was recorded on a modified unsealed road assessment form appended as Appendix 8. The modified form is adapted from the format of TMH 12 (Jones and Paige-Green 2011:67).

The description of distress followed a standard visual assessment manual for unsealed roads. A six-point classification system for a degree of severity ranging from 0 to 5; and a five-point classification system for extent ranging from 1 to 5 were employed. According to Jones and Paige-Green (2011:8) for research purposes, the maximum severity possible is of great interest and not the predominant severity. According to the format of the degree of severity, zero indicated no defect and a rating of 1-2 indicated acceptable conditions. A rating of 3-5 indicated unacceptable conditions. The following distresses related to gravel loss were rated, namely: dustiness; stoniness-embedded; stoniness-loose; loose material; potholes: corrugation; rutting; quantity and quality of gravel materials; slipperiness; skid resistance; and trafficability.

#### 4.4.6 Laboratory tests

Knowledge of gravel material's characteristics and classification enables the prediction of its performance. Performance prediction is one of the tools to find solutions to gravel road engineering problems (McKinlay 1988: 287). In this study, laboratory tests to determine sub grade and gravel materials characteristics, were conducted according to Tanzania`s Central Materials Laboratory (CML) procedures, referred to in the TZ-MoW (2000a:2-16). These procedures are based on British Standards (BS). Tests conducted were particle size distribution, and Atterberg limits (BS 1377: Part 2: 1990 cited in TZ-MoW 2000a: 2-16). These tests were conducted at TANROADS Iringa regional materials laboratory. Tests on the mineralogical composition of gravel materials sampled from borrow pits and test sections were conducted at the laboratory of Geological Survey of Tanzania (GST) in Dodoma.

#### 4.4.7 Rainfall, temperature and relative humidity data

Data on rainfall, air temperature and relative humidity which are deemed to cover Iringa region were obtained from the TMA Iringa regional office. These data covered the monitoring period of this study.

For the purpose of pavement design, the climatic condition of Tanzania is grouped into three zones (TZ-MoW1999:2.2) as demarcated in Figure 11.

The demarcation is based on the number of months per annum with higher rainfall than evaporation as shown in Table 14.

**Table 14: Climatic zones (Source: TZ-MoW 1999: 2.2)**

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

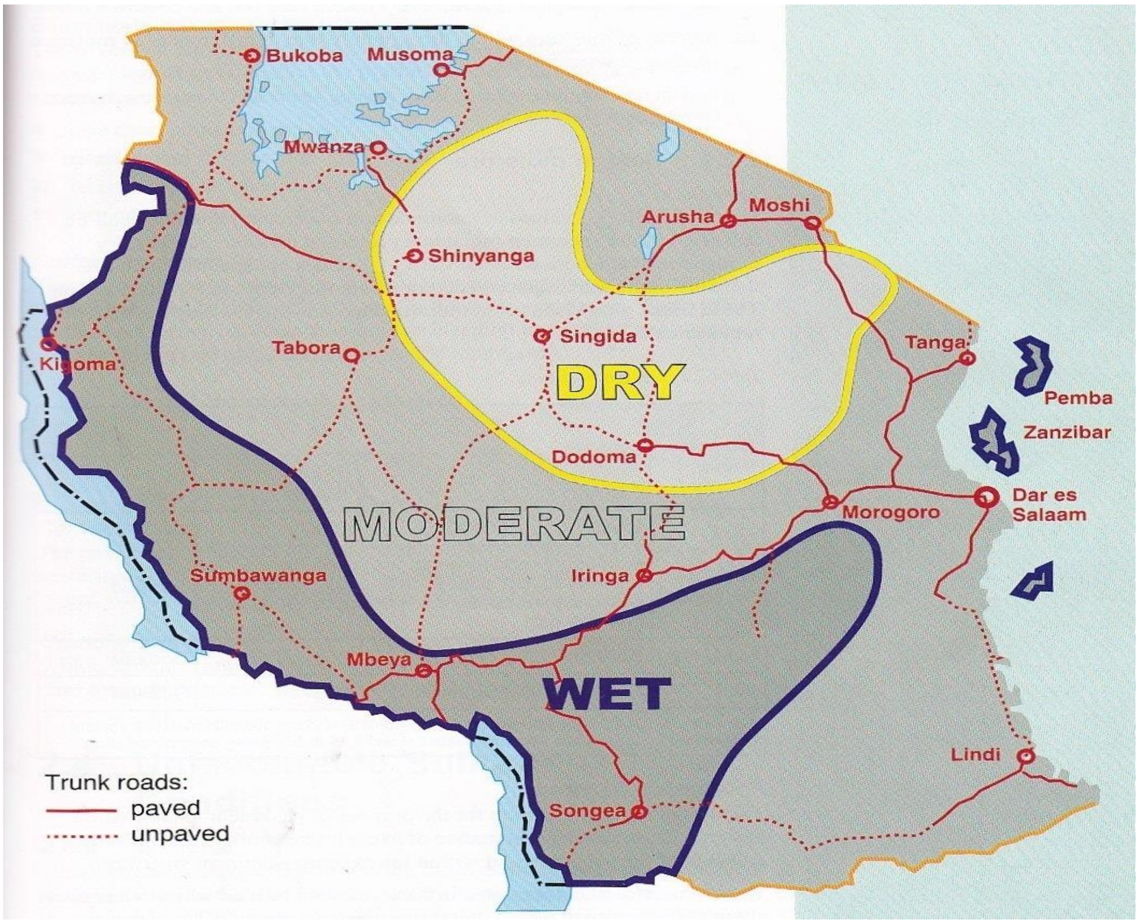


**Figure 11: Map showing climatic zones of Tanzania (Source: TZ- MoW 1999:2.3)**

### 4.4.8 Modelling

Computer modelling of gravel road deterioration provides the tool to predict how a gravel road network will perform even for the most complex situations. It provide quantitative information on the achievement of maintenance methods applied, assess interaction of various parameters affecting gravel loss, and predict statistically accurate the life-cycle of gravel road network, thus reducing risk of gravel road not meeting the anticipated design life and enabling future management of asset to be planned effectively.

Although both types of modelling methodology were discussed in the literature review, namely deterministic and probabilistic methods, the deterministic model was selected for this study. Stata programming (StataCorp 2011) and SPSS were employed in modelling a gravel loss prediction model based on panel data.

As briefly mentioned in Chapter 2, there is a need to establish a line of study in the discipline of engineering similar to econometrics under the term of pavemetric. Pavemetric shall concern itself with: a) operationalize empirically pavement theory, b) test pavement theory, and c) predict future behaviour in the pavement variable of interest in the basis of pavemetric model. In this study the word econometric will be associated with pavemetric. Panel data is among types of data employed in econometrics for empirical analysis (Gujarati 2014: 650).

#### 4.4.8.1 Empirical analysis in econometrics

Empirical evidence is knowledge acquired by means of observation or experimentation. Three types of data may be available for empirical analysis in econometrics, namely: time-series; cross-section; and panel data. Panel data which was employed in this study is briefly described below.

- **Panel data**: These are observations of the same cross-section unit (e.g. a road pavement or a road organization) over time. The other names for panel data are longitudinal data, micro panel data, pooled data (pooling of time series and cross-sectional observations), and combination of time series and cross-section data, event history analysis, and cohort analysis (Gujarati 2014:650).

#### 4.4.8.2 Panel regression model

Panel regression models are based on panel data. Panel data empirical analysis deals with two-dimensional data, that is, data which have both individual and time characteristics (Gujarati 2014:650).

#### 4.4.8.3 Structures of panel data

There are four structures of panel data as briefly described below.

i. **Cross-section oriented panel data (Short panel)**

   The number of cross-sections (N) is more than the time dimension (T). For example, a study covering 22 gravel roads over a period of three years, the number of vehicles noted when crossing a specified point in a year of study.

ii. **Time-series oriented panel data (Long panel)**

   The time dimension (T) is greater than the cross-sections (N). For example, the 10 years study of a gravel road's distress contributing to gravel loss.

iii. **Balanced panel data**

   Each cross-section unit has the same number of time series observations that is there are no missing observations for every cross-section.

iv. **Unbalanced panel data.**

   The number of observations differs among panel members, or in other words, some cross-sections do not have data.

In this study, both cross-sections oriented and balanced panel data were employed.

#### 4.4.8.4 Advantages of panel data

Baltagi (1998 cited in Gujarati 2014:651-652) lists the following advantage of panel data.

i. By combining time series of cross-section observations, panel data provides more informative data, more variability, less collinearity among variables, more degrees of freedom and is more efficient.
ii. By studying the repeated cross-section of observations, panel data are better suited to study the dynamics of change.
iii. By making data available for several thousand units, panel data can minimize the bias that might result through aggregating individuals or road organizations into broad aggregates.

iv. Panel data can better detect and measure effects that simply cannot be observed in pure cross-section or pure time-series data. For example, the effects of the techniques employed during re-gravelling on gravel loss can be easily studied if one conducts a series of gravel loss monitoring on a gravel wearing course which is just re-gravelled over a period of time.

### 4.4.9 Modelling approach

The basic framework for analysing the determinants of a gravel loss prediction model in this study was a panel data regression model of the following form in Equation 9 as adopted from Greene (2012).

**Equation 9:** $\boldsymbol{Y_{it} = x'_{it}\beta + z'_{i}\alpha + \varepsilon_{it}}$

where $Y_{it}$ is a scalar dependent variable (gravel loss), $x'_{it}$ is a vector of regressors (not including a constant term), $z'_{i}$ is a vector (containing a constant) of individual or group specific characteristics which may be observed or unobserved but not varying with time, $\varepsilon_{it}$ is a scalar disturbance term, $\alpha$ and $\beta$ are parameters and the $i$ and $t$ index road section and month or year respectively.

From Equation 9 if $z'_{i}$ is observed for all individual road sections, then it presents an ordinary linear model which can be solved by using ordinary least squares (OLS). However, it is challenging to observe all road specific characteristics as some of them are unobservable. For that reason, if $z'_{i}$ is unobservable and it happens that is correlated with $x'_{it}$ then the OLS estimator of $\beta$ is biased and inconsistent due to omitted variables (Greene, 2012). In addition, even if all variables were observable there would still be a problem in measuring them accurately due to approximations and round offs (Gujarati 2014:652-664) implying the problem of measurement errors. Using OLS in the presence of these problems leads to biased and inconsistent results.

To deal with this problem the intercept term can be allowed to vary with individual road test sections by assuming that differences across the road test sections can be captured in the differences in the intercept. Assuming further that all $\boldsymbol{x_{it}}$are independent of all $\boldsymbol{\varepsilon_{it}}$and the errors are homoscedastic and serially independent both within and between individuals, Equation 9 can be rewritten as Equation 10.

**Equation 10:** $\boldsymbol{Y_{it} = x'_{it}\beta + \alpha_i + \varepsilon_{it}}$

Where $\alpha_i$=$z'_i\alpha$.

The model above is referred to as a Fixed Effects (FE) model. The FE controls both road specific and time invariant characteristics such that the estimated coefficients cannot be biased because of omitted time invariant characteristics. Since in this model the intercept term is considered as an unknown parameter to be estimated, then dummy variables can be included, which allow the use of OLS in the estimation. According to Verbeek (2012), Equation 10 can then be rewritten as:

**Equation 11:** $\boldsymbol{Y_{it} = \sum_{j=1}^{N} \alpha_j d_{ij} + x'_{it}\beta + \varepsilon_{it}}$

Where $d_{ij}$ =1 if $i = j$ and 0 otherwise.

Equation 11 is known as the least square dummy variable (LSDV) regression. However, adding road dummies in the model results in a non-parsimonious model and thus may be difficult to interpret. That is, the model consists of too many parameters that may not be basically important. Furthermore, with a large number of dummy variables included one can run against the degrees of freedom (Gujarati 2014: 656-660).

The best way of obtaining the estimators for $\beta$ is to demean equation 10 and run the regression in deviations from individual means. That is the mean of each cross section is subtracted from each observation to remove the time invariant road specific effects and estimate $\beta$ only. Averaging Equation 10 over time, and subtracting the resulting equation from Equation 10, results in Equation 12.

**Equation 12:** $\boldsymbol{Y_{it} - \bar{Y}_i = (X_{it} - \bar{X}_i)'\beta + (\varepsilon_{it} - \bar{\varepsilon}_i)}$, **or** $\boldsymbol{\ddot{Y}_{it} = \ddot{X}'_{it}\beta + \ddot{\varepsilon}_{it}}$

This model is called within-groups estimator or just FEM estimator and produces unbiased and efficient estimates. Unfortunately, the Within-Groups estimator cannot be used to investigate time-invariant causes of the dependent variable (gravel loss) such as climate, and thus one cannot say anything about them.

To avoid the problems associated with the FEM the random effects model (REM) can be employed. This model assumes that the variations across roads are random and uncorrelated with the independent variables included in the model. That is $\boldsymbol{\alpha_i}$ are random, independently and identically distributed over the roads. The REM model is specified as shown in Equation 13.

**Equation 13:** $\boldsymbol{Y_{it} = \mu + x'_{it}\beta + \alpha_i + \varepsilon_{it}}$

The composite error term (also known as idiosyncratic error) $v_{i,t}$=$\alpha_i + \varepsilon_{i,t}$ is defined as consisting of two components: the road specific time invariant component $\alpha_i$ and the combined time series and cross-section component $\varepsilon_{it}$. The idiosyncratic error term is assumed uncorrelated with the explanatory variables of all past, current and future time periods of the same variable. It is also assumed that the idiosyncratic error is uncorrelated with the individual specific effects. In this case, the intercept ($\mu$) represents the mean value of all the (cross-sectional) intercepts. The $\alpha_i$ represents the (random) deviation of individual intercept from the mean value.

The advantage of this model is that it can include time invariant variables such as climate. However, the REM may suffer from inconsistency if the mean value of the composite error is not zero, and the individual effects and regressors are correlated. Furthermore, if the error terms are not serially independent as well as homoscedastic (equal spread or equal variance), the REM is inefficient. Thus, OLS can be inefficient, inconsistent or both, in REM, as per the above explanation.

However, even though FEM and REM are still the most popular approaches in estimating unobserved effects in panel data models, they only do so under the assumption of strict exogeneity (regressors) of the explanatory variables. The decision, whether to use FEM or REM is guided by the Hausman test, which tests whether the two estimators are significantly different (Gujarati 2014:654-660). In this study the Hausman test accepted REM modelling. According to Cameron and Trivedi (2010:257) the best method to obtain a consistent estimator is to use a population average (PA), as both FEM and REM are best under strict exogeneity of the explanatory variables. Population regression states that the expected value of the distribution of GL (dependent variables) is functionally related to independent variable. In simple terms, it tells how the average response of GL varies with independent variables (Gujarati 2014:666). Thus the final gravel loss prediction model was based on PA, and took the form shown in Equation 14.

**Equation 14:** $$\boldsymbol{GL_{it} = \beta_0 + \beta_1 ADT_{it} + \beta_2 PF_{it} + \beta_3 DR_{it} + \beta_4 PM_{it} + \beta_5 PP_{it} + \beta_6 D1 + \varepsilon_{it}}$$

Where**:** $GL$ is gravel loss, $ADT$ is the average daily traffic, $PF$ is the plasticity factor, $DR$ is dust ratio, $PM$ is plasticity modulus, $PP$ is plasticity product, $D_i$ is a dummy variable for climate. i = 1 if the road is located in a wet climate, i = 0 otherwise. $\varepsilon_{it}$ is the error term, $\beta' i$ are parameters, and $i$ and $t$ index road test section and year respectively.

The study was based on prediction of gravel loss, implying that all independent variables employed in the model influence to a certain degree gravel loss. The relationship between dependent and independent variables can either be linear or nonlinear, but in this study it is assumed to be linear. The $\beta_n$ are impact parameters, each respectively indicating the degree by which GL changes given a one unit changes in the corresponding variables (Murphy 2014). The signs of parameters accompanying variables in the model (Equation 14) should behave in line with the parameter's influence on gravel loss. The following are the hypothesized signs of parameters.

The parameter $\beta_1$ should take positive sign indicating that the unit increase in ADT will trigger unit increase in GL. PF is the product of percentage of fine component of marginal materials passing through a 0.075 mm-sieve and PL. PM and PP are the product of percentage of fine component of marginal gravel materials passing through a 0.425 and 0.075 mm sieve respectively and PI. DR is the quotient of percentage of fine component of marginal gravel materials passing through a 0.075 by 0.425 mm sieve. From the forgone definition it is clear that the variables PF, PM, PP, and DR describe the physical state of marginal gravel materials. According to Jones (1987:7) the rate of gravel loss varies with the change of physical state of marginal gravel materials. Taking PL and PI constant, the increase in PF signifies decrease in GL (i.e. traffic induced GL is less as the coarse fraction decreases). In this case $\beta_2$ should take negative sign. $\beta_3$ should take positive sign as an increase in DR signifies an increase in GL. The effect of PM and PP to GL is similar to PF, hence $\beta_4$ and $\beta_5$ should take negative sign. $\beta_6$ should take negative sign as the GL in wet climate (which is represented by D1) is less than in both dry and moderate climate.

# CHAPTER 5
# ANALYSIS AND DISCUSSION OF QUESTIONNAIRE RESPONSES

## 5.1 Introduction

There is a thin line dividing between gravel roads MMS and GRMS. Road management in general has the intention of maintaining and improving the existing road network to enable its continued use by traffic in an efficient and safe manner (Robinson, Danielson and Snaith 1998:1-2). Road maintenance can be defined as the function of preserving and restoring a road and keeping it in a condition of safe, convenient, and economical use (Wright, Dixon and Meyer 2004:620). The Local Authority Association (1989 cited in Robinson, Danielson and Snaith 1998:6) states that the aims of maintenance management systems include, but are not limited to: a) using a systematic approach to decision-making within a consistent and defined framework, b) assessing budget needs and resource requirements, c) adopting consistent standards for maintenance and for the design of associated works, d) allocating resources effectively, and e) reviewing policies, standards, and the effectiveness of programmes on a regular basis. Pearson (2012:208) is of opinion that MMS should answer questions such as: a) what budget is required? b) how many maintenance plants and staff are required? c) how often should each road be graded? d) what is the resulting level of serviceability? e) what volume of gravel material is needed to be replaced annually? and f) which roads should be upgraded to sealed standards? Huang (2012:424-425) argues that pavement evaluation and maintenance are not exact sciences; they depend to a large extent on past experience and engineering judgment.

Hence, running or developing the local MMS or GRMS, be it for unsealed or sealed pavement, needs a team of well-trained and experienced road organization staff and appropriate equipment. The data employed to run a gravel roads MMS should reflect the capacity of the road organization personnel to collect them. In this regard, the team should be of adequate size, education and experience. It is, therefore, essential for the benefit of road users, road organization, the environment, and the sustainability of gravel roads to establish the capacity of road organization personnel responsible for running gravel road maintenance management with the intention of meeting social, economic, and political demands.

The need to establish the adequacy of Tanzania road organizations in running gravel road MMS and GRMS was the reason for conducting the qualitative research aspect of this study. The survey also intended to find out which parameters are readily collected by the surveyed road organizations, so as to include them as variables in formulating a gravel loss prediction model.

This chapter presents analysis and discussion of the questionnaire responses. The study notes the challenges being faced by road organizations responsible for the maintenance management of gravel road network in Tanzania and attempts to map a way forward.

## 5.2 Attributes of respondents and their response rate

Two groups of respondents were selected for the study and had questionnaires sent to them. These are TANROADS regional offices and district/municipal councils engineers' offices. Each group uses a different package of GRMS for conserving the gravel road network under their jurisdiction.

TANROADS staff responsible for managing the trunk and regional roads use Road Maintenance Management Systems (RMMS), while the Local Government Authority (LGA) District/Municipal council engineers responsible for managing district roads use the District Roads Management Systems (DROMAS). Both these systems have been developed with experts and financial assistance from foreign countries, with the involvement of local experts at ministerial or top managerial levels (Mwaipungu and Allopi 2012a). These two groups of respondents have mutually exclusive experience on the performance of gravel roads under their jurisdiction and the extent of the effectiveness of the type of GRMS employed.

**Table 15: List of respondent TANROADS regional offices and district/municipal/city councils engineers' offices**

| TANROADS region offices | | District/municipal/City council engineer's offices | |
|---|---|---|---|
| 1.Coast | 2.Manyara | 1.Mugumu – Serengeti | 2.Arusha City |
| 3.Bukoba | 4.Dar es Salaam | 3.Chunya | 4.Mbeya |
| 5.Rukwa | 6.Dodoma | 5.Iringa Municipal | 6.Morogoro |
| 7.Mbeya | 8.Tabora | 7.Tukuyu | 8.Njombe |
| 9.Iringa | 10.Tanga | 9.Temeke Municipal | 10.Mkuranga |
| 11.Morogoro | 12.Arusha | 11. Kasulu | 12.Manyoni |
| | | 13. Iringa | 14. Mbozi |
| | | 15. Kyela | 16. Bahi |
| | | 17. Mvomelo | 18. Arumeru |
| | | 19. Kilolo | 20. Dodoma |

Although the questionnaires were sent to randomly selected TANROADS Regional offices and district/municipal council engineers all over the Tanzania mainland, the targeted areas were those TANROADS region officers and Districts and Municipal engineers surrounding and within the Iringa region.

The TANROADS regional offices sharing borders with the Iringa region are: Mbeya, Morogoro, Dodoma, Singida regions, and district and municipal council engineers' offices belonging to the mentioned regions.

Table 15 is the list of TANROADS regional offices and district/municipal councils' engineers who responded to the questionnaire sent to them.

Table 16 presents the number of questionnaires mailed to each category of respondents, the returned responses and the response rate in percentage. It should be stressed at the outset that both categories of populations are homogeneous, and according to Holt (1998:94) the more homogeneous a population is, the smaller the sample that can be drawn from it, and vice-versa. Henrrink, Hutter and Bailey (2011:16) further stress that in a qualitative study with a homogeneous population the sample can be small and deliberately so selected.

**Table 16: The number of questionnaires mailed to each category of respondents, and the response rate in percentage**

| Respondents | Sent questionnaires | No. responses | Response rate (%) |
|---|---|---|---|
| TANROADS | 20 | 12 | 60.00 |
| District/Municipal/ City | 50 | 20 | 40.00 |
| Total | 70 | 32 | 45.71 |

### 5.3 Data Analysis

The questionnaire comprised five main questions on the following themes: (i) management of gravel roads; (ii) local climatic conditions; (iii) statistical data on gravel road networks, condition survey and uses of collected road condition data after analysis; (iv) management of gravel materials borrow pits, quality control of gravel materials used for surfacing unsealed roads; and (v) construction and maintenance operation of unsealed roads. The analysis of responses follows the question order.

According to Henrrink, Hutter and Bailey (2011:17) qualitative data analysis is interpretive, whereby researchers seek to interpret the meanings of the participants responses, views and experiences. The following sections present the analysis of the survey results.

#### 5.3.1 Management of gravel roads

The effectiveness of achieved gravel road maintenance is simply a management challenge. The improvement of maintenance often involves institutional reform, human-resource development and changes to management practices before addressing technical issues (Mwaipungu and Allopi 2012b).

The task of managing a gravel road in an optimal manner still remains a technically complex practice, as it involves, among other variables, different personnel with distinct relevant engineering experiences and motivation. Responses obtained regarding the number of personnel running the gravel road management, and their engineering experience of the work varies widely for the road organizations being funded by the same government. Technical personnel range from 2-28, with the minimum number at district council level. The supporting staff varies between 1-71, with the lowest figure in the district council level and the highest at TANROADS Regional offices. This variation, grouped in the range of 2, is indicated in Table 17. This kind of huge variation puts those road organization's offices with less staff in a challenging position of managing effectively the gravel road network under their jurisdiction.

**Table 17: The frequency of the number of technical and supporting staff**

| Staff range in number | Technical staff frequency | Supporting staff frequency |
|---|---|---|
| 0-2 | 2 | 13 |
| 3-5 | 6 | 1 |
| 6-8 | 9 | 2 |
| 9-11 | 5 | 4 |
| 12-14 | 3 | 4 |
| 15-17 | 4 | 2 |
| 18-20 | 1 | 2 |
| > 20 | 2 | 4 |

From Table 18, it can be confidently concluded that both road organizations have staff with more than five years’ experience in supervising maintenance operations of gravel roads.

It can be noted that 69% of the road organization surveyed had staff with more than three years’ experience, which implies that they do not recruit new staff.

**Table 18: Experience of road organization staff in supervising maintenance operations of gravel roads**

| Range of experience in years | Frequency | Percentage (%) |
|---|---|---|
| <3, 3-5, and > 5 | 7 | 22 |
| <3 and 3-5 | 0 | 0 |
| <3 and > 5 | 3 | 9 |
| 3-5 and > 5 | 3 | 9 |
| < 3 | 0 | 0 |
| 3-5 | 5 | 16 |
| > 5 | 14 | 44 |
| Total | 32 | 100 |

From the distribution of staff with less than three years, three to five years and more than five years' experience it seems that there is no any pattern to give a room for transfer of knowledge and skills from those with greater than five years' experience to those with less experience as indicated in Figure 12.

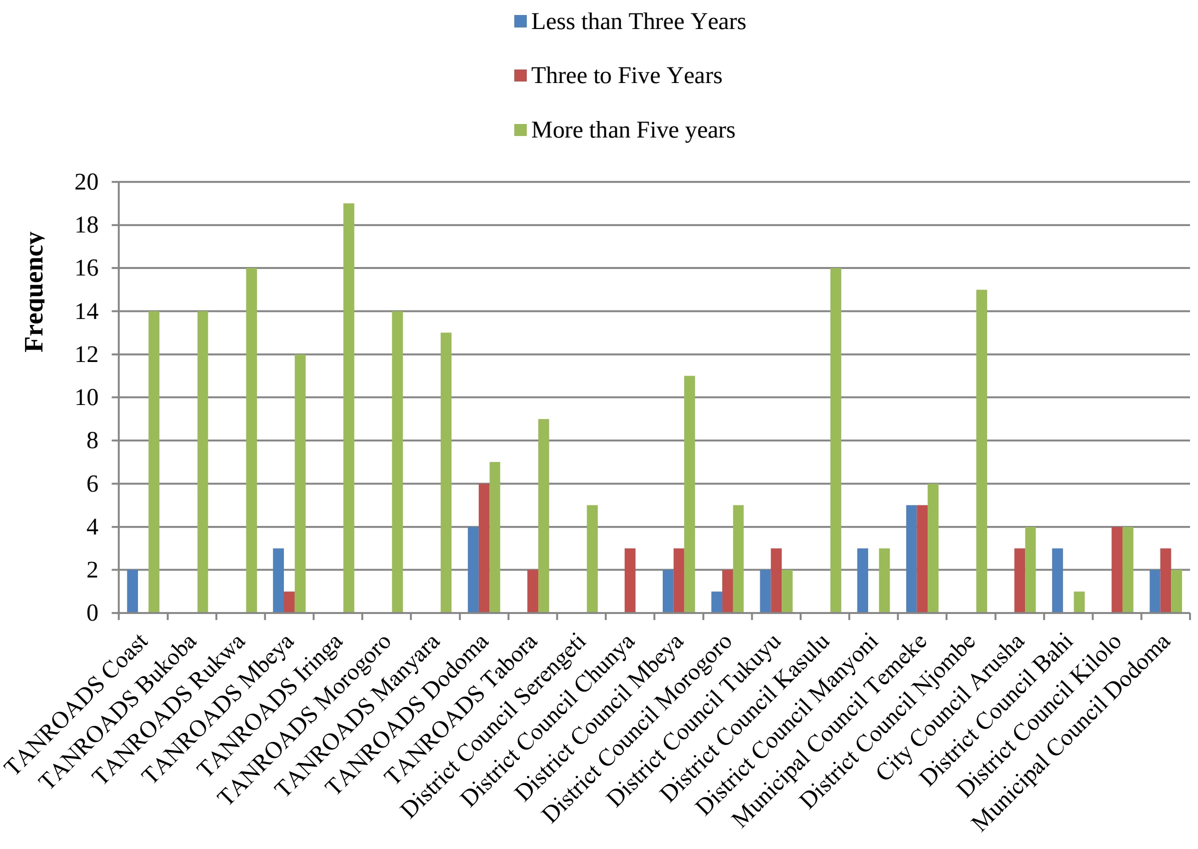


**Figure 12: Experience in supervising construction and maintenance operation of gravel roads of responded road organizations**

#### 5.3.1.1 Engineering and technical education

Table 19 shows road organization with the range of engineers and technicians, while Figure 13 shows the range of road organization with technicians, vocational education without secondary education and vocational education with secondary education. It can, therefore,  be noted from Table 19 that the range of staff with engineering education varies widely, with 13 (40.6%) road organizations, having between 1-2 engineers, and only two (6.3%) organizations having between 9-10 engineers. The same variation is noted for staff with technical and vocational education in Figure 13. With this type of variation in technical education, it is a bigger challenge to organise a uniform formalized system of gravel road management, not to mention implementing it effectively. According to Department of Transport, Republic of South Africa (1989:42) each road organization should be free to develop a maintenance management system which characteristically reflects its own capacity.

**Table 19: Frequency of road organization with the number of staff with engineering and technical education in the range indicated**

| Range of engineers/technician | Engineer | | Technician | |
|---|---|---|---|---|
| | Frequency | Percent (%) | Frequency | Percent (%) |
| 1-2 | 13 | 40.6 | 10 | 31.3 |
| 3-4 | 2 | 6.3 | 5 | 15.6 |
| 5-6 | 12 | 37.5 | 7 | 21.9 |
| 7-8 | 3 | 9.4 | 3 | 9.4 |
| 9-10 | 2 | 6.3 | 3 | 9.4 |
| 11-12 | 0 | 0 | 2 | 6.3 |
| > 13 | 0 | 0 | 2 | 6.3 |
| Total | 32 | 100 | 32 | 100 |

#### 5.3.1.2 The size of technical and supporting staff managing gravel roads

Although the number of regional and districts in Tanzania’s mainland has increased by almost 2% since the beginning of this study in 2011, this is not reflected in the size of technical personnel running gravel road management system.

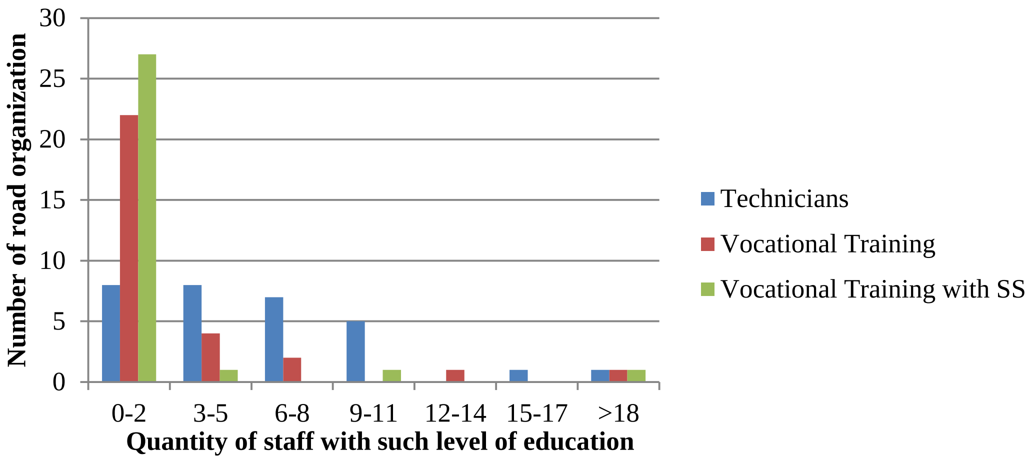


**Figure 13: Range of road organization with the number of staff with technicians, vocational, and vocational with the secondary school (SS) education certificate**

### 5.3.1.3 Training

Continuing training is a key feature of any pavement management system for it to be effective and implementable (Kuennen 2009:2). Training must be a central part of personnel management (Harral and Assif 1988:21). According to Robinson and Thagesen 1996b:452) the aim of training is to improve job performance by extending knowledge, inculcating skills, and modifying attitudes, so that individuals can work in the most economical, efficient and satisfying atmosphere. Twenty two (68.8%) road organizations responded positively to the question regarding the availability of funds for training staff, with only 10 (31.2%) respondents stating that there are no funds for such training. However, even such a number still raises an alarm, as training is a way of improving performance by changing the way work is done; also it is an indispensable requirement for improving resource allocation (Robinson and Thagesen 1996b:452).

### 5.3.2 Local climatic condition

Responses to the question on local climatic conditions indicate variations in the location of gravel roads with respect to climatic conditions.

**Table 20: Frequency of local climatic condition experienced in each respondent`s area of jurisdiction**

| Climate | Frequency | Percentage (%) |
|---|---|---|
| Wet | 3 | 9.4 |
| Dry | 2 | 6.3 |
| Moderate | 17 | 53.0 |
| Wet and Dry | 3 | 9.4 |
| Wet and Moderate | 3 | 9.4 |
| Dry and Moderate | 3 | 9.4 |
| Wet, Dry and Moderate | 1 | 3.1 |
| Total | 32 | 100 |

Some gravel roads fall either in one, two or three climatic conditions prevailing in Tanzania, which are wet, dry, and moderate climatic condition as shown in Table 20, with 53% falling in moderate climate.

On the question of whether there is an area which receives a unique climatic condition different from surrounding areas, three (9.4%) road organizations confirm that they have areas with a unique climatic condition. These areas' gravel roads might need a different gravel loss prediction model to address the situation. Although such cases as the ones reported above are few, it is a call for road organization to constantly study the environment in which they work. By studying their environment, they will be aware of any changes in climate patterns in order to improve further or find a better way to maintain the performance of the gravel road networks under their management within their financial limitations.

### 5.3.3 Statistical data on gravel road networks, condition survey, and uses of data after analysis

Although the questionnaire included questions requiring data on the length of earth road and tracks, this study discusses only data of gravel roads, which are its central focus and give only a picture of earth roads and tracks as shown in Figure 14.

The length of gravel roads under the judiciary of the road organizations which responded vary widely. The extent of variation ranges between 10 km to 3000 km.

**Table 21: The frequency of the road organization and the range of gravel road length under their jurisdiction**

| Range of gravel road length in km | Frequency of road organization managing such length | Percentage (%) |
|---|---|---|
| 0-250 | 12 | 37.5 |
| 250-500 | 6 | 18.8 |
| 500-750 | 3 | 9.4 |
| 750 - 1000 | 5 | 15.6 |
| 1000 - 1250 | 1 | 3.1 |
| 1250 - 1500 | 0 | - |
| 1500 - 1750 | 2 | 6.3 |
| 1750 - 2000 | 1 | 3.1 |
| 2000-2250 | 1 | 3.1 |
| > 2250 | 1 | 3.1 |
| Total | 32 | 100 |

Table 21 shows the frequency of road organization and the length of the gravel road in the ranges of 250 km under their judiciary.

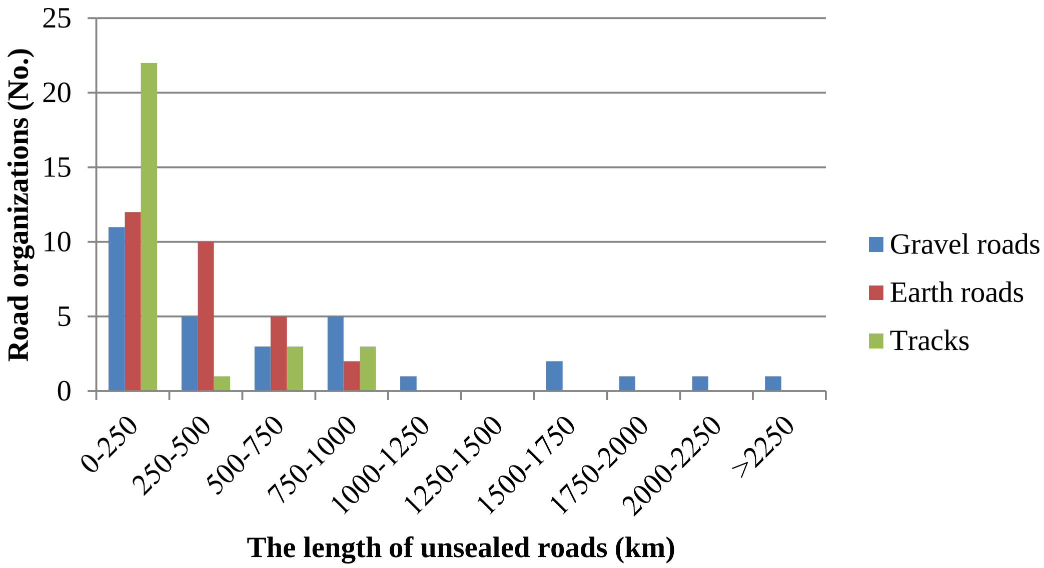


**Figure 14: The length of unsealed roads (km) under the jurisdiction of road organizations which responded to the questionnaire**

Figure 15 shows the length of gravel roads that engineers of the responding road organizations manage. Total length of all gravel roads under their jurisdiction is 21,226.2 km. There are 134 engineers, implying theoretically that each engineer is supposed to supervise an average length of 158.4 km of gravel road.

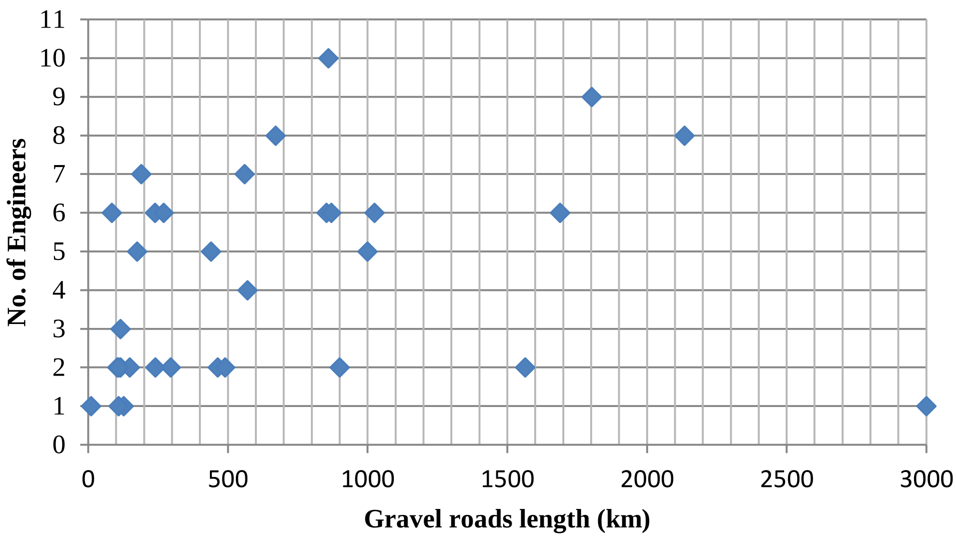


**Figure 15: The total length of gravel roads managed by each civil engineer**

It is noted from Figure 15 that one engineer in the same road organization, but different district or region is supervising 3000 km long of gravel road network, while in another district or region one engineer is supervising 10 km of gravel road. Figure 15 indicates that there is no relationship between the numbers of engineers road organizations has and the total length of gravel road network under their jurisdiction.

All respondents stated that they have an inventory of gravel roads under their management. Most respondent agree that they perform gravel road condition survey annual. However, there was one contrary response from the district/municipal council, where the respondent reported that they never conducted such an exercise. Others unique responses were: road organizations which conduct road condition surveys once in the time frame of two years, two surveys a year, and no fixed schedule for the survey. The need to have a consistent time frame for conducting condition surveys cannot be overemphasized. Condition surveys are the benchmark for the performance of gravel roads and the measure of the quality and effectiveness of the maintenance regime.

According to Larsen, Hildebrand, and Macdonald (2002:5), traffic is one of the main causes of pavement deterioration, and therefore, it is essential for road organizations to be able to produce an accurate traffic forecast. It is no wonder that 90.32% of road organizations responded that they do collect traffic volume data and conduct distress surveys. Unfortunately, none of the respondents indicated a collection of local climatic condition data, although it is believed to affect the performance of gravel roads immensely (Paige-Green 1999:163-171).

None of the road organizations indicated that they conduct time-series performance studies in terms of longitudinal roughness or gravel loss surveys. According to Ellis (1979:5), improved time-series quantification of the rate of deterioration of gravel roads is necessary in order to assess maintenance needs in economic terms, and to plan cost effective maintenance strategies.

It is evident that for reliable quantified data to be collected from gravel roads, effort is needed not only to equip road organizations, but also to give them training on the need of such data. These data are required not only for developing gravel road deterioration models but also for understanding the performance of gravel materials used to surface unsealed roads under their management. The data may also be used to formulate or improve gravel road specification. This understanding will have a longer-lasting effect on the performance and sustainability of gravel roads.

### 5.3.4 Quality control of gravel materials for surfacing unsealed roads

Each respondent indicated they had an active borrow pit for winning gravel materials. Regarding whether these road organizations follow routine procedures in seeking approval from the Ministry responsible with mining or conduct environmental impact assessment before opening new borrow pit, 21 (65.6%) respondents indicated that they did not look for approval. Of the 32 respondents, two (6.3%) do conduct environment impact assessments through contractors who have been awarded construction or maintenance works, nine (28.1%) seek approval and conduct environments impact assessment. Only 12 (37.5%) respondents out of 32 do not determine the geologic natures of these borrow pits due to scarcity of geologic laboratory with such a capacity. The active laboratories for conducting such a test are located in Dodoma and Dar es Salaam regions.

Most districts and municipal councils do not own or have a materials laboratory within their district, and depend on TANROADS laboratories, which are situated in regional headquarters. Common tests conducted in these TANROADS laboratories for determining physical and mechanical characteristics of gravel materials are Atterberg limits, compaction, sieve analysis, and California Bearing Ratio (CBR). These tests are sufficient for quality control purposes.

The importance of testing gravel materials before being put into use cannot be overemphasized. If no test is conducted on construction materials, then one has no right to use them (Ele International 2009). Paige-Green (2007b) insists that the properties of the gravel materials should be tested regularly during construction to ensure that they do not differ from accepted specification. Among 32 respondents, 18 agreed that they do test gravel materials before using them, three district councils use the test results obtained by TANROADS, particularly those which share the same borrow pits with TANROADS regional offices. Three district councils declared that they do not test their gravel materials before use, while two district councils declared that there are no funds for such tests, implying that if funds are available, they will also perform all necessary tests on gravel materials before using them to surface their unsealed roads.

Variations in materials test results are normally inevitable in gravel road construction or maintenance works. Eleven (34.4%) responded to this question by describing how variations in test results are addressed during quality control of construction or maintenance works on gravel roads. According to five (15.6%) respondents, variations in quality control test results are either addressed jointly by all stakeholders or by referring to standard specification. Four (11.3%) respondents said that they had not encountered variation as the tests are being conducted by the third parties who settle any variation if encountered with the parties involved, and one (3.3%) respondent said that variation encountered is within the acceptable range of ± 5 per cent.

### 5.3.5 Construction and maintenance operation of unsealed roads

The seven questions on construction and maintenance operation of unsealed roads were seeking to determine the type and availability rate of construction plant in the districts and regional offices concerned. These plant which are mainly applied during the construction and maintenance operation of gravel roads includes but not limited to graders, excavators, bulldozers, and compactors. Compactors come in different types and performance; common ones are sheep foot, steel roller, pneumatic roller, plate compactor, and pedestrian roller. The questions further intended to determine the quality control measures on construction and maintenance operations of gravel roads.

**i. Availability rate of construction plants**

The question of the availability rate of construction plant revealed the following results: 16 (50%) respondents said it is low, while 10 (31.3%) respondents said it is medium, and two (6.2%) said it is high. 'Low' means one plant per seven contractors, 'medium' one plant per four contractors and 'high' one plant per two contractors. Table 22 shows the availability rate of construction and maintenance plant.

**Table 22: Availability rate of construction and maintenance plant**

| Availability rate | Frequency of respondents | Percentage (%) |
|---|---|---|
| Low | 16 | 50.0 |
| Medium | 10 | 31.3 |
| High | 2 | 6.2 |
| No response | 4 | 12.5 |
| Total | 32 | 100 |

From Table 22 it can be noted that the low rate of availability of maintenance plant jeopardizes the timely execution of the construction or maintenance exercises. According to Anastasopoulos, Mannering and Haddock (2009:8) the timely application of the appropriate maintenance treatment preserves the gravel road network and extends design life. In this regard, therefore, inadequate supply of maintenance plant is the major hindrance for timely maintenance and preservation of gravel roads which needs to be addressed.

**ii. Grading methodology**

On grading methodology adopted during the grading exercise of gravel roads, it is noted from Table 23 that 28 (87.5%) respondents indicated that they are using self-propelled graders, three (9.4%) mentioned that they use both self-propelled and dragged equipment. However, they conceded that dragged equipment gave unsatisfactory results. Only one (3.1%) respondent indicated that they are using dragged equipment.

**Table 23: Types of grading methodology adopted during the grading exercise of gravel roads and its frequency**

| Use of grading equipment | Frequency of respondents | Percentage (%) |
|---|---|---|
| Self-propelled | 28 | 87.5 |
| Dragged | 1 | 3.1 |
| Self-propelled and dragged | 3 | 9.4 |
| Total | 32 | 100 |

### iii. Labour-based maintenance operation

According to Beenhakker et al (1987:305), the advantages of labour-based construction include: the amount of employment created per unit of investment (potentially large); economic conditions in rural areas are improved due to the construction workers` wages; and new individual skills are created. The disadvantages of labour-based construction include: increased initial costs until labour-based experience is developed; necessity of retraining supervisory engineers, training para-professionals or sub-professionals in low technology methods, and changing institutional attitude towards low or intermediate technology; increased overhead costs due to a different type of management; increased need for lower-echelon field supervisors due to large labour force; certain outputs, particularly compaction and surface smoothness, compare unfavourably with standards achieved with equipment.

Labour-based gravel road maintenance operation has to be encouraged. Labour-based gravel road maintenance operations involve breaking down various components of gravel road maintenance into small and simple activities that are easily carried out manually. Such activities are: vegetation control, earth work and gravelling (Tembo and Blockhuis 2004). On labour intensive maintenance method vis-à-vis equipment based method, 26 (81.3%) respondents concur that the labour intensive maintenance method is a minor option, whereas six (18.7%) respondents were of view that it is of medium priority. None of the respondents gave the method high priority. Table 24 indicates how labour intensive maintenance method is being perceived by respondents.

**Table 24: The level of acceptance of labour intensive maintenance methods**

| Level of acceptance of labour intensive method | Frequency of respondents | Percentage (%) |
|---|---|---|
| Low | 26 | 81.3 |
| Medium | 6 | 18.7 |
| Total | 32 | 100.0 |

In rural areas, the major maintenance method being employed is the mixed one which involves both equipment and labour based methods. Twenty six (80%) of respondents used both methods, while six (20%) respondents indicated that even in the rural areas, equipment based methods are being used for maintaining gravel roads.

**iv. Maintenance scheduling by grading**

Most gravel roads require that grading be scheduled at regular time intervals in order to remove corrugations, restore transverse profile, and bring back to the carriageway profile the gravel materials that have been swept to the sides by the action of traffic (Ellis, 1979:5). Furthermore, gravel roads deterioration gives little warning of what is to come (Harral and Asif 1988:4), hence maintenance scheduling is utmost important. On the question regarding scheduling of maintenance activities on unsealed roads, 25(78.1%) respondents reported that they conduct maintenance immediately at the end of the wet season, and the rationale behind such scheduling is as follows: a) to prevent maintenance works to be interfered with by the rain, which cannot be programmed, b) it is the source of moisture for compaction in dry areas, and to rectify defects, which were developed during the rainy season, c) intervention to restore and improve road conditions at the end of the rainy season yield good results, d) to restore the surface profile and clean drainage structures, e) to rectify distress caused by washout and rain, f) the nature of soil, which is predominantly clay, dictates that maintenance be done at the end of the rainy season, g) it is easy to notice defects, and h) the soil possesses moisture content, which is somehow near optimum moisture content.

However, there were some different viewpoints amongst respondents where one (3.1%) respondent said that they conducted maintenance at the beginning of the wet season, and four (12.5%) respondents said that they conducted maintenance twice a year, both at the end of the dry and wet season. Table 25 depicts the maintenance schedule of gravel roads as adopted by respondents.

Reading from the response above, it is evident that the schedule for collecting data on road conditions, if the data has to be reliable, should be set between the periods not scheduled for maintenance activities. Such scheduling is effective if the results shall be used to determine the intensity of maintenance. However, experience indicates that determining the intensity of maintenance activity does not mean that maintenance activity is actually carried out.

**Table 25: Season in which maintenance is scheduled**

| Maintenance schedule | Frequency of respondents | Percentage (%) |
|---|---|---|
| Immediately at the end of wet season | 27 | 83.4 |
| At the beginning of wet season | 1 | 0.3 |
| In both seasons | 4 | 13.3 |
| Total | 32 | 100 |

### v. Compaction

Compaction is the way in which the soil particles are packed more closely together through a reduction in the air spaces by mechanical and/or vibratory means, without change in the moisture content (Underwood1995:217). Regarding the question of whether the compacting effort achieved after compaction exercise is being evaluated or not, 30 (93.8%) respondents agree that evaluation is being done while two (6.2%) respondents indicated that the exercise was not being evaluated. Seventeen (53.2%) out of 32 respondents use performance specification, and 13 (40.6%) out of 32 respondents use both performance specification and method specification. Table 26 indicates the common specification methods used in measuring compaction exercise achieved on gravel wearing course.

**Table 26: Common specification methods used in measuring compaction exercise achieved on gravel wearing course**

| Specification adopted | Frequency of respondents | Percentage (%) |
|---|---|---|
| Performance | 17 | 53.2 |
| Both Performance and Method | 13 | 40.6 |
| None | 2 | 6.2 |
| Total | 32 | 100 |

### 5.4 Conclusions and recommendations

In conclusion regarding the answers and viewpoints expressed by respondents arising from the questionnaire, it is reasonable to mention that:

- There is a big variety in terms of experience, education and number of personnel running GRMS. These variations do not allow the comfort of having a uniform format of GRMS thorough out the country. Each TANROADS region office and district council should be tasked to have a unique MMS or GRMS to reflect its capacity.

- The distribution of staff with less than three years, three to five years and more than five years' experience does not display any definite pattern to give room for transfer of knowledge and skills from those with more experience to those staffs with less experience, which needs to be addressed.

- Although there are only a few responses regarding areas which experience unique climatic condition, this should be taken cautiously as the world is currently facing a climate-change phenomenon. Road organization should constantly study the environment in which they are working so as to be the first to note any changes from normal. This alertness will give them room to take appropriate measures to maintain and improve further the performance of gravel road networks under their management.

- It was noted from the responses received that the average length of gravel road under the judiciary of each engineer, regardless of the road organization which one is coming from, is 158.4 km. Such length is quite long for one engineer to manage effectively bearing in mind the activities involved in the GRMS and MMS. The manageable length recommended by this study is 100 km per engineer.

- None of respondent indicated that they collect local climatic condition data or conduct time-series performance studies. This should be addressed as time series quantification of the rate of gravel road deterioration is necessary in order to assess maintenance needs in economic terms and plan cost effective maintenance strategies.

- It is advantageous to perform maintenance activities on gravel roads after the rain season so as to get rid of all the distress caused by its effect and made worse by traffic loading and volume.

In the same regard, it can be recommended that:

- The pavement performance prediction models adopted or to be adopted for prediction of gravel road deterioration should reflect the capacity of the road organization in question to collect data on gravel roads, which are relevant to the model in question.

- There is a need for the government to establish materials laboratories or to encourage/motivate the private sector to run one for testing road building materials in each district.

- The quality of road works should be ascertained by a third party, and not by road organization engineers/technicians, in order to minimize and eventually eradicate corrupt practices in the road construction industry.

- Data on rainfall should be collected at particular locations preferably at ward or village level for this data to be effective in predicting rainfall's effects on the performance of gravel roads in those areas.

- The road organizations have to constantly study the political and economic environment in which they work. This knowledge will assist in developing, improving and maintaining the appropriate performance of the gravel road networks under their management within their financial capacity.

- A programme of continuous training of engineers to master existing technology and incorporate new ones in existing GRMS is a must for sustainability of gravel road infrastructure. Hence, funds for such exercises should be made available.

- The policy leading to the allocation of insufficient funds for gravel road conservation is not sustainable in the long term, and certainly does not permit an optimisation of the cost-benefit relationship. Without an adequate gravel road conservation system, vehicle operating costs escalate, and the economy in general is damaged. Prolonged under maintenance eventually results in a net diminution of the gravel road network.

- Transparency in addressing the root causes of gravel road deterioration is a necessary condition for an optimal allocation of maintenance funds in any economy.

# CHAPTER 6
# MATERIALS LABORATORY TEST RESULTS, TRAFFIC AND CLIMATIC DATA ANALYSIS

## 6.1 Introduction

This chapter discusses terrain, topography, and climate and seasons of the surveyed areas. It also presents and discusses the materials laboratory test results obtained from soil samples taken from the borrow pits used for surfacing the gravel roads selected for road condition and gravel loss survey. Furthermore, test results of gravel wearing course materials and loose materials from test sites are presented. Test results presented and discussed are those of sieve analysis and Atterberg limits. Other parameters derived from these results such as grading modulus, grading coefficients and shrinkage products are also presented.

Primary and secondary data obtained during the study are presented in summary, and analysed. Primary data are classified traffic volumes collected manually on, near or between test sections. Secondary data are the amount of average rain, temperature and relative humidity. Secondary data were collected by the Tanzania Meteorological Agency (TMA), Iringa station.

## 6.2 Iringa region

Iringa region is situated in the southern highlands of Tanzania and lies between latitude 6˚ 54′ and 10˚ 30′ South and longitudes 33˚ 30′ and 37˚ 00′ East (Awadhi and Starkey 2007). It borders with Singida and Dodoma regions in the North, Mbeya region in the West, Morogoro region in the East and Njombe region in the South.

### 6.2.1 Topography and terrain

The topography varies significantly within Iringa region with the highland zone characterized by mountains and undulating terrain with altitudes between 1600-2700 m above sea level. The midland zone is characterized by scattered mountains, hills, and flat areas with swamps and ponds. These are at an altitude of between 1200 to 1600 m above sea level. The lowland zone is located mainly in the rift valley and is characterized by flat undulating topography with an altitude between 500 to 1200 m above sea level (Awadhi and Starkey 2007). The test sections under TANROADS Iringa management lay in mid and low land zones.

The nature of the terrain, as described above, dictates: the route location, which varies with the characteristics of terrain; the amount of civil works involved; and the drainage work required for the safe keeping of the infrastructure. As far as the drainage work is concerned, efforts were made to locate gravel roads on self-drainage areas.

## 6.3 Climate and seasons

Yoder and Witczak (1975:177) and Sargious (1975:44) stress that climate is one of the most important factors affecting pavement performance. The extent of damage on gravel roads due to climatic agents will depend on a combination of factors, including the type of wearing course, sub grade, the amount of traffic and the severity of climatic element.

Climate and season changes are being affected by nature and human activities. The natural revolution of the earth is associated with seasonal changes (Byers 1974:10). Human activities related to road infrastructure, which are associated with climate and season changes are road construction, maintenance, and production of road construction materials, road furniture, and waste. To that effect, highway engineers are being called to study and be at the frontline to understand the environment in which the roads are being constructed and maintained to be able to safeguard against environment and climate seasonality.

### 6.3.1 General Iringa region climate

The tropical climate of Iringa region varies from semi and warm to cool depending on the topography. The rainfall regime in the region is semi-arid/uni-modal with rains falling between November and May. Over two-thirds of the region enjoys evenly distributed rains during the rainy season. In the drier areas, the pattern is broken by a period of lesser rainfall in January and February. The driest areas are Isimani and Pawaga divisions in the North of the region, lying at the altitudes around 500 m above sea level. In these areas, the average annual rainfall is 500 mm with a pattern of high annual variation. Conversely, at an altitude of 2,000 m to 2,500 m above sea level, rainfall is as high as 2,000 mm. Rainfall in the intermediate zones falls between these extremes. Temperature varies with altitude; the hottest temperature 28˚C in November is recorded at Mtera in the low land North of Iringa region.

### 6.3.2 Temperature, relative humidity and rainfall data

Climatic data, namely air temperature, relative humidity and rainfall were collected from Tanzania Meteorological Agency (TMA) Iringa Station. Data of air temperature and relative humidity are for four years from 2010 to 2013. These data were collected at 6:00 am and 12:00 noon. Rainfall data were collected for 53 years. Following is a brief description of temperature, relative humidity and rainfall data.

#### 6.3.2.1 Temperature

According to Sargious (1975:44) air temperature influences the performance of the pavement and supporting medium. Sudden temperature variations accompanied by fluctuations in soil moisture cause the binding medium in gravelling materials to dry out and lose its binding power, and generate dust and loose particles.

**Table 27: Average monthly air temperature for years 2010-2013 (Source: TMA Iringa station)**

| Month | 2010 | | 2011 | | 2012 | | 2013 | |
|---|---|---|---|---|---|---|---|---|
| | Average Air Temperature | | | | | | | |
| | 6:00 | 12:00 | 6:00 | 12:00 | 6:00 | 12:00 | 6:00 | 12:00 |
| **January** | 20.90 | 24.80 | 21.00 | 25.60 | 20.40 | 24.90 | 20.50 | 25.50 |
| **February** | 27.30 | 25.70 | 20.00 | 24.50 | 21.30 | 26.20 | 20.60 | 26.10 |
| **March** | 21.00 | 26.20 | 20.00 | 24.40 | 20.20 | 25.30 | 20.60 | 24.90 |
| **April** | 21.80 | 26.90 | 20.20 | 24.50 | 20.30 | 23.00 | 19.50 | 25.50 |
| **May** | 21.10 | 26.20 | 20.00 | 25.50 | 19.70 | 25.10 | 15.50 | 25.30 |
| **June** | 19.20 | 24.90 | 19.20 | 25.60 | 17.40 | 24.90 | 17.50 | 24.70 |
| **July** | 18.40 | 22.60 | 17.60 | 25.20 | 17.40 | 25.00 | 17.10 | 24.70 |
| **August** | 18.20 | 24.80 | 17.10 | 25.30 | 18.70 | 25.60 | 17.50 | 22.90 |
| **September** | 19.60 | 25.50 | 20.40 | 26.10 | 20.40 | 27.40 | 20.10 | 27.20 |
| **October** | 22.80 | 28.40 | 22.30 | 26.30 | 22.10 | 28.10 | 21.90 | 27.40 |
| **November** | 23.00 | 28.00 | 23.60 | 27.00 | 23.00 | 26.80 | 17.70 | 27.70 |
| **December** | 21.60 | 26.10 | 21.00 | 24.40 | 21.60 | 25.40 | | |
| **Mean** | 21.24 | 25.84 | 20.20 | 25.37 | 20.21 | 25.64 | 18.95 | 25.63 |
| **Std Dev.** | 2.47 | 1.55 | 1.78 | 0.83 | 1.73 | 1.34 | 1.98 | 1.41 |

Table 27 and Figure16 show data variations of average monthly morning and noon air temperatures for the years 2010, 2011, 2012 and 2013. From the data it is noted that the hottest months are October and November, with average, morning air temperature of 22.1˚C and average noon air temperature of 27.5˚C. The coolest months are June, July and August with average, morning air temperature of 17.9˚C and average noon air temperature of 24.7˚C. From Figure 16 it is noted that the air temperature data varies between 15˚C and 28˚C, with the majority of the data falling between 20˚C and 27 ˚C.

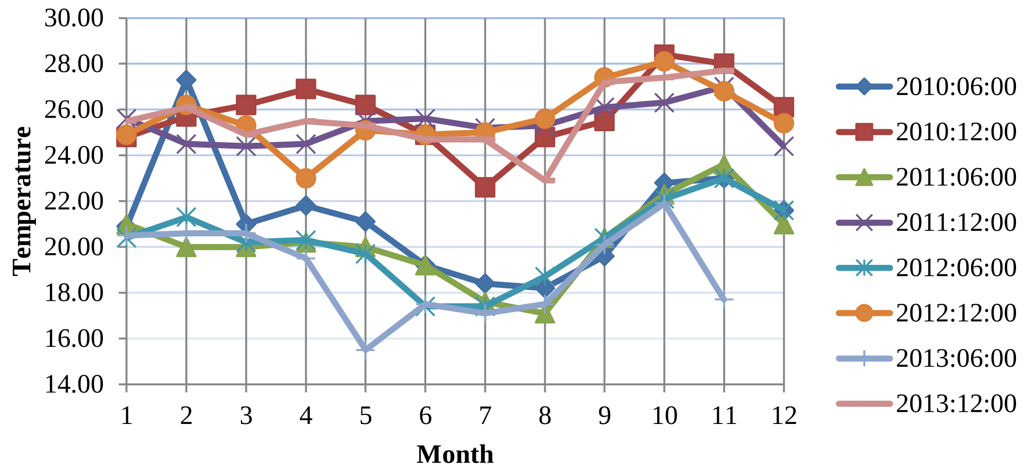


**Figure 16: Average monthly air temperature for years 2010-2013 (Source: TMA Iringa station)**

### 6.3.2.2 Relative humidity

According to Byers (1974:112), relative humidity (RH) is a highly variable quantity. It involves the ratio of two vapour pressures, the actual and the saturation. Table 28 and Figure 17 display data of average monthly morning and noon relative humidity from year 2010 to 2013. From the data, it is noted that the least relative humidity months are October and November, with average, morning relative humidity of 51.85 and average noon relative humidity of 32.75.

**Table 28: Average monthly relative humidity for years 2010-2013 (Source: TMA Iringa station)**

| Month | 2010 | | 2011 | | 2012 | | 2013 | |
|---|---|---|---|---|---|---|---|---|
| | Average Relative Humidity (RH) | | | | | | | |
| | 6:00 | 12:00 | 6:00 | 12:00 | 6:00 | 12:00 | 6:00 | 12:00 |
| January | 81.00 | 66.00 | 52.50 | 74.00 | 81.00 | 61.00 | 80.00 | 60.00 |
| February | 79.00 | 63.00 | 73.00 | 60.00 | 77.00 | 55.00 | 80.00 | 57.00 |
| March | 81.00 | 61.00 | 80.00 | 66.00 | 81.00 | 58.00 | 78.00 | 63.00 |
| April | 71.00 | 49.00 | 77.00 | 60.00 | | | 72.00 | 53.00 |
| May | 65.00 | 45.00 | 69.00 | 48.00 | 65.00 | 49.00 | 66.00 | 44.00 |

**Table 28: Continued**

| Month | 2010 | | 2011 | | 2012 | | 2013 | |
|---|---|---|---|---|---|---|---|---|
| | Average Relative Humidity (RH) | | | | | | | |
| | 6:00 | 12:00 | 6:00 | 12:00 | 6:00 | 12:00 | 6:00 | 12:00 |
| June | 60.00 | 42.00 | 63.00 | 40.00 | 61.00 | 40.00 | 59.00 | 36.00 |
| July | 58.00 | 40.00 | 61.00 | 33.00 | 56.00 | 34.90 | 57.00 | 34.00 |
| August | 56.00 | 35.00 | 58.00 | 35.00 | 59.00 | 35.00 | 59.00 | 36.00 |
| September | 54.00 | 32.00 | 53.00 | 35.00 | 52.60 | 29.60 | 54.00 | 30.00 |
| October | 48.00 | 29.00 | 50.00 | 29.00 | 53.00 | 33.00 | 48.00 | 29.00 |
| November | 51.00 | 32.00 | 57.00 | 37.00 | 56.80 | 41.00 | 51.00 | 32.00 |
| December | 67.00 | 49.00 | 74.00 | 58.00 | 67.80 | 53.00 | | |
| Mean | 64.25 | 45.25 | 63.96 | 47.92 | 64.56 | 44.50 | 64.00 | 43.09 |
| Std Dev. | 11.69 | 12.72 | 10.34 | 15.07 | 10.77 | 11.07 | 11.83 | 12.85 |

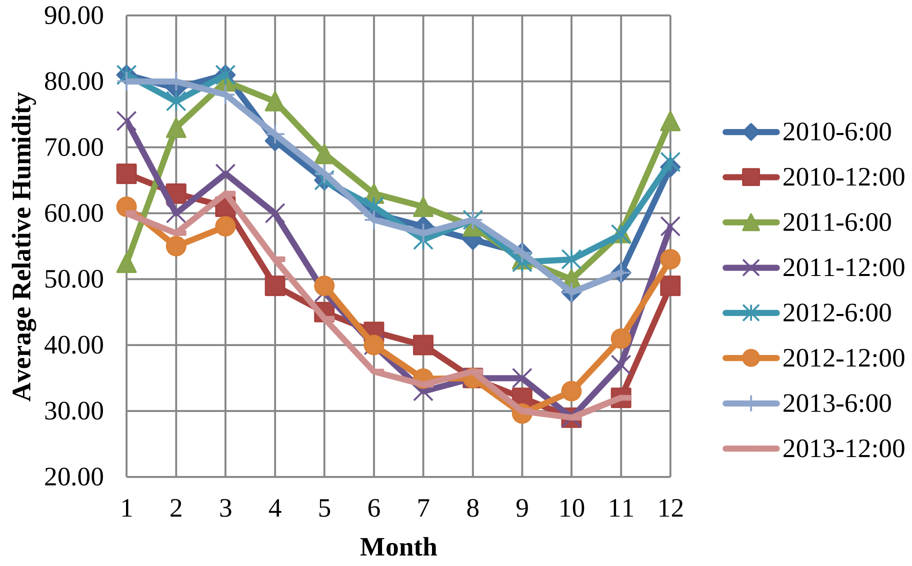


**Figure 17: Average monthly relative humidity for years 2010-2013 (Source: TMA Iringa station)**

The months with high RH are January, February and March with an average morning RH of 76.96 and average noon relative humidity of 62.

#### 6.3.2.3 Rainfall

The in-place moisture content in unsealed pavement is influenced by the amount of rainfall. The amount and intensity of rainfall is the enemy of of unsealed roads performance (O'Flaherty 2002:84). According to Yoder and Witczak (1975:186), the effect of rainfall on unsealed road performance is obscured by the factor of intensity of rainfall as compared to total annual rainfall accounting for many scatterings of data. Periods of long rainfall of low intensity can have more influence on marginal gravel materials performance than concentrated periods of high intensity, since the amount of moisture absorbed by the soil is greater under the former condition (Sargious 1975:44).

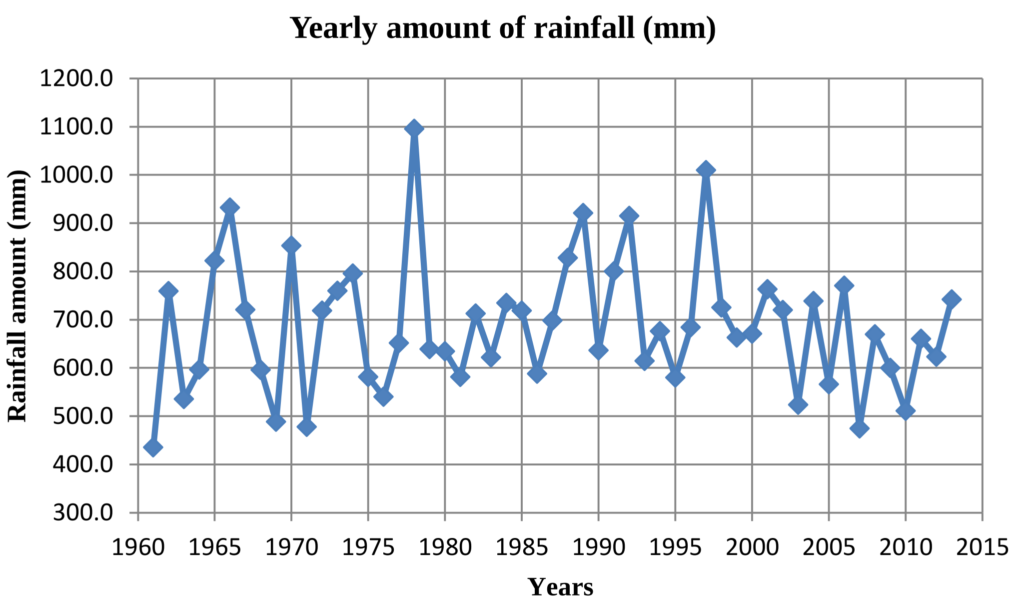


**Figure 18: Mean annual rainfall (Source: TMA Iringa office)**

Although some regional and global pattern of rainfall can be identified, rainfall is most often unpredictable and highly variable both in time and space (Hassing 1996:170). In general, rainfall data gathered over a 30-year period define the latest normal trend to be used for climate reference. At any given time of the year, an extreme high rainfall amount might be defined as one that occurs only once in every 30 years.

Figure 18 shows the fluctuations of average annual rainfall for 53 years, starting in 1960 as it was recorded by the TMA Iringa office. It is noted that the band of most rainfall fall is between 500 and 800 mm. Outliers fall above 1000 mm and below 500 mm. From data gathered it is clear that in Iringa region average rainfall lies between 500 and 800 mm that range accounting for 76% of rainfall as shown in the pie chart in Figure 19.

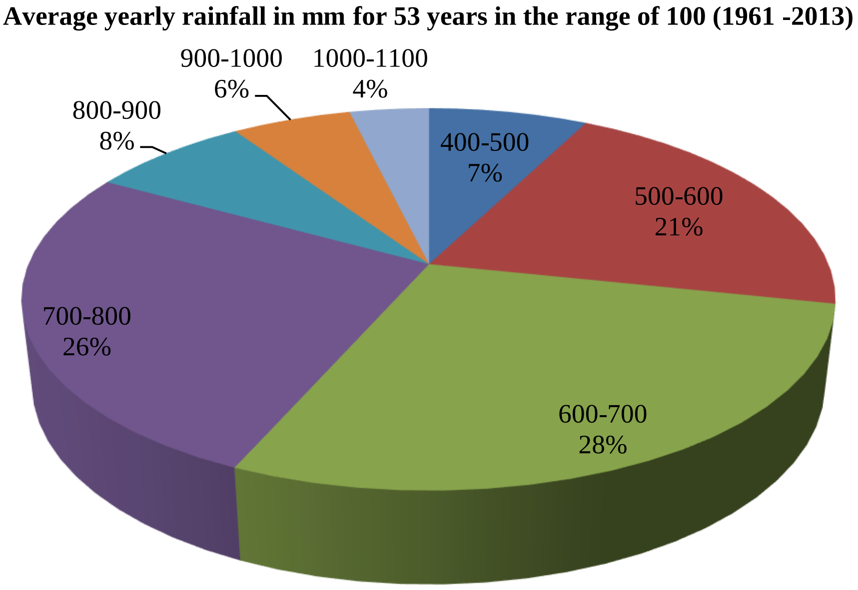


**Figure 19: The range and proportional percentage of Iringa region rainfall**

These climatic variations within the region may cause considerable variations in the performance of gravel roads. Variations of such a nature warrant empirical study so as to be in a position to relate it to gravel road performance and predict its effect.

It should be noted that the TMA Iringa region office uses daily rainfall gauges to record rainfall. According to Hassing (1996:170), the accuracy of such measurements is influenced by the wind and any obstructions in the vicinity. The wind effects imply an under-estimation of the real rainfall. The under-estimation can be as high as 10-15%, depending on wind speeds and exposure.

The measurement made by a daily rainfall gauge presents point rainfall that is the rainfall at a particular location (Hassing 1996:170). Most often, however, one is interested in the total rain falling on a selected catchment area. Such information can be obtained by a number of daily rainfall gauges scattered in the catchment area in question.

**Table 29: Annual average rainfall in mm (Source: TMA Iringa station)**

| Year | Av. rainfall (mm) | Year | Av. rainfall (mm) | Year | Av. rainfall (mm) |
|---|---|---|---|---|---|
| 1961 | 435.4 | 1979 | 639.3 | 1997 | 1010.1 |
| 1962 | 759.6 | 1980 | 634.4 | 1998 | 725.3 |
| 1963 | 535.8 | 1981 | 581.4 | 1999 | 663.4 |
| 1964 | 596.7 | 1982 | 712.7 | 2000 | 671.5 |
| 1965 | 822.3 | 1983 | 621.8 | 2001 | 763.1 |
| 1966 | 932.5 | 1984 | 735.2 | 2002 | 720.3 |
| 1967 | 721.2 | 1985 | 718.9 | 2003 | 523.6 |
| 1968 | 596.4 | 1986 | 588.5 | 2004 | 738.8 |
| 1969 | 488.7 | 1987 | 698.2 | 2005 | 566.5 |
| 1970 | 853.8 | 1988 | 828.2 | 2006 | 770.5 |
| 1971 | 478.1 | 1989 | 921.3 | 2007 | 474.5 |
| 1972 | 719.0 | 1990 | 636.4 | 2008 | 669.7 |
| 1973 | 760.4 | 1991 | 800.4 | 2009 | 600.2 |
| 1974 | 796.2 | 1992 | 915.1 | 2010 | 511.1 |
| 1975 | 581.5 | 1993 | 614.9 | 2011 | 660.4 |
| 1976 | 540.3 | 1994 | 676.5 | 2012 | 623.4 |
| 1977 | 651.8 | 1995 | 580.3 | 2013 | 742.1 |
| 1978 | 1095.9 | 1996 | 684.2 | | |

However, as mentioned earlier, over two third of Iringa region enjoys evenly distributed rains during the rainy season, which may offset the disadvantage of point rainfall data collection results. Table 29 shows the annual average amount of point rainfall data collected for 53 years at the TMA Iringa station.

## 6.4 Gravel materials laboratory test results and analysis

### 6.4.1 General

Every work of construction in civil engineering is built on soil or rock and in many instances; these are also the raw materials for civil and building construction works. Rock can be defined as natural aggregates of mineral that are connected by strong bonding, while soil may be defined as the unconsolidated sediments and deposits of solid particles that have resulted from the disintegration of rock (McCarthy 2007:4). Based on their texture, soils can be divided into coarse and fine grained soils. Coarse-grained soils are defined as those with particle size greater than 0.075 mm, such as sands and gravel, and fine-grained soils are those with particle size less than 0.075 mm (Garber and Hoel 2014:896).

The physical characteristics of soil are important factors in most civil and building engineering constructions. Soils exist in many varieties, and are the accumulated result of many separate factors and processes. Their characteristics depend on the parent rocks from which they are derived on the weathering process of these rocks and the weathering of the soil itself at its various stages of formation. The continuing process of pedogenesis, in which hard rocks are slowly weathered and broken down and their constituent minerals chemically altered comes in different forms. The processes of metamorphism and weathering over aeon have transformed some of the rock material into the infinite variety of soils seen today. The variation of soils also depends on: the means of transport bringing the soil to its present location; the manner of deposition of the soil; and on its history of loading, drainage, wetting and drying (McKinlay 1988:265). This implies that the physical and mechanical characteristics of soils and that of gravel materials are cyclic, and likely to differ within short distances.

According to Ellis (1979:5) the choice of gravel material is limited by what is available and economy in design depends on the skills and resources that can be deployed to locate the very best materials that exist within an economic haul distance from the unsealed road to be gravelled. Khanna and Justo (1982: iv) are of the view that the inherent economy in construction depends upon the maximum use of local materials, which for gravel roads is gravel materials.

### 6.4.2 Soil tests

According to O'Flaherty (2002:99) the highway engineer should use soil tests for guidance purposes when locating, designing and constructing roadways. For the results of these tests to be of optimum value, they must be carried-out correctly and the data obtained from them analysed intelligently. Khanna and Justo (1982: iv) also point-out that during the design and construction of a highway, it is imperative to carry out tests on construction materials for their scientific designing and economic utilization.

In view of the wide diversity in soil types, it is desirable to classify them into groups of soils possessing similar physical properties. Soils are normally classified based on simple laboratory tests such as grain size analysis and consistency limits and indices (Khanna and Justo 1982: 1-14). Following is a brief discussion on tests conducted on the sample of soils taken randomly from sites in this study, namely particle size distribution and consistency tests.

#### 6.4.2.1 Particle size analysis for coarse and fine grained soils

According to McCarthy (2007:40) particle size and shape are factors that have been found to be related to, or affect the material behaviour of, soil, to a certain degree. Particle size analysis is the process of determining the relative proportions of the different grain sizes that make up a given soil sample (Sargious 1975:58). Soils with similar particle size distribution curves would, in a general sense, be expected to show similar engineering characteristics. This remark is supported by Scott (1980:9) who asserts that from the shape of grading curve, it is possible to classify coarse-grained soils and to make an estimate of their engineering properties, although predictions of soil behaviour based on particle size distribution curves should be made cautiously. This is due to the fact that laboratory-based particle size distribution curves do not convey the arrangement, particle shape, and packing density of the in-situ soil.

AASHTO (2009:T27-2) points out that sieve analysis data can be employed not only in determining compliance of the particle size distribution with applicable specification requirement, but may also be useful in developing an empirical relationship of gravel material's performance. O`Flaherty (2002:100) noted that the results of particle size analysis are of most value when used for soil classification purposes; further use of the results should be treated with care unless verification by performance studies permits empirical relationships to be formulated. In this study, the analysis of gravel particle size distributions was used as one of parameters to formulate a gravel loss prediction model, and to assess the performance relationship of gravel materials used as gravel wearing course.

The results of a particle-size analysis can be presented in either of two ways. The first of these is a table in which the percentage of the total sample that passes a given sieve size or is smaller than a specified particle diameter is listed. The second way is to make a plot of the sieve or particle size versus the percentage passing the given sieve. Tables 30, 31, and 32 below show the results of sieve analysis for the particles passing a 2 mm sieve, a 0.425 mm sieve, and a 0.075 mm sieve. The results are from samples taken from borrow pits used for surfacing gravel roads under study and samples of gravel wearing course and loose materials taken from test sites.

**Table 30: Summary of sieve analysis, grading modulus (GM) and grading coefficient (GC) for borrow pits**

| Borrow Pit | Road Name | Road section | % < 2 mm | % < 0.425mm | % < 0.075 mm | GM | GC |
|---|---|---|---|---|---|---|---|
| $Chama_{1*}$ | Iringa -Idete | Italula | 58.64 | 39.56 | 27.28 | 1.72 | 42.50 |
| $Chama_2$ | Iringa -Idete | Italula | 52.06 | 44.29 | 30.07 | 1.74 | 35.03 |
| Ilamba $PS_1$ | Iringa - Idete | Ilamba | 75.21 | 60.20 | 41.91 | 1.23 | 35.35 |
| Ilamba $PS_2$ | Iringa - Idete | Ilamba | 73.4 | 48.89 | 27.58 | 1.5 | 41.95 |
| Ilamba $PS_3$ | Iringa - Idete | Ilamba | 67.95 | 54.62 | 40.91 | 1.37 | 40.86 |
| Old $Kilolo_1$ | Iringa - Idete | Kilolo | 43.29 | 35.58 | 21.67 | 1.99 | 49.01 |
| Old $Kilolo_2$ | Iringa - Idete | Kilolo | 39.85 | 32.04 | 18.82 | 2.09 | 48.31 |
| $Kitayawa_1$ | Iringa - Idete | Kitayawa | 42.29 | 31.34 | 14.71 | 2.12 | 34.47 |
| $Kitayawa_2$ | Iringa - Idete | Kitayawa | 25.78 | 19.5 | 10.58 | 2.44 | 28.19 |
| CUJ | Iringa - Idete | Tagamenda | 27.64 | 10.75 | 4.59 | 2.57 | 47.18 |
| $Nyamihuu_1$ | Iringa - Msembe | Nyamihuu | 71.13 | 55.02 | 54.51 | 1.19 | 40.97 |
| $Nyamihuu_2$ | Iringa - Msembe | Nyamihuu | 82.63 | 62.56 | 62.23 | 0.93 | 36.11 |
| $Kalenga_1$ | Iringa - Msembe | Bangamoyo | 54.97 | 37.02 | 23.37 | 1.85 | 42.15 |
| $Kalenga_2$ | Iringa - Msembe | Bangamoyo | 78.41 | 53.08 | 34.02 | 1.34 | 40.60 |
| $Mangalali_1$ | Iringa - Msembe | Mangalali | 56.98 | 35.85 | 25.27 | 1.82 | 43.33 |
| $Mangalali_2$ | Iringa - Msembe | Mangalali | 47.10 | 25.15 | 14.59 | 2.13 | 56.60 |
| $Mangalali_3$ | Iringa - Msembe | Mangalali | 76.42 | 54.39 | 53.54 | 1.16 | 39.63 |
| $Mangalali_4$ | Iringa - Msembe | Mangalali | 62.83 | 34.49 | 14.52 | 1.88 | 60.54 |
| Nzihi | Iringa - Msembe | Nzihi | 66.61 | 22.89 | 10.14 | 1.86 | 73.15 |
| Magozi | Iringa -Pawaga | Magozi | 80.25 | 67.40 | 48.64 | 1.04 | 28.41 |
| $Umasaini_1$ | Iringa -Pawaga | Umasaini | 55.10 | 24.90 | 8.32 | 2.12 | 57.45 |
| $Umasaini_2$ | Iringa -Pawaga | Umasaini | 51.13 | 31.93 | 15.47 | 2.01 | 40.90 |
| $Kiwele_1$ | Iringa -Pawaga | Mapinduzi | 72.69 | 53.29 | 53.20 | 1.21 | 45.12 |
| $Kiwele_2$ | Iringa -Pawaga | Mapinduzi | 61.49 | 40.83 | 38.90 | 1.59 | 56.83 |
| Hoho $PS_1$ | Iringa -Pawaga | Kidete | 67.05 | 56.61 | 55.86 | 1.20 | 22.62 |
| Hoho $PS_2$ | Iringa -Pawaga | Kidete | 59.99 | 48.57 | 47.87 | 1.44 | 30.76 |
| Pawaga SS | Iringa -Pawaga | Pawaga SS | 47.82 | 31.77 | 19.57 | 2.01 | 43.03 |
| Ilolo | Iringa -Pawaga | Ilolo Mpya | 45.41 | 36.05 | 27.02 | 1.92 | 36.91 |
| $Mgongo_1$ | Iringa Municipal | Don Bosco | 60.85 | 36.84 | 30.61 | 1.72 | 42.72 |
| $Mgongo_2$ | Iringa Municipal | Don Bosco | 69.44 | 41.15 | 30.43 | 1.59 | 49.31 |
| $Mgongo_3$ | Iringa Municipal | Don Bosco | 52.87 | 27.64 | 18.05 | 2.01 | 60.70 |
| Mgongo4 | Iringa Municipal | Don Bosco | 63.30 | 41.38 | 32.54 | 1.63 | 52.10 |
| Average | | | **58.72** | **40.81** | **30.38** | **1.70** | **42.89** |
| Standard deviation | | | **14.39** | **13.18** | **15.44** | **0.41** | **9.53** |

The selection of listed sieve sizes is based on the fact that the amount of materials passing or retained on each of these sieves are used in testing or deriving a number of parameters employed in characterizing the soil behaviour. Some of these parameters are liquid limit (LL), plastic limit (PL), shrinkage limit (SL), and shrinkage product (SP).

**Table 31: Summary of sieve analysis, grading modulus, and grading coefficient for surfacing materials**

| Road Name | Road section | % < 2 mm | % < 0.425mm | % < 0.075 mm | GM | GC |
|---|---|---|---|---|---|---|
| IMC | Don Bosco$_{1*}$ | 81.17 | 59.48 | 59.24 | 1 | 36.08 |
| IMC | Don Bosco$_2$ | 81.17 | 59.45 | 59.22 | 1 | 34.74 |
| Iringa - Msembe | Mwika B | 73.72 | 17.23 | 5.97 | 2.03 | 76.91 |
| Iringa - Msembe | Mangalali$_1$ | 71.25 | 47.76 | 47.63 | 1.33 | 48.5 |
| Iringa - Msembe | Mangalali$_2$ | 76.42 | 54.39 | 53.54 | 1.16 | 39.63 |
| Iringa - Pawaga | Umasaini$_3$ | 51.13 | 31.93 | 15.47 | 2.01 | 40.9 |
| Iringa - Pawaga | Mgela | 70.18 | 39.44 | 23.9 | 1.66 | 55.76 |
| Average | | **75.33** | **47.12** | **37.31** | **1.40** | **45.65** |
| Standard deviation | | **13.07** | **16.68** | **20.65** | **0.44** | **14.76** |

Note: * Sample Number

**Table 32: Summary of sieve analysis, grading modulus, and grading coefficient for surfacing layer loose materials**

| Road Name | Road section | % < 2 mm | % < 0.425mm | % < 0.075 mm | GM | GC |
|---|---|---|---|---|---|---|
| Iringa-Pawaga | Mtakuja | 80.54 | 36.16 | 28.30 | 1.55 | 63.55 |
| Iringa-Pawaga | Mapinduzi | 73.98 | 30.65 | 8.35 | 1.87 | 61.41 |
| Iringa-Pawaga | Mgera | 73.47 | 29.63 | 12.07 | 1.85 | 55.71 |
| Iringa-Pawaga | Muhunga | 59.93 | 33.04 | 10.71 | 1.96 | 52.29 |
| Iringa-Msembe | Nyamihuu | 90.88 | 32.11 | 10.28 | 1.67 | 67.58 |
| Iringa-Msembe | Nzihi | 66.61 | 22.89 | 10.14 | 2.00 | 73.15 |
| Iringa - Msembe | Mangalali | 74.63 | 34.89 | 28.52 | 1.62 | 63.28 |
| Iringa - Msembe | Mwika | 80.88 | 25.09 | 21.56 | 1.72 | 71.60 |
| Iringa - Msembe | Bangamoyo | 87.65 | 67.36 | 49.95 | 0.95 | 29.74 |
| Iringa - Msembe | Kalenga | 89.36 | 36.23 | 15.06 | 1.59 | 62.18 |

**Table 32: Continued**

| Road Name | Road section | % < 2 mm | % < 0.425mm | % < 0.075 mm | GM | GC |
|---|---|---|---|---|---|---|
| Iringa - Idete | Ilamba | 72.30 | 38.13 | 7.52 | 1.82 | 59.20 |
| Iringa - Idete | Itwanga | 90.31 | 44.91 | 12.76 | 1.52 | 54.79 |
| Iringa - Idete | Amani | 63.66 | 26.59 | 7.84 | 2.02 | 70.79 |
| Average | | **77.25** | **35.21** | **17.16** | **1.70** | **60.41** |
| Standard deviation | | **10.37** | **11.30** | **12.22** | **0.28** | **11.29** |

From Table 32 it is noted that the sample of loose gravel materials taken from the gravel road materials passing through the 2 mm sieve range from 60-90%, with an average of 77.25%. Materials passing through 0.425 mm sieve range from 23-67%, with an average of 35.21% and for materials passing through the 0.075 mm sieve range from 7-50% with an average of 12.29%. According to Paige-Green (1989:6.3-6.4) the grading analysis of the same type of gravel materials, marginal or otherwise, but in different locations, will vary considerably depending on the conditions and stage of weathering.

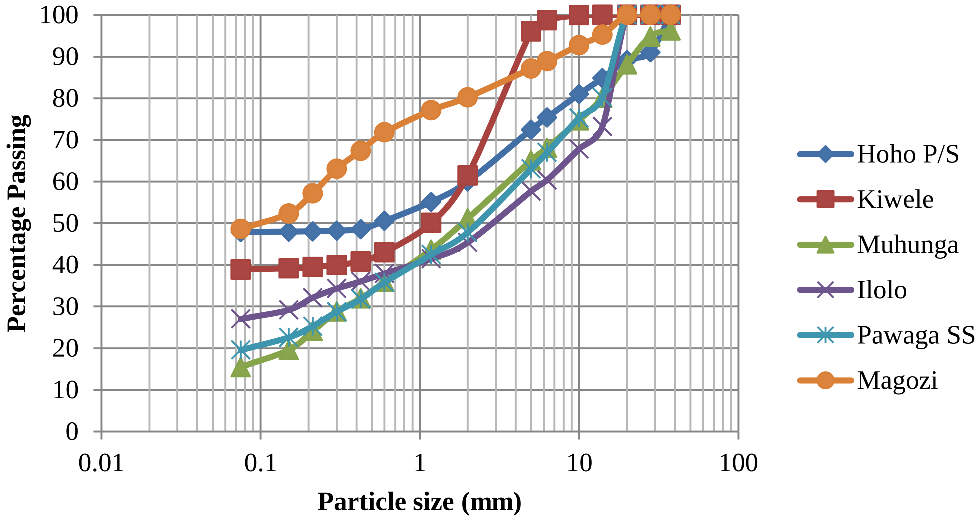


**Figure 20: Typical particle size distribution curve for marginal gravel materials**

Figure 20 reveals that all six gravel borrow pits materials along the Iringa–Pawaga gravel road pass through a 37.5 mm sieve by 100%. This is above the minimum of

95% given by TZ-MoW (1999:11.3) and TZ-MoW (2000b:3000:24) for marginal materials to be employed for surfacing unsealed roads. It should be taken therefore, that Figure 20 is typical of the results of particle size distribution for all gravel borrow pits deployed to surface the gravel roads under study, namely Iringa – Msembe, Iringa – Idete, Iringa – Pawaga and Don Bosco road in Iringa municipal council.

- **Grading coefficient**

Grading coefficient (GC) is one of the parameters derived from particle size distributions results. GC indicates the performance characteristics of gravel wearing course materials. According to TZ-MoW(1999:11.3) and TZ-MoW(2000b: 3000-24) Table 3702/1 the range of GC acceptable for marginal gravel materials is from 16-34 inclusive.

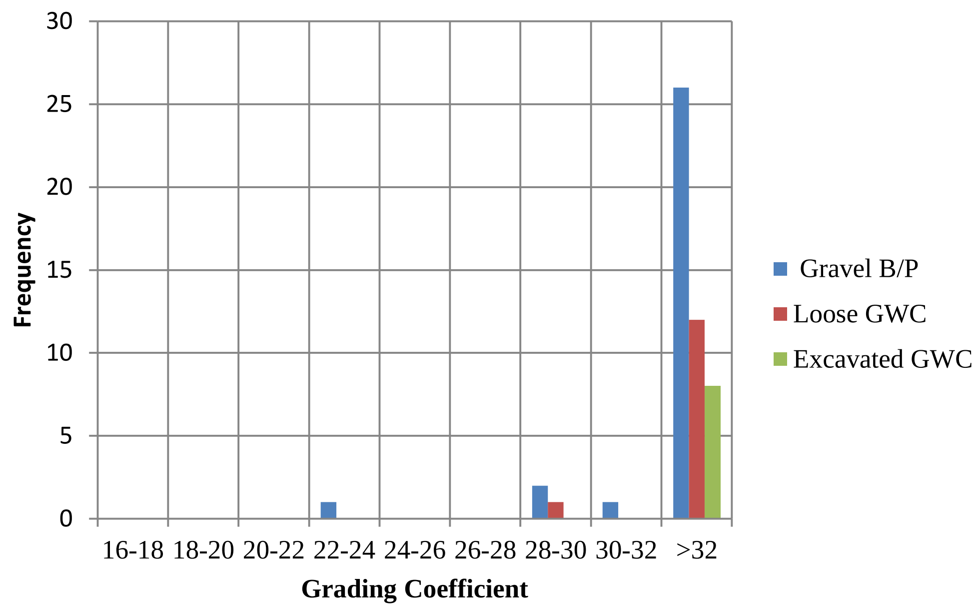


**Figure 21: Frequency of GC for marginal gravel materials sampled from gravel borrow pits, loose gravel wearing course materials, and excavated gravel wearing course materials**

From the test results of samples of gravel materials borrow pits, loose materials from gravel wearing course and the excavated materials used for surfacing the gravel roads under study, only 13.3% of 30 samples of gravel borrow pits tested were within the said GC range. None of the excavated samples of gravel wearing course were within the range and only one out of 13 samples of loose gravel materials taken from the gravel road surface were within the range as shown in Figure 21. In this regard, it is worth mentioning here that it might be that the range provided is too narrow for marginal materials. More study is needed to cover a wider area before one can suggest the appropriate range of GC for the whole of Tanzania.

- **Grading modulus**

The grading modulus is a function describing the shape of the particle size distribution curve. According to South African Bureau of Standards (SABS) (1996:2) this can be defined as cumulative fractions of material retained on sieves of nominal aperture size of 2.0 mm, 0.425 mm and 0.075 mm as shown in Equation 15.

**Equation 15: GM = (P2.0 + P0.425 + P0.075)/100**

Where P is the percentage of the gravel materials retained on 2, 0.425, and 0.075 mm-sieves respectively.

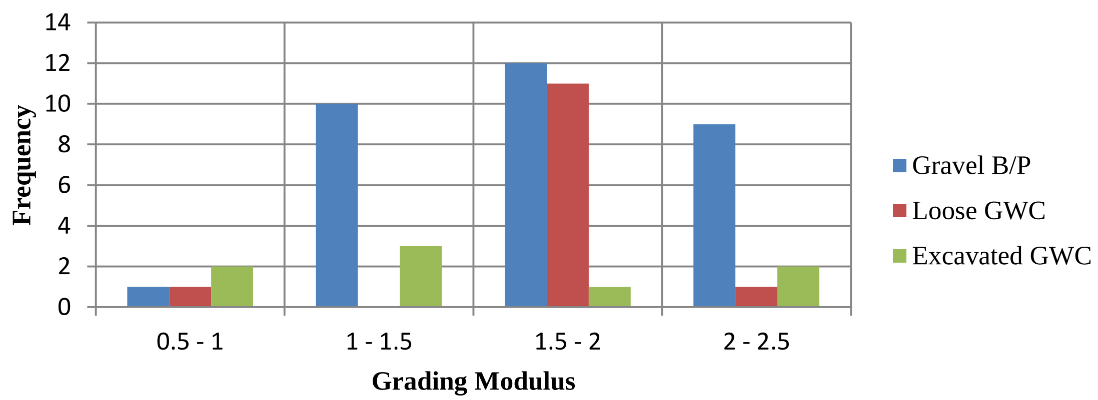


**Figure 22: Frequency of GM for marginal gravel materials sampled from gravel borrow pits, road surfaces loose gravel wearing course materials, and excavated gravel wearing course materials**

According to SABS (1996:2) gravel materials with a high fine fraction will in general have a grading modulus value of less than 0.8, while gravel materials with a low fine fraction will have a grading modulus value of more than 1.0.

TZ-MoW (1999:7.4) and TZ-MoW (2000b:3000-23) standard documents define GM as shown in Equation 16.

**Equation 16: GM = (300 -% < 2.0 - % < 0.425 - % < 0.075)/100**

Where symbol '<' stands for a percentage of the gravel materials passing a given sieve size.

These two expressions, as indicated in Equations 15 and 16, give different results of GM for the same particle size analysis. This is due to the fact that Equation 15 is talking about materials retained, while Equation 16 is talking about materials passing through the specified sieves.

From the study of gravel materials samples taken from borrow pits under study (Figure 22) it was noted that gravel materials with a high fine fraction will in general have a grading modulus value of less than 2.0, while gravel materials with a low fine fraction will have a grading modulus value of more than 2.0.

#### 6.4.2.2 Atterberg consistency tests

Consistency is that property of a soil which is manifested by its resistance to flow (O`Flaherty 2002:101). In about 1910, Swedish soil scientist Albert Atterberg suggested that soil consistency should be described by arbitrarily dividing a soil`s cohesive range into six stages and expressing the limits of each range in terms of moisture content. The limits chosen were: (i) upper limit of viscous flow, (ii) liquid limit, or lower limit of viscous flow, (iii) sticky limit, (iv) cohesion limit, (v) plastic limit, and (vi) shrinkage limit. Amongst these limits, liquid limit (LL), plastic limit

(PL) and the shrinkage limit (SL) are the most favourable to highway and soil engineers.

A value, usually used in conjunction with the liquid and plastic limit is the plasticity index. The plasticity index (PI) of a soil is the arithmetic difference between the liquid and plastic limits; in other words, it is the range of moisture content over which the soil is in a plastic state (Garber and Hoel 2014:905).

PI can be used to estimate directly the strength of a soil (O`Flaherty 2002:103). According to Naidoo and Purchase (2001) gravel materials with a PI off less than 6 lack sufficient plasticity to be effective gravel wearing materials. Both the LL and PI can be used, to a certain extent, as a quality-measuring device for pavement materials, in order to exclude granular materials with too many fine-grained particles that have cohesive plastic qualities (O`Flaherty 2002:103). Table 33 shows values for the plasticity characteristics of gravel surfacing materials typically specified for different climatic zones as per Ellis (1979:5). Plasticity would vary considerably for the same type of gravel materials depending on the condition and stage of weathering (Paige-Green 1989:6.3-6.4).

**Table 33: Plasticity characteristics preferred for gravel surfacing materials (Source: Ellis 1979:5)**

| Climate | LL (Not to exceed a specified value) (%) | PI ranges (%) | Linear shrinkage range (%) |
|---|---|---|---|
| Moist temperate and wet tropic | 35 | 4-9 | 2.5 -5 |
| Seasonally wet tropical | 45 | 6-20 | 4-10 |
| Arid or semi-arid | 55 | 15-30 | 8-15 |

The results of consistency tests of gravel materials from borrow pits used for surfacing gravel road test sections under study are presented in Table 34, with summaries of descriptive analysis presented in Table 35. Figure 23 and 24 shows the respective ranges of LL and PI.

**Table 34: Summary of Atterberg limits data on TANROADS Iringa region roads under study**

| Road name | Road section/climate | Borrow pit name (Sample identity) | LL (%) | PL (%) | PI (%) | SL (%) | SP |
|---|---|---|---|---|---|---|---|
| Iringa - Pawaga | Umasaini/dry | Umasaini | 32 | 17 | 15 | 7 | 136 |
| Iringa - Pawaga | Umasaini/dry | Umasaini (GWC) | 29 | 20 | 9 | 5 | 160 |
| Iringa - Pawaga | Kimalanogwa/dry | Magozi (A) | 23 | 16 | 7 | 4 | 192 |
| Iringa - Pawaga | Kimalanogwa/dry | Magozi (B) | 24 | 15 | 9 | 6 | 257 |
| Iringa - Pawaga | Ilolo Mpya/dry | Ilolo (A) | 43 | 26 | 17 | 9 | 309 |
| Iringa - Pawaga | Ilolo Mpya/dry | Ilolo (B) | 37 | 23 | 14 | 7 | 324 |
| Iringa - Pawaga | Kidete/moderate | Hoho Primary School | 32 | 19 | 13 | 7 | 404 |
| Iringa - Pawaga | Mapinduzi/moderate | Kiwele | 31 | 20 | 11 | 6 | 263 |
| Iringa - Pawaga | Mgela/moderate | Mgela (GWC) | 31 | 19 | 12 | 6 | 225 |
| Iringa - Idete | Tagamenda/moderate | Chuo cha Ustawi wa Jamii (A) | 24 | 16 | 8 | 5 | 54 |
| Iringa - Idete | Tagamenda/moderate | Chuo cha Ustawi wa Jamii (B) | 25 | 18 | 7 | 4 | 46 |
| Iringa - Idete | Ilamba/wet | Ilamba Primary School (A) | 35 | 22 | 13 | 8 | 252 |
| Iringa - Idete | Ilamba/wet | Ilamba Primary School (B) | 47 | 32 | 15 | 7 | 229 |
| Iringa - Idete | Ilamba/wet | Ilamba Primary School (c) | 50 | 31 | 19 | 12 | 637 |
| Iringa - Idete | Kitayawa/moderate | Kitayawa (A) | 34 | 24 | 10 | 5 | 390 |
| Iringa - Idete | Kitayawa/moderate | Kitayawa (B) | 30 | 19 | 11 | 7 | 224 |
| Iringa - Idete | Kitayawa/moderate | Kitayawa (C) | 34 | 22 | 12 | 6 | 125 |
| Iringa - Idete | Kilolo/wet | Old Kilolo (A ) | 47 | 33 | 14 | 8 | 280 |
| Iringa - Idete | Kilolo/wet | Old Kilolo (B) | 41 | 26 | 15 | 9 | 305 |
| Iringa - Idete | Kilolo/wet | Old Kilolo (C1) | 37 | 24 | 13 | 7 | 229 |
| Iringa - Idete | Kilolo/wet | Old Kilolo (C2) | 45 | 30 | 15 | 7 | 229 |
| Iringa - Idete | Ndiwili/wet | Chama (A) | 28 | 20 | 8 | 6 | 226 |

**Table 34: Continued**

| Road name | Road section/climate | Borrow pit name (Sample identity) | LL (%) | PL (%) | PI (%) | SL (%) | SP |
|---|---|---|---|---|---|---|---|
| Iringa - Idete | Ndiwili/wet | Chama (B) | 39 | 29 | 10 | 5 | 221 |
| Iringa - Idete | Ndiwili/wet | Chama (C) | 42 | 25 | 17 | 9 | 380 |
| Iringa - Msembe | Bangamoyo/ moderate | Kalenga (A) | 34 | 22 | 12 | 7 | 264 |
| Iringa - Msembe | Bangamoyo/ moderate | Kalenga (B) | 32 | 20 | 12 | 6 | 303 |
| Iringa - Msembe | Mangalali/ moderate | Mangalali Primary School (A) | 32 | 19 | 13 | 6 | 231 |
| Iringa - Msembe | Mangalali/ moderate | Mangalali Primary School (B) | 23 | 14 | 9 | 6 | 205 |
| Iringa - Msembe | Mangalali/ moderate | Mangalali Primary School (C) | 33 | 21 | 12 | 6 | 144 |
| Iringa - Msembe | Mangalali/ moderate | Mangalali Primary School (D) | 22 | NP | NP | 2 | 74 |
| Iringa - Msembe | Nzihi/moderate | Nzihi | 45 | 25 | 20 | 11 | 369 |
| Iringa - Msembe | Nyamihuu/ moderate | Nyamihuu | 35 | 21 | 14 | 6 | 354 |

From the results presented in Table 34, it is evident that LL of most gravel materials used for surfacing gravel roads in Iringa-Idete, Iringa-Pawaga and Iringa-Msembe does not exceed 45% except Kilolo and Ilamba where it is 47%.

**Table 35: Summary of descriptive analysis of Atterberg limits data**

| Parameters | Average | Standard deviation |
|---|---|---|
| Liquid Limit (LL) (%) | 34 | 8 |
| Plastic Limit (PL) (%) | 22 | 5 |
| Plasticity Index (PI) (%) | 12 | 3 |
| Shrinkage Limit (SL) (%) | 7 | 2 |
| Shrinkage Product (SP) | 247 | 116 |

According to the limits provided in Table 33 (Ellis1979:5) those materials belong to moist temperate and wet tropical, and seasonally wet tropical climates. Sixty four point five percent of LL test results belong to moist temperate and wet tropical climate areas.

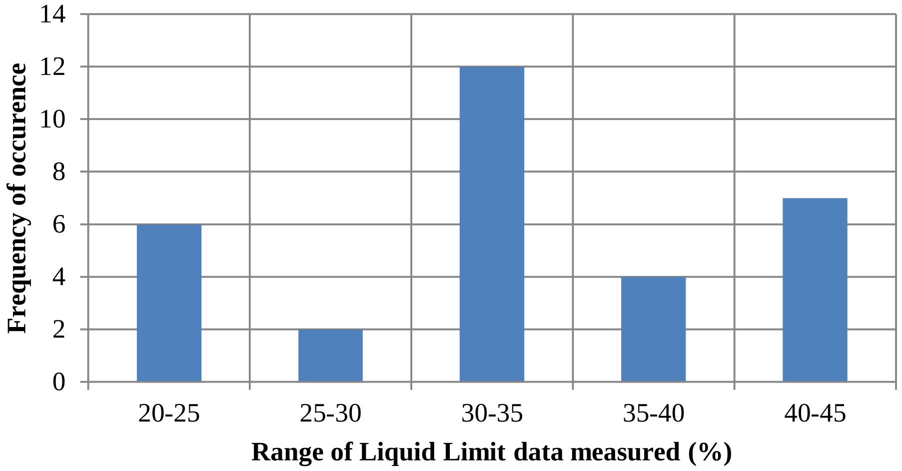


**Figure 23: Ranges of Liquid Limit for samples of gravel materials taken from test sites**

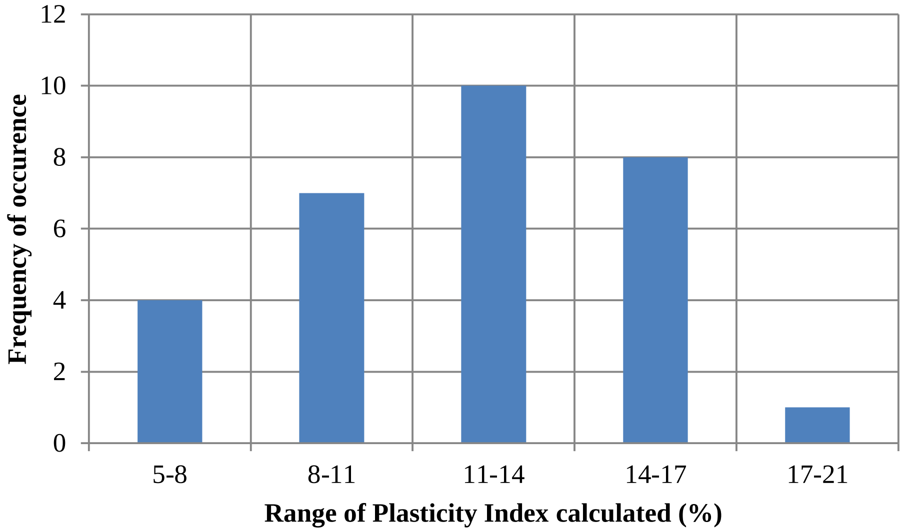


**Figure 24: Ranges of plasticity index for samples of gravel materials taken from test sites**

According to the limits given by Ellis, the range of PI results as shown in Figure 24 falls in moist temperate and wet tropical, and seasonally wet tropical climates, with 35.5% of PI test results belonging to moist temperate and wet tropical climate areas.

The PI is basically an indication of the moisture susceptibility of the gravel materials; with a high value indicating susceptibility (Lay 2009:112). However, studies in Australian pavement materials have found no correlation between PI and pavement performance. Lay (2009:112) stresses that it is better to try to understand the general characteristics of a material than to rely on the PI value.


**Figure 25: Ranges of shrinkage product for samples of gravel materials taken from test sites**

- **Shrinkage product**

Shrinkage Product (SP) is the product of shrinkage limit and materials passing through a 0.425 mm sieve (Lay 2009:112). According to TZ-MoW (1999:11.4) the ideal SP for marginal gravel materials to be used for surfacing gravel roads is 270, as the low SP indicates a material that may ravel and corrugate whereas a high product indicates material that could be slippery in service. Figure 25 shows that most of the marginal gravel materials sampled ranged from 120 - 400, with only 4 samples out of 31 outside the range. This implies that 87.1% of sampled marginal gravel materials qualify in terms of SP.

- **The average and standard deviation of Atterberg limits test results per Climate**

**Table 36: The average Atterberg limits test results per climate**

| Climate | Atterberg limits | | | | |
|---|---|---|---|---|---|
| | LL (%) | PL (%) | PI (%) | SL (%) | SP |
| Dry | 31 | 20 | 9 | 6 | 230 |
| Wet | 41 | 28 | 14 | 8 | 299 |
| Moderate | 31 | 20 | 12 | 6 | 230 |

**Table 37: The standard deviation of Atterberg limits test results per climate**

| Climate | Atterberg limits | | | | |
|---|---|---|---|---|---|
| | LL (%) | PL (%) | PI (%) | SL (%) | SP |
| Dry | 8 | 4 | 4 | 2 | 79 |
| Wet | 7 | 6 | 3 | 2 | 129 |
| Moderate | 6 | 3 | 3 | 2 | 117 |

Table 36 gives the average gravel material consistencies test results per climate. From the table it is noted that the test results for dry and moderate climates are very close in comparison to the wet climate.

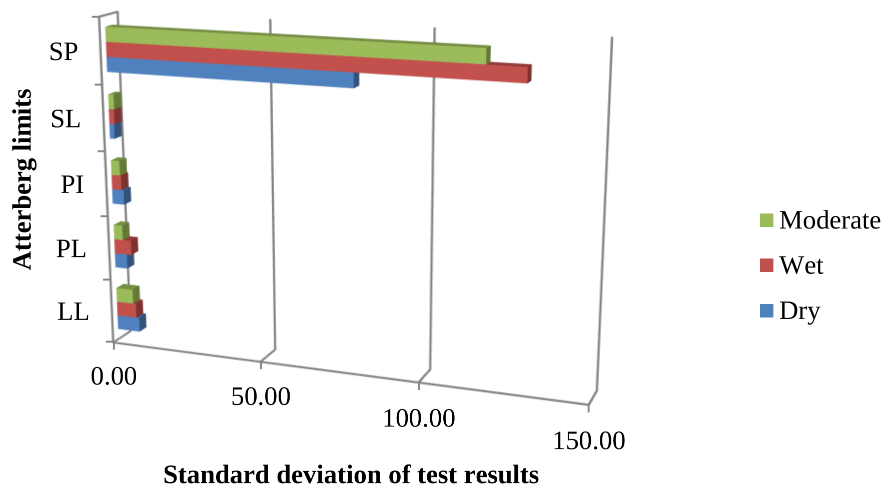


**Figure 26: The standard deviation of Atterberg limits test results per climate**

The figure of standard deviation results (Table 37 and Figure 26) are in units for all parameters of consistency, except for SP which is in tens and hundredths indicating big variation.

The SP result shows big variation, particular for gravel materials in wet climate areas. This might be attributed to the fact that SP combines the results of two tests that of SL and materials passing a 0.425 mm sieve.  The variation noted is the characteristics of particle size distribution in the marginal materials. The results noted are most appropriate in specifying the expected consistency of test results of marginal materials to be deployed in each climatic zone.

### 6.4.3 Traffic

Larsen, Hildebrand and Macdonald (2002:5) stress that traffic is one of the main causes of gravel roads deterioration. Figure 27 is typical of the heavy traffic plying one of the gravel roads under study.


**Figure 27: Heavy vehicle plying one of the gravel roads under study**

Figure 28 indicates the relationship between traffic and environment on a gravel road's deterioration. According to Figure 28, where traffic intensity is low, it is the environment which plays a significant role in the gravel road's deterioration, while at higher traffic intensity; the environment plays an insignificant role, although its role in deterioration cannot totally be ignored.

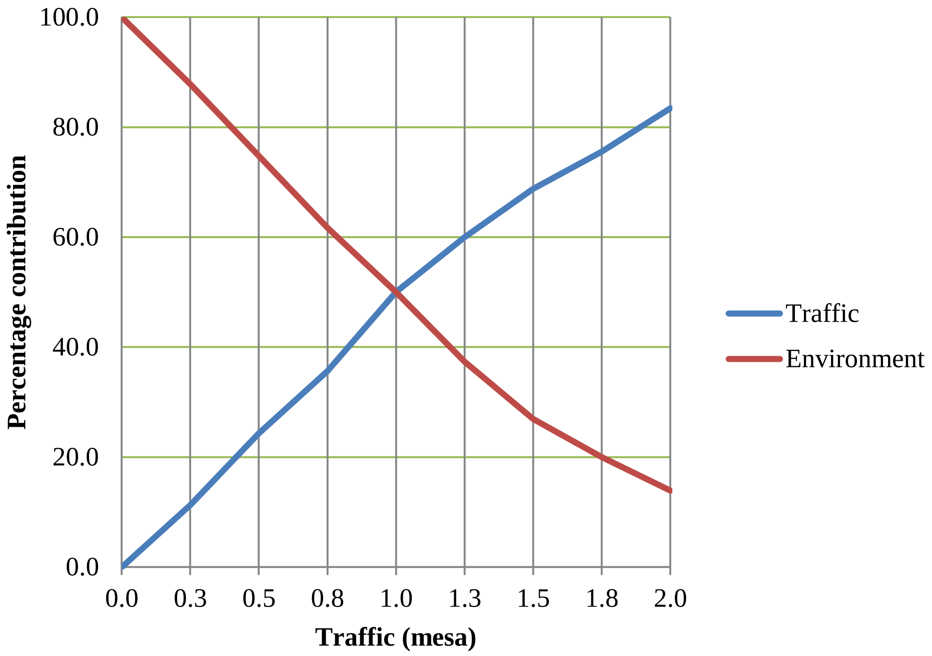


**Figure 28: The relationship between traffic and environment on gravel road deterioration (Source: TRL 1999 cited in Paige-Green 2007b)**

In order to evaluate the relationship between traffic volume, climate and gravel road performance it is of paramount importance to know the traffic volume traversing test sections (Mwaipungu 1999:39). In addition to that, knowledge on the interaction between vehicles and the gravel wearing course is also required to map the gravel materials' performance.

The knowledge of these interactions once acquired and translated into action balances both vehicle and gravel road design. The end result is in minimization of gravel road deterioration and finally total transport costs.

**Table 38: 24-hours classified traffic volume**

| Test Site | Light vehicles | Heavy vehicles | Total vehicles | Motor Cycles |
|---|---|---|---|---|
| | ADL | ADH | ADT | |
| Mwika A | 222 | 46 | 268 | 107 |
| Mwika B | 222 | 46 | 268 | 107 |
| Mangalali | 222 | 46 | 268 | 107 |
| Muhimbili | 242 | 32 | 276 | 38 |
| Nzihi | 366 | 32 | 398 | 127 |
| Nyamihuu | 83 | 23 | 106 | 53 |
| Kidete | 43 | 14 | 57 | 66 |
| Mapinduzi | 30 | 27 | 57 | 24 |
| Mapinduzi-Kilendu | 71 | 9 | 80 | 47 |
| Muhunga | 71 | 9 | 80 | 47 |
| Kimalonogwa | 71 | 9 | 80 | 47 |
| Mkwambilenga | 71 | 9 | 80 | 47 |
| Pawaga SS | 71 | 9 | 80 | 47 |
| Tagamenda | 184 | 43 | 227 | 67 |
| Kitayawa | 118 | 34 | 151 | 36 |
| Igula | 118 | 34 | 151 | 36 |
| Ndiwili | 154 | 53 | 207 | 43 |
| Utengule | 114 | 47 | 161 | 46 |
| Itwanga | 33 | 11 | 44 | 51 |
| Amani | 33 | 11 | 44 | 51 |
| Ilamba | 33 | 11 | 44 | 51 |
| Average | 122 | 26 | 149 | 59 |
| Standard Deviation | 90 | 16 | 101 | 28 |

Note: 1. ADL-Cars (Saloon, RAV 4, & Escudo), Buses under 25 seats, Lorries under 5 tons, Pick-Up, Vans and 4WD.
2. ADH-Buses over 25 seats, Semitrailers, Lorries over 5 tons, Lorries with Trailer, and Tractors.

To establish traffic volume traversing test sections, manual classified traffic counts were carried out near or between or at each test section using the traffic count form appended in Appendix 7.

Traffic surveys were conducted for seven days. On each day, a 12-hour count was performed from 0600 to 1800 hrs. The 12-hour counts were adjusted to 24-hour counts based on the estimate that a further 10% of traffic travelled between 1800 to 0600 hours (Greening *et al.* 2006:7).

The estimated 24-hour classified traffic volumes on each site are listed in Table 38. The said table shows that light traffic volume ranges from 30-366 vehicles per day (vpd), with the average of 122 vpd. Heavy traffic volume ranges from 9-47 vpd, with the average of 26 vpd. The total average daily traffic (ADT) volume is 149 vpd.

## 6.5 Conclusions and recommendations

- Climatic data were all collected from one meteorological station, stationed at Nduli airport in Iringa. This station is deemed to represent the climatic pattern of the whole of Iringa region. However, for realistic results climatic data to be reflected in gravel road performance should be collected in the area traversed by the gravel road in question.

- The specification given by both TZ-MoW (1999:11.3) P&MDM and TZ-MoW (2000b:3000:24) SSRWs for marginal material's particle size distribution to be used for surfacing gravel roads cover a wide range of gravel materials with different performance expectations. This simplifies the selection of gravel materials for surfacing, but it is not realistic. More study is needed to peg the grading limits for the type of marginal gravel materials available in each region in Tanzania.

- The range of grading coefficient from 16-34 as provided by TZ-MoW (1999:11.3) P&MDM and (2000b:3000:24) SSRWs is too narrow for the tested marginal materials used for surfacing the gravel roads under study. This range definitely has to be revised, as it is similar to the one employed in South Africa.

This study proposes a new GC range for Iringa region, which is 23 – 72 inclusive.

- There are two expressions in place for determining the grading modulus as presented in Equations 15 and 16 for South African and Tanzanian situations respectively. Due to the current state of interrelationship between these two countries in civil engineering, there is a need to arrive at one expression so as to avoid any misinterpretation of results derived from the same gravel material samples.

- Atterberg limits test results showed insignificant variation with specified specification, as issued by TZ-MoW (1999:7.5) in Table 7.3. According to the said Table, the maximum LL range is from 45 to 55; and the PI range from 16 to 24. Liquid Limit and Plasticity Index results also fall within the climatic range as specified by Ellis (1979:5) in Table 33, and Shrinkage product results fall within the specified limits of 120-400 (TZ-MoW 1999:11.3).

# CHAPTER 7
# CONDITION SURVEY AND GRAVEL LOSS DATA ANALYSIS AND MODELLING

## 7.1 Introduction

The exercises of a gravel loss monitoring and condition survey were performed simultaneously. The relationships between these two exercises are directly proportional. This implies that, as long as the gravel road condition is good, the gravel loss is insignificant. However, once changes in road surface elevation are evident, certain changes in road surface condition in terms of distress will become evident too. These distresses normally reflect gravel materials, climate, and traffic volume characteristics unique to the road location.

This chapter briefly expounds on how gravel road condition and distress contribute to gravel loss. It also touches on distresses prevalent in each test section and the summary of distress covering all the stretches of the gravel roads under study. The chapter further gives summaries and discussion related to the gravel loss results. Tables of all independent parameters, primary and secondary, employed for modelling gravel loss are presented. The modelling result of the gravel loss prediction model by using econometric (pavemetric) principles is presented and discussed.

### 7.1.1 Maintenance management systems (MMS)

The basic purpose of maintenance management systems is to capture information about maintenance activities performed, and resources utilised. The system further provides maintenance engineers and managers with the information and analytical tools needed to allow them to make an educated guess (Whight *et al.* 1996:629). Typical features of an MMS include but are not limited to: i) development of an annual work program, ii) budgeting and allocating resources, iii) work authorization, iv) performance evaluation, and v) fiscal control (Whight *et al.* 1996:630; Kendrick *et al.* 2004: 258; Underwood 1995:458-477). From the above it is noted that the visual condition survey is among the tools of MMS.

## 7.2 Visual condition survey

Michigan Technological University (2014:5.1) states that a visual condition survey is the process of collecting data to determine the structural integrity, distress, and overall riding quality of the pavement. They further point out that condition surveys provide a rational method of allocating limited resources. The visual assessment is most applicable for determining re-gravelling requirements, grading frequencies, whether the gravel material on the road is suitable for the prevailing traffic characteristics and environment, and what type of distresses are typical on the gravel road in question (Jones and Paige-Green 2011:1). Surface distress is damage observed on the pavement surface. Distress evaluation is the measure mostly used by maintenance personnel to determine the where, when, and what type of maintenance is required.

### 7.2.1 Attributes of gravel road distress

The appearance of gravel road distress is varied and often extremely complex. In this study, the task of describing distress was achieved by recording its main characteristics – the so-called attributes of distress. The attributes referred to are: i) type, ii) degree, and iii) extent. These are described as follows:

- **Type of distress:** Common types of distress encountered on gravel roads under study included, but not limited to: gravel loss; potholes; rutting; erosion; corrugation; loose materials; stoniness; and dust. These were assessed in terms of their interactive effect on the functional performance of the gravel road together with material properties, road profile, riding quality and drainage.

- **Degree:** The degree of a particular type of distress is a measure of its severity. The degree recorded gave the predominant severity of a particular type of distress. The most important categories of degrees are 1, 3, and 5. If there is any uncertainty regarding the condition between degrees 1 and 3 or 3 and 5, the defect may be marked as 2 or 4 respectively (Jones and Paige-Green 2011:6).
- **Extent:** The extent of distress is a measure of how wide spread the distress is over the length of the road segment. The extent is also indicated on a five-point scale in which the length of road affected by the distress is estimated as a percentage. Jones and Paige-Green (2011:6) points out that the extent of the distress should be recorded only for that width of the road affecting the traffic.

### 7.2.2 Visual assessment of the condition and performance of gravel roads

Gravel road test sections for visual assessment were randomly selected and of 300 m long. Each test section had its surface condition recorded on a data sheet as per Appendix 7. The current condition of distress was assessed by walking along the test section and observing type, severity and extent of distress.

The distresses that were recorded are as listed in Table 39. Following is a brief description of each distress assessed with the emphasis of its contribution to gravel loss.

1. **Potholes**: Potholes are bowl shaped distress. Once pothole formation has been initiated, drainage deteriorates and water ponds in the depressions. Enlargement of potholes by traffic occurs through compaction and remoulding of the weakened material (in the wet state) and removal of the material from the hole by vehicle wheels and splashing. Materials with a low soaked strength are thus likely to develop larger and deeper potholes in shorter periods (Pearson

2012:204) and accelerate gravel loss. The influence of potholes on riding quality.

**Table 39: Gravel road distresses recorded during the condition survey**

| Element | Distress | Conditions |
|---|---|---|
| Carriageway | Potholes | Degree: 0,1,2,3,4,5; Extent: 1,2,3,4,5 |
| | Rutting | Degree: 0,1,2,3,4,5; Extent: 1,2,3,4,5 |
| | Erosion-Transverse | Degree: 0,1,2,3,4,5; Extent: 1,2,3,4,5 |
| | Erosion-Longitudinal | Degree: 0,1,2,3,4,5; Extent: 1,2,3,4,5 |
| | Stoniness - embedded | Degree: 0,1,2,3,4,5; Extent: 1,2,3,4,5 |
| | Stoniness-loose | Degree: 0,1,2,3,4,5; Extent: 1,2,3,4,5 |
| | Dustiness | Degree: 0,1,2,3,4,5 |
| | Loose material | Degree: 0,1,2,3,4,5; Extent: 1,2,3,4,5 |
| | Corrugation | Degree: 0,1,2,3,4,5; Extent: 1,2,3,4,5 |
| | Slipperiness | Acceptable/Unacceptable |
| | Skid resistance | Acceptable/Unacceptable |
| | Trafficability | Acceptable/Unacceptable |
| | Riding quality/Safety | Very good (>80 km/h); Good (80 km/h); Average (60km/h), Poor (40 km/h), Very poor (20km/h) |
| | Road profile/shape | Very good (5%); Good (2%); Flat; Uneven; Very uneven |
| Drainage from the road | | Well above ground; Slightly above; Level with ground; Slightly below; Canal |
| Material | Gravel quality | Very good; Good; Average; Poor; Very Poor |
| | Gravel quantity | Plenty; Sufficient; Isolated exposures; Extensive exposures; None |
| Gravel road performance | | Very good; Good; Average; Poor; Very Poor |

2. **Rutting**: These generally form as a result of gravel loss from the wearing course by traffic abrasion and by deformation of the subgrade and compaction of the wearing course (Pearson 2012:205). Ruts are assessed in terms of their capacity to retain water using a visual estimate of their average depth. The higher the severity degree of rutting is, the higher the effects of directional instability of a vehicle and gravel loss.
3. **Erosion**: Erosion is the loss of gravel wearing course caused by the flow of water over the gravel road. The ability of a gravel material to resist erosion depends on its shear strength under the conditions in which the water flow occurs (Pearson 2012:205). Much of eroded gravel is deposited in the drains and culverts. Erosion of the wearing course also results in a change in the properties of the material as various fractions of the material are selectively removed (Jones and Paige-Green

2011:7). In this study, transverse and longitudinal erosions were quantified by their depth and width using a 2.0 m straight edge and wedge.

4. **Stoniness-loose and embedded**: Stoniness is the relative percentage of material in the road that is larger than the recommended maximum size of 37.5 mm (Pearson 2012:204). Stoniness was assessed by estimating the extent and severity. Figure 29 shows the variation of stones sizes in a gravel wearing course, and it reveals a lacks of gravel sizes control at the source of marginal gravel materials before being delivered to the site.

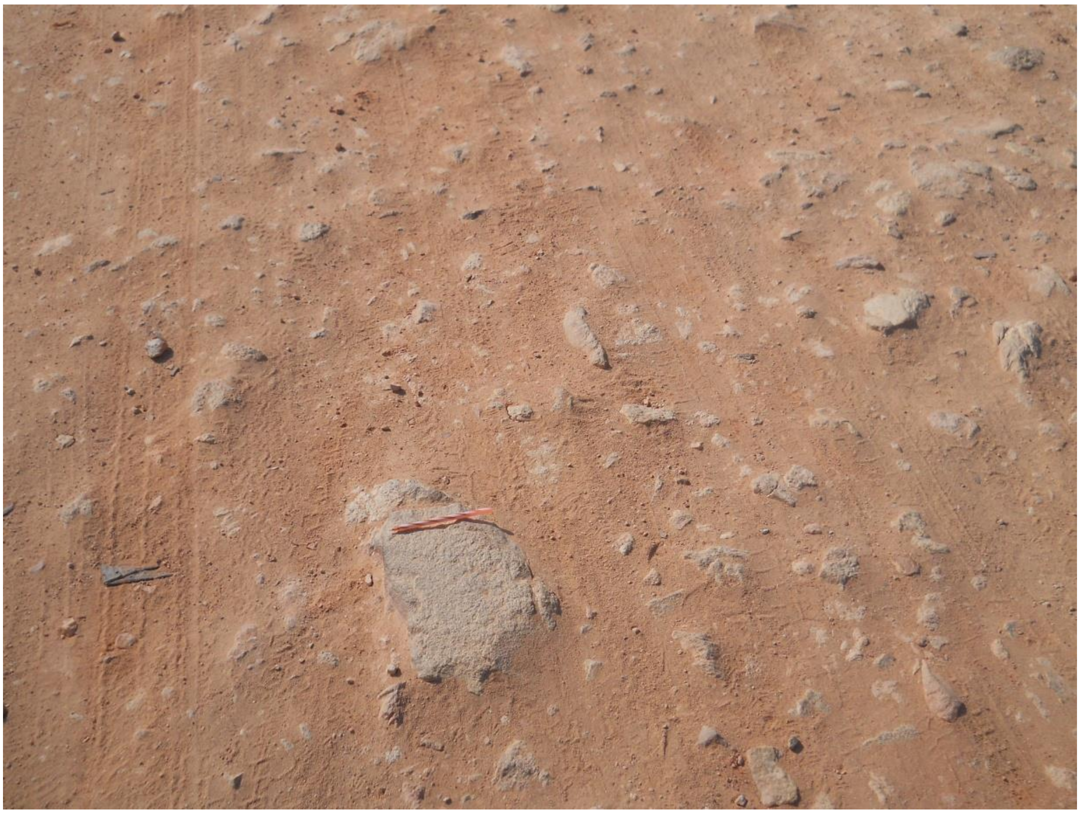

**Figure 29: The extent of stoniness embedment showing the variation in sizes of stones used for gravelling**

5. **Dustiness**: Dust is the fine material released from the road under the wheels of moving vehicles and turbulence caused by vehicles and wind (Pearson 2012:204). Dust is one of the major sources of gravel loss. For assessment purpose, dust was rated in terms of three degrees, namely 1 which signifies

no loss of visibility, 3 signifying some loss of visibility and 5 which is the dangerous loss of visibility. The higher the traffic volume, speed, and loading the heavier the dust generated. The extent of dust is not normally estimated.

6. **Loose material**: This is formed by the ravelling of the wearing course material under traffic. It is mainly caused by a deficiency of fine material due to lack of cohesion, a poor particle size distribution (e.g. gap grading) in the wearing course materials; and inadequate compaction (Pearson 2012:206). It is a major sign of pending gravel loss. Loose material was assessed by estimating its thickness variation across carriageway. Figure 30 shows the extent of ravelling in one of the test sections along Iringa-Msembe road.

**Figure 30: The extent of ravelling in one of test sections along Iringa-Msembe road**

7. **Corrugation**: Only low plasticity materials corrugate significantly, especially those with high sand and fine-gravel fractions (Jones and Paige-Green 2011:6).

8. **Slipperiness and skid resistance**: Slipperiness is the loss of traction caused by an accumulation of excessively fine or plastic material on the surface of the wearing course in wet conditions, while skid resistance is affected by the excess of loose, fine gravel (between 2 and 7 mm in diameter) that accumulates on the road surface through ravelling under traffic or poor grading practices during dry conditions (Pearson 2012:205). Slipperiness can often be evaluated by observing wheel tracks formed during wet weather and wheel tracks retained in the road after drying. Skid resistance is evaluated in terms of the effect of loose material on vehicle stability, and the general impression gained while driving and braking on the dry road. Slipperiness and skid resistance were rated as either acceptable or unacceptable. The impression of wheel tracks reflected on gravel roads, indicate the quantity of gravel material lost on that particular road section.
9. **Trafficability**: The mechanism affecting trafficability is the loss of traction between the tyres and the road resulting from the low shear strength of the material. This results in churning of the material and sinking of the vehicles into the weak layer. Sandy materials are more prone to impassability when dry, while clayey materials become impassable when wet. For assessment purposes, trafficability was rated as either acceptable or unacceptable. The churning of the materials signifies the loss of gravelling materials.
10. **Riding quality and influencing factors**: Defects influencing riding quality are: corrugation; loose material; stoniness; ruts; and erosion.

**Table 40: Assessment of riding quality as recommended by the study**

| Rating | Descriptor | Description |
|---|---|---|
| 1 | Very good | Estimated comfortable /safe speed between 60 and 70 km/h |
| 2 | Good | Estimated comfortable /safe speed between 50 and 60 km/h |
| 3 | Average | Estimated comfortable /safe speed between 30 and 50 km/h |
| 4 | Poor | Estimated comfortable /safe speed between 20 and 30 km/h |
| 5 | Very poor | Estimated comfortable /safe speed 20 km/h |

Riding quality is easily rated as a function of the estimated comfortable and safe driving speed (unaffected by geometric constraints or road width), and was interpreted as indicated in Table 40. Riding quality contributes to gravel loss in terms of dust generated when traffic speed is high.

11. **Road profile/shape**: The profile (shape) of a road has a major impact on gravel road performance. Gravel roads with a good profile tend to shed water rapidly avoiding the development of potholes and potentially impassable conditions. Where the profile is flat water tends to pond in localized depressions resulting in softening of the wearing course and the development of potholes. Failure to repair a flat road timely will usually result in the development of ruts under traffic. These may become preferential water paths resulting in erosion, accelerated gravel loss and significant deterioration in riding quality.
12. **Gravel quality:** The properties contributing to good gravel are particle size distribution and cohesion. The gravel should have a range of particle sizes ranging from very fine up to about 40 mm in order to provide a strong framework of stones interlocked by a tight matrix of fines. Too many large stones result in poor riding quality and difficulties with maintenance. The fines need to have some plasticity to provide cohesion when dry. However, plasticity should not be so high that the road becomes slippery and impassable. Table 41 is a typical visual assessment of gravel quality. The quality of marginal gravel materials is determined by the range of particle sizes distribution noted in its mixes.

**Table 41: Visual assessment of gravel quality**

| Rating | Descriptor | Description |
|---|---|---|
| 1 | Very good | Evenly distributed range of particle sizes with sufficient plasticity, No significant cracking, ravelling and / or excessive oversize |
| 2 | Good | Minor cracking or cracking and/or minimal oversize |
| 3 | Average | Cracking, loose material or stones clearly visible |
| 4 | Poor | Poor particle size distribution. High plasticity to cause slipperiness. Sufficient ravelling to cause loss of traction. |
| 5 | Very poor | Cracking and/ or quantity of loose material/ stones are significant and affect the safety of road users. Excessive over size |

13. **Gravel quantity/Layer thickness**: Most gravel roads are constructed with a wearing course of about 150 mm thick of compacted gravel materials. Under

traffic and environmental influences, this thickness gradually wears away and requires periodic replacement. If it is not replaced, the subgrade is exposed to traffic. The rate of gravel loss is a function of material properties, climate, and the traffic volume characteristics. However, as the traffic increases or the material quality deteriorates with time, this annual loss increase significantly. The rate also increases if profile and drainage are poor. In this study gravel quantity was physically measured on the road by excavating small holes in the wheel tracks, noting the material quality, traffic and any evidence of subgrade exposure.

The exercise was conducted five times on a segment to determine a representative average for the segment. Output from the assessment was the millimetres of material remaining. The direct measurement of layer thickness is essentially a measure of the degree of severity of gravel loss, while estimation of the subgrade exposure represents an extent.

**Table 42: Visual assessment of gravel quantity**

| Rating | Descriptor | Description | Residue thickness (mm) |
|---|---|---|---|
| 1 | Plenty | Good shape and no stone protrusion | > 125 |
| 2 | Sufficient | No exposures of subgrade, but some stone protrusion | 100-125 |
| 3 | Isolate exposures | Less than 25% exposure of the subgrade | 50-100 |
| 4 | Excessive exposures | Up to 75% exposure of the subgrade | 25-50 |
| 5 | None | 75 to 100% exposure of the subgrade | 0-25 |

Table 42 shows results for a typical visual assessment of gravel quantity. The height of stones above the surrounding road surface gives a rough indication of the amount of gravel materials that has been lost.

14. **Gravel road performances**: This is assessed primarily in terms of driver and passenger comfort and the driver's perception of safety. This is estimated after driving on the segment concerned before the detailed assessment is carried out in order to eliminate any bias that may result after completing the detailed assessment (Jones and Paige-Green 2011:6).

### 7.2.3 The condition survey results of test sections under performance study

#### 7.2.3.1 General results of the condition survey of gravel roads under study

At the beginning of the study in 2011, the total numbers of test sections were 25. In the course of study, three sections were abandoned, two as the result of upgrading to sealed surface and one due to extensive vandalism of control points and benchmarks, which invalidated the gravel loss study.

The following is the general state of distress conditions on 22 test sections. Detail will follow under each gravel road.

- **Slipperiness and skid resistance** were at acceptable levels on all 22 test sections.
- **Trafficability** was unacceptable at Ndiwili and Itwanga test sections on the Iringa-Idete road. On the rest of the test sections, the trafficability was acceptable.
- **Drainage from the road** was ranged from poor in those test sections with flat and uneven cross sections to average in those test sections with good cross-section.
- **Quality of marginal gravel materials** employed as wearing course ranges from good to average. In this regard, the sections on each road fared as follows: Iringa-Pawaga **-** six sections had average quality and two had good quality; Iringa-Msembe **-** three sections had average quality and five sections had good quality; and Iringa-Idete **-** five sections had good quality, and three sections had average quality.
- **Gravel quantities** which signify gravel loss were sufficient on all test sections, except at Kidete, Mapinduzi, and Muhunga on the Iringa-Idete road, and Mwika B on the Iringa-Msembe road where the quantities were at isolated exposure's levels.

- **The riding quality/safety** for the then current condition of gravel road alignment was good as the vehicles on almost all test sections could ride at 60 km/h, except on sections with poor trafficability (Ndiwili and Itwanga), the speed ranged from average to poor (50-20 km/h).
- **Tranverse and longitudinal erosions** at Igotikafu along the Iringa-Pawaga road the severity was at 3 degree. The Iringa-Msembe road had three test sections, which fared badly on erosion, namely Mangalali which had transverse erosion severity at 3 degree, while Mwika B and Nyamihuu, had longitudinal erosion severity of 4 and 3 degree respectively. The rest of the test sections on all three roads under study fared well due to being on self-draining terrain.
- **The gravel road's performances** of all test sections were at 3 degree of severity, which is the border line between good and bad condition.

Table 43 shows the frequency of condition survey visits to each test section. The variation in the number of visits was necessitated by the need to establish a relationship between the distress prevalent on the gravel road test section in question and the physical characteristics of marginal gravel materials employed as wearing course.

**Table 43: The frequency of the condition survey visits on each test section**

| **Msembe** | **Frequency of visit** | **Idete** | **Frequency of visit** | **Pawaga** | **Frequency of visit** |
|---|---|---|---|---|---|
| **Trial sections** | | **Trial sections** | | Trial sections | |
| Kalenga | 2 | Tagamenda | 6 | Kidete | 6 |
| Bangamoyo | 2 | Kitayawa | 6 | Mapinduzi | 6 |
| Mwika A | 4 | Igula | 6 | Kilendu | 6 |
| Mwika B | 4 | Ndiwili | 4 | Umasaini | 6 |
| Mangalali | 4 | Italula | 5 | Kimalanogwa | 2 |
| Muhimbili | 6 | Kilolo | 1 | Mkwambilenge | 1 |
| Nzihi | 6 | Itwanga | 4 | Ilolo mpya | 3 |
| Nyamihuu | 4 | Amani | 4 | Igotikafu | 3 |
| | | Ilamba | 5 | Don-Bosco | 2 |

Table 44 is a summary of the degree and extent of distress on the gravel roads under study.

**Table 44: The summary of extent of distress on the four gravel roads under study**

| Distress/ road condition | Gravel road name | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Idete (R625) | | Pawaga (R621) | | Msembe (R 595) | | Don-Bosco IMC | |
| | Degree | Extent | Degree | Extent | Degree | Extent | Degree | Extent |
| Potholes | 0 | 5 | 0 | 5 | 0 | 5 | 0 | 5 |
| Rutting | 0 | 5 | 3 | 5 | 2 | 4 | 0 | 5 |
| Erosion-transverse | 0 | 5 | 0 | 5 | 0 | 5 | 0 | 5 |
| Erosion-longitudinal | 0 | 5 | 0 | 5 | 0 | 5 | 0 | 5 |
| Stoniness - embedded | 0 | 5 | 4 | 5 | 1 | 4 | 2 | 3 |
| Stoniness-loose | 3 | 5 | 2 | 4 | 0 | 5 | 4 | 5 |
| Corrugation | 0 | 5 | 0 | 5 | 0 | 5 | 0 | 5 |
| Loose material | 0 | 5 | 4 | 5 | 2 | 4 | 1 | 2 |
| Dust | 4 | - | 4 | - | 4 | - | 4 | - |
| Slipperiness | Acceptable | | Acceptable | | Acceptable | | Acceptable | |
| Skid resistance | Acceptable | | Acceptable | | Acceptable | | Acceptable | |
| Trafficability | Acceptable | | Acceptable | | Acceptable | | Acceptable | |
| Riding quality | Average | | Average | | Average | | Poor | |
| Road shape | Good | | Flat | | Flat | | Flat | |
| Drainage | Slightly above | | Slightly above | | Slightly above | | Canal | |
| Gravel quality | Good | | Average | | Good | | Average | |
| Gravel quantity | Isolated exposure | | Isolated exposure | | Isolated exposure | | Isolated exposure | |
| Performance | Average | | Average | | Average | | Poor | |

### 7.2.3.2 The frequency and state of condition survey on Iringa - Msembe road

The frequency of the condition survey conducted on test sections along Iringa - Msembe road varied from four to six. Two sections, namely Kalenga and Bangamoyo were upgraded to a sealed surface after two visits, which reduced the test sections to six from eight. Mwika A, Mwika B, and Nyamihuu were visited four times, while Mangalali, Muhimbili, and Nzihi had six visits.

The geological type of gravel materials employed for surfacing gravel roads on Mwika A and B, and Muhimbili and Nzihi roads are quartzitic brownish red or quartzitic silt stone respectively. The geologic type of gravel wearing course on Nyamihuu is brownish red lateritic and on Mangalali is grey mudstone. The gravel material's characteristics in terms of particle size distribution and shrinkage product met the requirements for marginal materials according to TZ-MoW (1999:11.4), as 100 % passed the 37.5 mm sieve, and shrinkage product range between 120 and 400. The grading coefficient (GC) for the gravelling materials in all test sections did not meet the requirement as per TZ-MoW (1999:11.4), which range from 12-32. The GC for the test sections ranges from 36 to 72 inclusive. The climate prevailing on the test sections is moderate.

The predominant distresses in the test sections varied with the unique characteristics of the section in question. Distresses ranging from 3 to 5 degree of severity were corrugation, dustiness, potholes, loose materials, road profile and erosion. Apart from Mwika B, the rest test sections had their road profile in flat conditions. Nzihi and Muhimbili test sections had corrugations at 4 degree. Loose materials severity was at 4 degree on the Mwika A, Muhimbili and Nzihi test sections. Potholes on Mwika A were at 3 degree. Dustiness severity ranged from 3 to 4 degree, with the following five test sections at 4 degree, namely Mwika A, Mangalali, Muhimbili, Nzihi, and Nyamihuu, while one test section, Mwika B the severity was at 3 degree. The severity of longitudinal erosion was at 4 degree on Mwika B, and 3 degree on Nyamihuu test sections. Stoniness embedded with 4 degree of severity was prevalent on Mwika A, Mwika B, and Mangalali test sections.

These sections had fast changing surface condition due to: the characteristic of marginal gravel materials employed, high traffic volume travelling at a speed above 60 km/h, and lack of timely and appropriate maintenance. This phenomenon confirms Alzubaidi and Magnusson’s statement (2002:4) that the deterioration of gravel roads is governed by the behaviour of the gravel and roadbed materials, the drainage capacity, the combined action of traffic and climate and the absence of sufficient maintenance activities.

#### 7.2.3.3 The frequency and state of the condition survey on Iringa - Idete road

Total frequencies of road condition surveys conducted on Iringa - Idete road were 35. Each trial section was visited at least four times and at most six times. Kilolo trial sections were abandoned after only one visit after being in the pipeline of being upgraded to sealed condition, and Itwanga section was selected to replace it.

The major geological type of gravel material on the Iringa - Idete road is quartzitic. Two colours of quartzitic are predominant that is brownish grey for Tagamenda, Kitayawa, Igula and Ndiwili test sections, and brownish red for Utengule, Itwanga, Amani and Ilamba test sections. A brownish red quartzitic soil falls in the wet climate condition, while brownish grey quartzitic falls in the moderate climate condition.

The gravel materials' characteristics in terms of particle size analysis met the requirement of the specification for marginal materials as per TZ-MoW (1999:11.4) for road works as 100% passed through a 37.5 mm sieve. The results of shrinkage product fared as follows: Tagamenda, Amani and Ilamba test sections did not meet the specified limits of SP. Tagamenda`s wearing material's SP was below the minimum of 120, while Amani and Ilamba SP was above the maximum of 400. The remaining five sections, namely Kitayawa, Igula, Ndiwili, Italula and Itwanga were within 120-400, which is the set specification limits for SP. The average GC for Kitayawa and Igula test sections was 31, which is on the higher side of the specified limit of 16-34. The remaining six test sections had a GC range of between 35 and 49. Prevalent distresses, with the degree of severity at 3 and 5 on these sections were poor cross section and dust.

#### 7.2.3.4 The frequency and state of the condition survey of Iringa - Pawaga road

Total frequencies of the road condition surveys performed on Iringa - Pawaga roads were 28. Total numbers of visits on each trial section are as shown in Table 43 column six.

Gravel materials employed to surface unsealed road segments along Iringa-Pawaga road have five types of geological characteristics. The main one is brownish grey quartiztic which was used to surface three sections, namely Kidete, Mapinduzi, and Kilendu. Light blue ferrugnous siltstone surfaced Muhunga, brownish red lateritic surfaced Kimalanongwa test section, while grey limestone quartzitic surfaced Mkwambilenge, and brownish quartzitic surfaced Pawaga secondary school. The particle size distribution of marginal gravel materials employed for surfacing the test sections passes through a 37.5 mm sieve by 100%, and had SPs ranging from 155 to 400. Kimalanongwa and Kidete test sections had GC ranges between 28-32 and 23-31 respectively, hence meeting the TZ-MoW (1999:11.3) condition. The remaining five test sections had GC ranges from 37-62, which is above the specified limits of 16-34.

Four sections are in a dry climate, namely Muhunga, Kimalanogwa, Mkwambilenge, and Pawaga Secondary School, while three test sections are in moderate climates, namely Kidete, Mapinduzi, and Kilendu.

Prevalent distress on the test sections along Iringa-Pawaga road at 3 to 5 degree severity were road profile/shape, dustiness, rutting, loose aggregate, stoniness embedded and loose. The road profile/shape was flat in almost all test sections. Severity of dust was at 5 degree on road sections in the dry climatic area, while in the moderate area, the severity was at 3 degree. Loose aggregate was at 5 degree at Kidete, Mapinduzi, Kilendu, Umasaini (Muhunga), Mkwambilenge and Igotikafu. Stoniness embedded was 5 degree at Kidete, while Mapinduzi, Kilendu, Umasaini

(Muhunga) were at 4 degree. Stoniness loose at Kilendu and Mwambilenge were at 5 degree and at Kidete, Muhunga and Igotikafu were at 4 degree. Rutting was at 5 degree at Mapinduzi and Mwambilenge, while at Igotikafu and Muhunga were at 4 degree. Rutting at Kilendu was at 3 degree. Potholes, transverse erosion, longitudinal erosion and corrugation are not prevalent on marginal gravel materials employed to surface the test sections along Iringa-Pawaga road.

### 7.2.3.5 The frequency and state of the condition survey on Don-Bosco road

The Don-Bosco road is under the management of Iringa Municipality Council. The road was visited twice for a condition survey. Generally, the road receives routine maintenance by grading annually. The traffic volume on this road is extremely high, particularly during burial ceremonies as it accesses one of a major and busy grave yards in the municipality. Within two to three months after grading the road reverts to a bad condition.

**Figure 31: Stoniness embedded which is the prevalent distress on Don-Bosco road**

The prevalent distress on this section is stoniness embedded, which start to protrude just weeks after grading and force vehicles to seek refuge on the shoulder or pedestrian walkway as shown in Figure 31.

#### 7.2.3.6 Concluding remarks

In general, test results of GC for all the marginal gravel materials borrow pits employed to surface test sections did not meet the requirement set out in Figure 32, as per TZ-MoW (1999:11.4). Despite not meeting the stated specifications, these materials performed relatively well as noted during the condition survey. It should be brought to attention that Figure 32 is based on South African research conducted in the nineteen eighties and reported by Paige-Green (2006:2) with slight changes.

The South African gravel road specifications were developed from roads selected using factorial design, including material types, traffic, and climate and covered a wide range of environmental conditions.

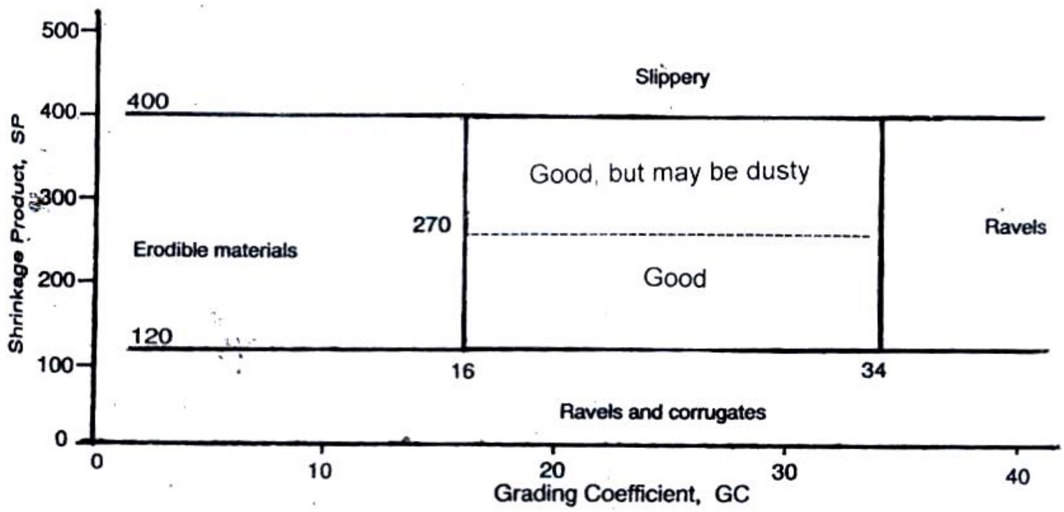


**Figure 32: Performance specification for gravel wearing course**
**(Source: TZ-MoW 1999:11.4)**

The South Africa specification has an SP range from 100-365, and GC range from 16-34. This proves further the danger of adopting directly the specification employed in other countries without doing adequate local calibration through empirical research.

From the above it is sufficient to mention here that there is a need to adjust the window frame of GC for the marginal materials as none of the distress associated with gravel materials by not meeting the given range as shown in Figure 32 were observed during the condition survey. The range for the Msembe road was 36-72, the Pawaga road was 23-62, and the Idete road 31-49. This study recommends a GC range from 23-72 for marginal materials, as it is more accommodating for all the marginal gravel materials used to surface gravel roads covered by the study.

### 7.3 Gravel loss monitoring exercise

#### 7.3.1 Introduction

Before the start of gravel loss surveys, a visit schedule and how the exercise shall be conducted were established.

#### 7.3.2 Schedule

Most of Iringa region experiences one annual rainfall season followed subsequently by cold and sunny periods. The rain season starts late November or early December and continues until March or early April while the cold spate starts late April up to middle July. The sunny period begins middle of July and continues until late November. In order to assess the seasonal effects on gravel loss, if any, the road test sites were monitored thrice per year thus falling within each mentioned season.

The road test sections were monitored for a period of two and a half years, starting from April, 2011, with most sites being monitored seven times, as shown in Table

45. Surveys conducted during each site visit were changes in road surface spot elevation and road condition.

**Table 45: Gravel loss survey monitoring dates**

| Road Name | Test section | Monitoring dates | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1st Visit | 2nd Visit | 3rd Visit | 4th Visit | 5th Visit | 6th Visit | 7th Visit |
| IMC | Don-Bosco | 9/4/11 | 15/9/11 | 11/1/12 | 16/6/12 | 5/10/12 | 8/2/13 | 9/8/13 |
| Iringa-Pawaga | Kidete<br>Mapinduzi<br>Kilendu<br>Muhunga | 26/5/11 | 13/9/11 | 10/1/12 | 19/5/12 | 10/9/12 | 16/1/13 | 10/8/13 |
| | Kimalanogwa<br>Mkwambilenge<br>Pawaga SS | 28/5/11 | 16/9/11 | 12/1/12 | 20/5/12 | 11/9/12 | 17/1/13 | 11/8/13 |
| Iringa-Msembe | Mwika A<br>Mwika B<br>Mangalali | 25/5/11 | 20/9/11 | 30/1/12 | 24/5/12 | 13/9/12 | 7/1/13 | 30/7/13 |
| | Muhimbili<br>Nzihi<br>Nyamihuu | 19/5/11 | 9/10/11 | 24/1/12 | 25/5/12 | 15/9/12 | 12/1/13 | 28/7/13 |
| Iringa-Idete | Tagamenda<br>Kitayawa<br>Igula<br>Ndiwili | 21/6/11 | 21/9/11 | 8/1/12 | 1/7/12 | 1/12/12 | 13/4/13 | 22/11/13 |
| | Utengule<br>Itwanga<br>Amani<br>Ilamba | 19/5/11 | 22/9/11 | 28/1/12 | 9/5/12 | 26/9/12 | 14/2/13 | 30/6/13 |

### 7.3.3 Gravel loss

Gravel loss was estimated by monitoring changes in the elevation of the cross-section profile of the gravel road carriageway. The monitoring were made between each pair of pegs at every 20 m along the road test sections. At each cross-section, the spot height was measured at 25 cm intervals using the rod and level as illustrated in Figure 33. The 25 cm intervals were marked around a 2 mm diameter nylon string using masking tape.

**Figure 33: Gravel loss survey at one of test section along Iringa-Idete road**

The nylon string was held tightly around a four inch long nail fixed across the carriageway width between a pair of pegs. The spot heights were then referenced to the benchmark readings. A typical form for recording the cross-section profile measurements at 25 cm intervals is as given in Chapter 4 Table 12.

Before measuring the cross-section profiles, it was important to check whether the reference pegs have moved since last recording. Any movement of the benchmark affects the repeaterbility of benchmark spot height level and estimated gravel loss.

As a routine exercise, at the start of each new round of measurement, the noted relative height of benchmarks and each peg were compared against the original survey records. Changes in vertical movement noted were addressed when calculating the reduced levels between successive surveys.

The width of the carriageway was determined at each test section. The average reduced level across the defined width was used to estimate the height of the gravel wearing course at each test section. The same defined width of a cross-section was used throughout the monitoring period. The change in the average height of the carriageway between surveys was used as the indicator of change in gravel loss.

### 7.3.4 Gravel loss data analysis

#### 7.3.4.1 Data collection

The gravel loss constituted by far the largest data set for test sections. Profile heights were taken at 25 cm interval over a 6 m cross-sectional width at an interval of 20 m along a 100 m long site. This equated to 150 readings on one site during each site visit. In total 23,100 profile heights from the 7 surveys conducted at 22 sites were recorded.

#### 7.3.4.2 Rate of gravel loss

The height of the gravel road wearing surface at each cross-section was estimated by taking the average of the readings over the carriageway width at the cross-section. The average height of the site was then determined by taking the average of the 11 cross sectional heights. The gravel loss on each site was then determined by comparing the average height of the site from each previous survey. The gravel loss between surveys on all test sites are summarised in Table 46.

In Table 46, six gravel loss values are negative implying gravel gain. For this study, this was attributed to lose materials (raveling) shifted by wind or vehicles turbulent force and aligned between control pegs. This concluding remark differs from the one reached by Paige-Green (1989:6.12) who noted the gravel gain on test sections with low traffic and high values of the gravel materials plastic factor in the dry areas.

According to Table 46, 11 test sections had no gravel loss data. This was due to their wearing surfaces being graded during either the 3rd, 4th or 5th visits, and hence no levels were taken.

**Table 46: Gravel loss results between surveys in mm**

| Road (climate) | Test section | Carriageway gravel loss survey (mm) | | | | | | Mean (mm) | Std. (mm |
|---|---|---|---|---|---|---|---|---|---|
| | | 1st - 2nd | 2nd- 3rd | 3rd- 4th | 4th- 5th | 5th- 6th | 6th- 7th | | |
| IMC | Don-Bosco | 2 | 54 | - | - | 13 | 41 | 28 | 24 |
| Pawaga (moderate/ dry) | Kidete | 49 | 1 | 17 | 16 | 1 | 4 | 15 | 18 |
| | Mapinduzi | 3 | 10 | - | 7 | 3 | 5 | 6 | 3 |
| | Kilendu | 35 | 40 | - | 10 | 6 | 9 | 20 | 16 |
| | Muhunga | 77 | 39 | - | 11 | 38 | 3 | 34 | 29 |
| | Kimalanongwa | 56 | 69 | 11 | 3 | 27 | 27 | 32 | 26 |
| | Mkwambilenge | 51 | 85 | 43 | 69 | 84 | 2 | 56 | 31 |
| | Pawaga SS | 85 | 92 | 98 | 55 | 58 | 52 | 73 | 21 |
| Msembe (moderate) | Mwika A | 36 | -3 | 56 | 3 | 18 | 29 | 23 | 22 |
| | Mwika B | 14 | 66 | 10 | -20 | 11 | 30 | 19 | 28 |
| | Mangalali | 3 | 22 | - | 28 | 5 | 22 | 16 | 11 |
| | Muhimbili | 7 | 1 | - | 41 | 62 | 1 | 22 | 28 |
| | Nzihi | 3 | 43 | - | 10 | 14 | 7 | 15 | 16 |
| | Nyamihuu | 7 | 82 | 62 | - | 4 | 9 | 33 | 37 |
| Idete (moderate/ wet) | Tagamenda | 150 | -70 | 30 | 70 | 10 | 40 | 38 | 72 |
| | Kitayawa | 40 | 30 | 50 | - | 50 | 0 | 34 | 21 |
| | Tagamenda | 150 | -70 | 30 | 70 | 10 | 40 | 38 | 72 |
| | Kitayawa | 40 | 30 | 50 | - | 50 | 0 | 34 | 21 |
| | Igula | -62 | 39 | 121 | -6 | 16 | 29 | 23 | 60 |
| | Ndiwili | 45 | 5 | 10 | 37 | 8 | 20 | 21 | 17 |
| | Utengule | 8 | 28 | - | - | 11 | 7 | 14 | 10 |
| | Itwanga | 4 | 5 | 7 | 6 | 3 | 4 | 5 | 1 |
| | Amani | 2 | - | 4 | -1 | 2 | 6 | 3 | 3 |
| | Ilamba | 4 | 6 | 3 | 4 | 3 | 7 | 5 | 2 |

From Table 46, it is noted that the minimum, average, gravel loss during the entire period of study was 3 mm and the highest was 73 mm. The mean of this huge variation was 24 mm. This result is somehow similar with the one obtained by Paige-

Green (1989:6.13), where the predicted annual gravel losses ranged from 4.5 mm for a lightly trafficked , fine grained, low plasticity material in a dry area to about 65 mm for a cohesive, coarsely graded gravels under high traffic in a dry area. The study did not produce the consistent range of gravel loss; this might be attributed to either marginal gravel material characteristic or inconsistent in the quality of work output during construction and maintenance activities.

#### 7.3.4.3 Gravel loss threshold

The annual rate of gravel loss peculiar to the area of study is a tool to determine a threshold on which to peg the timing of grading or re-gravelling cycles (Patterson 1991:143; Dierk 1992:82). The rate can also be employed as a tool for quality control.

**Table 47: Gravel loss thresholds**

| Rating level | | Annual gravel loss (mm) | Severity of distress |
|---|---|---|---|
| 1 | Very good | 27 | GL is not noticeable to road user |
| 2 | Good | 34 | GL is slightly noticeable |
| 3 | Fair/Regular/Moderate | 45 | GL is noticeable |
| 4 | Poor/Bad | 67 | Isolated exposures of subgrade |
| 5 | Very poor/Very bad | 80 | Extensive exposures of subgrade |

Based on the result of the gravel loss survey as shown in Table 46, the gravel loss threshold proposed by this study as an indicator of the quality of construction, rehabilitation and marginal gravel material characteristics is as shown in Table 47. It should be borne in mind that the gravel loss in inevitable, and is one of major characteristic of gravel roads. This is confirmed by Morris (1990:196), who assert that the abrasion of gravel materials from gravel roads is to be expected.

The gravel loss thresholds as proposed in Table 47 is based on a five-year life cycle of properly managed gravel road with initial pavement thickness of 150 mm and residual thickness of 15 mm at the end of design life. Rating levels 1 and 2 are for well-designed and constructed gravel roads, while rating 3 is for fairly-constructed gravel road. Rating levels 4 and 5 are for poor constructed gravel roads. Poorly constructed gravel roads are affected by initial compaction effect. This was noticed on the Muhunga section which was re-gravelled and experienced initial rapid gravel loss after being opened to traffic. Similar experience was noted by Paige-Green (1989:6.13), and was attributed to inadequate compaction during construction. It should be stressed here that only gravel roads with gravel loss rating 1 and 2 will attain the five years design life before being rehabilitated.

#### 7.3.4.4 Gravel loss as gravelling layer auditing tool

The construction industry in general is consistently leading as one of the most corrupt industries, and roadwork is one of its major victims. Large payments to benefit or change contracts and circumvent regulations are common in the road construction industry (Kenny 2007:1). According to Kenny the consequences of corruption activities are to influence the quality of construction and maintenance output of the road infrastructure. The end result is that the economic benefit which was expected is not realized.

It is known that despite the agreed design thickness of gravel road wearing course, the final thickness of gravelling layers to be attained at a site is a matter of consent between the contractor and the immediate supervisor, who either comes from the client or the consultant firm. The quality of compaction effort can also be affected by corrupt practice. Compaction is compromised by either reducing the number of roller passes and the vibrations of the drum or by not providing the adequate water required to be mixed with gravel material so as to attain the optimum moisture content ideal for compaction. When the contractor and client representative or consultant has colluded to tamper with the design thickness or quality of work, this will affect the gravel road's performance. Only the physical auditing of the quality of the finished work can circumvent corruption and the gravel loss survey can be employed to this end.

Quantifying compaction in terms of gravel loss as measured by a gravel loss survey will necessitate the introduction of a one year liability period on the gravelling exercise which is similar to the liability imposed on drainage structures. Currently the liability period for gravel pavements in Tanzania is three months as confirmed through face to face conversation with Tanzania Road Fund Board Deputy Manager Technical Services, Eng. Lwakatare on 15 January 2015 and Planning Engineer of TANROADS Iringa Regional, Eng. Rwesingisa on 16 January 2015.

For quality control and ascertaining the integrity of those who executed the exercise, the gravel loss exercise has to be performed in the intervals of three month.

### 7.3.5 Variables for formulating the gravel loss model

According to Henning, Giummarra and Brass (2007) there are many independent variables to be concerned with during modelling gravel loss models. This fact is noted in Tables 48, 49, and 50, which show variables used to formulate a gravel loss prediction model for the Iringa region. The ever-present dependent variable in each Table is gravel loss (GL), while other independent variables in Table 48 are average daily traffic (ADT), average annual rainfall, grading modulus (GM), grading coefficient (GC), shrinkage product (SP), gravel materials passing through a 37.5 mm-sieve, and plasticity factor (PF). In Table 49 independent variables are gravel materials passing 2.00, 0.425, and 0.075 mm-sieves, liquid limit (LL), plasticity index (PI), shrinkage limit (SL), and road longitudinal gradient (Grad). Independent variables in Table 50 are dust ratio (DR), plasticity modulus (PM), plasticity product (PP), coarseness index (CI), and gravel material's geology. Grading modulus (GM) was calculated from particle size analysis results of gravel materials used for surfacing the gravel roads under study as shown in Equation 16.

Plasticity factor (PF) is derived from the product of percentage of fine component of gravel materials passing through a 0.075-mm sieve and plastic limit (PL), as shown in Equation 17.

**Equation 17: PF = [(% < 0.075) x PL] (%)**

Other materials parameters which were used during formulating the gravel loss prediction model are shrinkage product (SP), coarseness index (CI), dust ratio (DR), plasticity modulus (PM) and plasticity product (PP). The formulae used to determine them are as shown in Equation 18, 19, 20, 21, and 22 respectively.

**Equation 18: SP = [LS x (% < 0.425)]**

**Equation 19: CI = [100 – (% < 2.00)] (%)**

**Equation 20: DR = (% < 0.075) / (% < 0.425)**

**Equation 21: PM = [(% <0.425) x PI] (%)**

**Equation 22: PP = [(% < 0.075) x PI] (%)**

**Table 48: Variables for formulating the gravel loss model in terms of material's characteristics, traffic, and rain**

| Test section | Year | Variables | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | GL (m) | ADT | Rain (mm) | GM | GC | SP | P37.5 | PF |
| Mwika A | 2011 | **0.003** | 268 | 660.4 | 1.85 | 42.15 | 264 | 100 | 5.18 |
| | 2012 | **0.003** | 240 | 623.4 | 1.34 | 40.60 | 303 | 100 | 6.87 |
| | 2013 | **0.011** | 274 | 742.1 | 1.76 | 71.60 | 345 | 100 | 8.09 |
| Mwika B | 2011 | **0.030** | 268 | 660.4 | 1.85 | 42.15 | 264 | 100 | 5.18 |
| | 2012 | **0.011** | 240 | 623.4 | 1.34 | 40.60 | 303 | 100 | 6.87 |
| | 2013 | **0.030** | 274 | 742.1 | 1.76 | 71.60 | 345 | 100 | 8.09 |
| Mangalali | 2011 | **0.012** | 268 | 660.4 | 1.82 | 43.33 | 218 | 100 | 4.69 |
| | 2012 | **0.017** | 240 | 623.4 | 2.13 | 56.60 | 144 | 100 | 1.97 |
| | 2013 | **0.022** | 274 | 742.1 | 1.16 | 39.63 | 197 | 100 | 3.08 |
| Muhimbili | 2011 | **0.004** | 268 | 660.4 | 1.86 | 44.86 | 369 | 100 | 6.45 |
| | 2012 | **0.041** | 240 | 623.4 | 1.74 | 53.84 | 218 | 100 | 5.43 |
| | 2013 | **0.038** | 274 | 742.1 | 1.92 | 52.64 | 230 | 100 | 6.56 |

**Table 48: Continued**

| Test section | Year | Variables | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **GL (m)** | **ADT** | **Rain (mm)** | **GM** | **GC** | **SP** | **P37.5** | **PF** |
| Nzihi | 2011 | **0.023** | 268 | 660.4 | 1.86 | 44.86 | 369 | 100 | 6.45 |
| | 2012 | **0.012** | 240 | 623.4 | 1.74 | 53.84 | 218 | 100 | 5.43 |
| | 2013 | **0.007** | 274 | 742.1 | 1.92 | 52.64 | 230 | 100 | 6.56 |
| Nyamihuu | 2011 | **0.050** | 106 | 660.4 | 1.19 | 40.97 | 354 | 100 | 11.52 |
| | 2012 | **0.037** | 115 | 623.4 | 0.93 | 36.11 | 357 | 100 | 12.80 |
| | 2013 | **0.007** | 109 | 742.1 | 1.24 | 38.43 | 362 | 100 | 8.58 |
| Kidete | 2011 | **0.025** | 57 | 660.4 | 1.20 | 22.62 | 404 | 100 | 10.33 |
| | 2012 | **0.009** | 68 | 623.4 | 1.44 | 30.76 | 312 | 100 | 7.73 |
| | 2013 | **0.004** | 80 | 742.1 | 1.36 | 55.76 | 319 | 92.94 | 5.97 |
| Mapinduzi | 2011 | **0.007** | 57 | 660.4 | 1.21 | 45.12 | 343 | 100 | 9.83 |
| | 2012 | **0.005** | 68 | 623.4 | 1.59 | 56.83 | 263 | 100 | 5.65 |
| | 2013 | **0.005** | 80 | 742.1 | 1.48 | 61.62 | 276 | 100 | 6.32 |
| Mapinduzi-Kilendu | 2011 | **0.038** | 57 | 660.4 | 1.21 | 45.12 | 343 | 100 | 9.83 |
| | 2012 | **0.008** | 68 | 623.4 | 1.59 | 56.83 | 263 | 100 | 5.65 |
| | 2013 | **0.009** | 80 | 742.1 | 1.48 | 61.62 | 276 | 100 | 6.32 |
| Muhunga | 2011 | **0.058** | 70 | 660.4 | 2.12 | 57.45 | 125 | 96.28 | 1.67 |
| | 2012 | **0.024** | 69 | 623.4 | 2.01 | 40.60 | 203 | 100 | 2.82 |
| | 2013 | **0.003** | 80 | 742.1 | 2.24 | 52.30 | 176 | 100 | 3.51 |
| Kimalanongwa | 2011 | **0.063** | 70 | 660.4 | 1.04 | 28.41 | 289 | 100 | 7.72 |
| | 2012 | **0.007** | 69 | 623.4 | 1.12 | 32.46 | 358 | 100 | 10.57 |
| | 2013 | **0.027** | 80 | 742.1 | 1.09 | 29.48 | 426 | 100 | 6.61 |
| Mkwambilenga | 2011 | **0.068** | 70 | 660.4 | 1.92 | 36.91 | 309 | 100 | 6.94 |
| | 2012 | **0.056** | 69 | 623.4 | 2.01 | 40.32 | 247 | 100 | 6.38 |
| | 2013 | **0.043** | 80 | 742.1 | 1.78 | 42.16 | 250 | 100 | 5.38 |
| Pawaga SS | 2011 | **0.088** | 70 | 660.4 | 2.01 | 43.03 | 208 | 100 | 3.83 |
| | 2012 | **0.077** | 69 | 623.4 | 1.98 | 44.18 | 190 | 100 | 3.16 |
| | 2013 | **0.055** | 80 | 742.1 | 2.12 | 42.67 | 155 | 100 | 2.56 |
| Tagamenda | 2011 | **0.049** | 198 | 660.4 | 2.57 | 47.18 | 54 | 100 | 0.73 |
| | 2012 | **0.038** | 187 | 623.4 | 2.42 | 45.28 | 80 | 100 | 1.48 |
| | 2013 | **0.025** | 205 | 742.1 | 1.96 | 38.90 | 68 | 100 | 1.60 |
| Kitayawa | 2011 | **0.022** | 172 | 660.4 | 2.12 | 34.47 | 157 | 100 | 3.54 |
| | 2012 | **0.018** | 161 | 623.4 | 2.44 | 28.19 | 139 | 100 | 2.06 |
| | 2013 | **0.020** | 185 | 742.1 | 2.09 | 29.32 | 179 | 100 | 3.83 |
| Igula | 2011 | **0.039** | 172 | 660.4 | 2.12 | 34.47 | 157 | 100 | 3.54 |
| | 2012 | **0.041** | 161 | 623.4 | 2.44 | 28.19 | 139 | 100 | 2.06 |
| | 2013 | **0.023** | 185 | 742.1 | 2.09 | 29.32 | 179 | 100 | 3.83 |
| Ndiwili | 2011 | **0.012** | 172 | 660.4 | 1.72 | 42.50 | 253 | 100 | 6.10 |
| | 2012 | **0.008** | 161 | 623.4 | 1.74 | 35.03 | 182 | 100 | 8.32 |
| | 2013 | **0.014** | 185 | 742.1 | 1.82 | 46.28 | 339 | 100 | 6.82 |
| Italula/Utengule | 2011 | **0.010** | 168 | 660.4 | 1.72 | 42.50 | 253 | 100 | 6.10 |
| | 2012 | **0.008** | 161 | 623.4 | 1.74 | 35.03 | 182 | 100 | 8.32 |
| | 2013 | **0.009** | 172 | 742.1 | 1.82 | 46.28 | 339 | 100 | 6.82 |
| Itwanga | 2011 | **0.004** | 50 | 660.4 | 1.99 | 49.01 | 280 | 100 | 7.22 |
| | 2012 | **0.004** | 64 | 623.4 | 2.07 | 48.31 | 275 | 100 | 4.79 |
| | 2013 | **0.003** | 49 | 742.1 | 2.13 | 47.68 | 245 | 100 | 4.72 |

**Table 48: Continued**

| Test section | Year | Variables | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | GL (m) | ADT | Rain (mm) | GM | GC | SP | P37.5 | PF |
| Amani | 2011 | **0.002** | 50 | 660.4 | 1.23 | 35.35 | 473 | 100 | 8.97 |
| | 2012 | **0.002** | 64 | 623.4 | 1.50 | 41.95 | 349 | 100 | 8.70 |
| | 2013 | **0.004** | 49 | 742.1 | 1.37 | 40.86 | 637 | 100 | 12.72 |
| Ilamba | 2011 | **0.004** | 15 | 660.4 | 1.23 | 35.35 | 473 | 100 | 8.97 |
| | 2012 | **0.003** | 17 | 623.4 | 1.50 | 41.95 | 349 | 100 | 8.70 |
| | 2013 | **0.003** | 20 | 742.1 | 1.37 | 40.86 | 637 | 100 | 12.72 |
| Don Bosco | 2011 | **0.029** | 1197 | 660.4 | 1.72 | 42.72 | 263 | 100 | 6.67 |
| | 2012 | **0.025** | 1029 | 623.4 | 1.59 | 49.31 | 421 | 100 | 8.00 |
| | 2013 | **0.027** | 1213 | 742.1 | 2.01 | 60.70 | 379 | 100 | 6.82 |

**Table 49: Variables for formulating gravel loss model in terms of materials characteristics and road alignment**

| Test section | Year | Variables | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | GL (m) | P2 | P0.425 | P0.075 | LL | PI | SL | Grad |
| Mwika A | 2011 | **0.003** | 54.97 | 37.02 | 23.37 | 34.0 | 11.82 | 7.14 | 0 |
| | 2012 | **0.003** | 78.41 | 53.08 | 34.02 | 31.8 | 11.61 | 5.71 | 0 |
| | 2013 | **0.011** | 60.26 | 48.34 | 36.87 | 32.6 | 10.67 | 7.14 | 0 |
| Mwika B | 2011 | **0.030** | 54.97 | 37.02 | 23.37 | 34.0 | 11.82 | 7.14 | 0 |
| | 2012 | **0.011** | 78.41 | 53.08 | 34.02 | 31.8 | 11.61 | 5.71 | 0 |
| | 2013 | **0.030** | 60.26 | 48.34 | 36.87 | 32.6 | 10.67 | 7.14 | 0 |
| Mangalali | 2011 | **0.012** | 56.98 | 33.85 | 25.27 | 31.3 | 12.75 | 6.43 | 0 |
| | 2012 | **0.017** | 47.10 | 25.15 | 14.59 | 23.0 | 9.49 | 5.71 | 0 |
| | 2013 | **0.022** | 62.83 | 34.49 | 14.52 | 32.9 | 11.72 | 5.71 | 0 |
| Muhimbili | 2011 | **0.004** | 55.11 | 33.29 | 25.61 | 45.0 | 19.83 | 11.07 | 0 |
| | 2012 | **0.041** | 40.26 | 30.54 | 20.36 | 43.0 | 16.32 | 7.14 | 0 |
| | 2013 | **0.038** | 50.28 | 32.28 | 24.35 | 41.3 | 14.36 | 7.14 | 0 |
| Nzihi | 2011 | **0.023** | 55.11 | 33.29 | 25.61 | 45.0 | 19.83 | 11.07 | 0 |
| | 2012 | **0.012** | 40.26 | 30.54 | 20.36 | 43.0 | 16.32 | 7.14 | 0 |
| | 2013 | **0.007** | 50.28 | 32.28 | 24.35 | 41.3 | 14.36 | 7.14 | 0 |
| Nyamihuu | 2011 | **0.050** | 71.13 | 55.02 | 54.51 | 35.3 | 14.17 | 6.43 | 1 |
| | 2012 | **0.037** | 82.63 | 62.56 | 62.23 | 33.3 | 12.73 | 5.71 | 1 |
| | 2013 | **0.007** | 74.62 | 56.24 | 45.86 | 30.2 | 11.48 | 6.43 | 1 |
| Kidete | 2011 | **0.025** | 67.05 | 56.61 | 55.86 | 31.8 | 13.31 | 7.14 | 0 |
| | 2012 | **0.009** | 59.99 | 48.57 | 47.87 | 30.3 | 14.16 | 6.43 | 0 |
| | 2013 | **0.004** | 52.26 | 44.64 | 40.52 | 28.3 | 13.56 | 7.14 | 0 |
| Mapinduzi | 2011 | **0.007** | 72.69 | 53.29 | 50.29 | 30.5 | 10.96 | 6.43 | 0 |
| | 2012 | **0.005** | 61.49 | 40.83 | 38.90 | 26.7 | 12.18 | 6.43 | 0 |
| | 2013 | **0.005** | 58.62 | 38.64 | 36.67 | 31.6 | 14.36 | 7.14 | 0 |
| Mapinduzi-Kilendu | 2011 | **0.038** | 72.69 | 53.29 | 50.29 | 30.5 | 10.96 | 6.43 | 0 |
| | 2012 | **0.008** | 61.49 | 40.83 | 38.90 | 26.7 | 12.18 | 6.43 | 0 |
| | 2013 | **0.009** | 58.62 | 38.64 | 36.67 | 31.6 | 14.36 | 7.14 | 0 |
| Muhunga | 2011 | **0.058** | 55.10 | 24.90 | 8.32 | 29.4 | 9.30 | 5.00 | 1 |
| | 2012 | **0.024** | 51.13 | 31.93 | 15.47 | 28.6 | 10.4 | 6.36 | 1 |
| | 2013 | **0.003** | 47.68 | 28.26 | 14.38 | 32.8 | 8.4 | 6.24 | 1 |

**Table 49: Continued**

| Test section | Year | Variables | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **GL (m)** | **P2** | **P0.425** | **P0.075** | **LL** | **PI** | **SL** | **Grad** |
| Kimalanongwa | 2011 | **0.063** | 80.25 | 67.40 | 48.68 | 23.3 | 7.44 | 4.29 | 0 |
| | 2012 | **0.007** | 76.16 | 62.68 | 42.16 | 33.7 | 8.62 | 5.71 | 0 |
| | 2013 | **0.027** | 70.26 | 58.18 | 38.28 | 26.8 | 9.54 | 7.32 | 0 |
| Mkwambilenga | 2011 | **0.068** | 45.41 | 36.05 | 27.02 | 42.6 | 16.91 | 8.57 | 0 |
| | 2012 | **0.056** | 40.24 | 34.64 | 28.09 | 37.1 | 14.39 | 7.14 | 0 |
| | 2013 | **0.043** | 42.63 | 33.76 | 28.67 | 32.6 | 13.82 | 7.41 | 0 |
| Pawaga SS | 2011 | **0.088** | 47.82 | 31.77 | 19.57 | 29.8 | 10.21 | 6.56 | 0 |
| | 2012 | **0.077** | 45.62 | 26.63 | 14.17 | 31.7 | 9.42 | 7.14 | 0 |
| | 2013 | **0.055** | 44.74 | 24.34 | 12.63 | 30.4 | 10.15 | 6.38 | 0 |
| Tagamenda | 2011 | **0.049** | 27.64 | 10.75 | 4.59 | 23.9 | 7.89 | 5.00 | 1 |
| | 2012 | **0.038** | 30.82 | 18.65 | 8.56 | 25.0 | 7.70 | 4.29 | 1 |
| | 2013 | **0.025** | 29.86 | 13.54 | 9.24 | 24.8 | 7.46 | 5.00 | 1 |
| Kitayawa | 2011 | **0.022** | 42.29 | 31.34 | 14.71 | 34.0 | 9.92 | 5.00 | 0 |
| | 2012 | **0.018** | 25.78 | 19.50 | 10.58 | 30.3 | 10.86 | 7.14 | 0 |
| | 2013 | **0.020** | 30.26 | 24.34 | 16.68 | 32.6 | 9.64 | 7.34 | 0 |
| Igula | 2011 | **0.039** | 42.29 | 31.34 | 14.71 | 34.0 | 9.92 | 5.00 | 0 |
| | 2012 | **0.041** | 25.78 | 19.50 | 10.58 | 30.3 | 10.86 | 7.14 | 0 |
| | 2013 | **0.023** | 30.26 | 24.34 | 16.68 | 32.6 | 9.64 | 7.34 | 0 |
| Ndiwili | 2011 | **0.012** | 52.06 | 44.29 | 30.07 | 27.8 | 7.53 | 5.71 | 0 |
| | 2012 | **0.008** | 50.21 | 36.43 | 29.09 | 38.4 | 9.79 | 5.00 | 0 |
| | 2013 | **0.014** | 58.64 | 39.56 | 27.28 | 42.0 | 17.00 | 8.57 | 0 |
| Italula/ Utengule | 2011 | **0.010** | 52.06 | 44.29 | 30.07 | 27.8 | 7.53 | 5.71 | 1 |
| | 2012 | **0.008** | 50.21 | 36.43 | 29.09 | 38.4 | 9.79 | 5.00 | 1 |
| | 2013 | **0.009** | 58.64 | 39.56 | 27.28 | 42.0 | 17.00 | 8.57 | 1 |
| Itwanga | 2011 | **0.004** | 43.29 | 35.58 | 21.67 | 47.3 | 13.98 | 7.86 | 0 |
| | 2012 | **0.004** | 39.85 | 32.08 | 18.82 | 40.8 | 15.36 | 8.57 | 0 |
| | 2013 | **0.003** | 42.65 | 34.32 | 19.24 | 37.4 | 12.88 | 7.14 | 0 |
| Amani | 2011 | **0.002** | 75.21 | 60.20 | 41.91 | 34.5 | 13.09 | 7.86 | 0 |
| | 2012 | **0.002** | 73.40 | 48.89 | 27.58 | 47.0 | 15.44 | 7.14 | 0 |
| | 2013 | **0.004** | 67.95 | 54.62 | 40.91 | 49.5 | 18.41 | 11.67 | 0 |
| Ilamba | 2011 | **0.004** | 75.21 | 60.20 | 41.91 | 34.5 | 13.09 | 7.86 | 0 |
| | 2012 | **0.003** | 73.40 | 48.89 | 27.58 | 47.0 | 15.44 | 7.14 | 0 |
| | 2013 | **0.003** | 67.95 | 54.62 | 40.91 | 49.5 | 18.41 | 11.67 | 0 |
| Don Bosco | 2011 | **0.029** | 60.85 | 36.84 | 30.61 | 34.6 | 12.82 | 7.15 | 0 |
| | 2012 | **0.025** | 69.44 | 41.15 | 30.34 | 36.8 | 10.44 | 10.23 | 0 |
| | 2013 | **0.027** | 63.30 | 41.38 | 32.54 | 32.2 | 11.24 | 9.17 | 0 |

**Table 50: Variables for formulating gravel loss model in terms of material characteristics, geology and climate**

| Test section | Year | Variables | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **GL (m)** | **CI** | **DR** | **PM** | **PP** | **Climate** | **Material Geology** |
| Mwika A | 2011 | **0.003** | 45.03 | 0.63 | 4.38 | 276 | Moderate | Quartizic |
| | 2012 | **0.003** | 21.59 | 0.64 | 6.16 | 395 | Moderate | Quartizic |
| | 2013 | **0.011** | 39.74 | 0.76 | 5.16 | 393 | Moderate | Quartizic |

**Table 50: Continued**

| Test section | Year | Variables | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **GL (m)** | **CI** | **DR** | **PM** | **PP** | **Climate** | **Material Geology** |
| Mwika B | 2011 | **0.030** | 45.03 | 0.63 | 4.38 | 276 | Moderate | Quartizic |
| | 2012 | **0.011** | 21.59 | 0.64 | 6.16 | 395 | Moderate | Quartizic |
| | 2013 | **0.030** | 39.74 | 0.76 | 5.16 | 393 | Moderate | Quartizic |
| Mangalali | 2011 | **0.012** | 43.02 | 0.75 | 4.32 | 322 | Moderate | Mudstone |
| | 2012 | **0.017** | 52.9 | 0.58 | 2.39 | 138 | Moderate | Mudstone |
| | 2013 | **0.022** | 37.17 | 0.42 | 4.04 | 170 | Moderate | Mudstone |
| Muhimbili | 2011 | **0.004** | 44.89 | 0.77 | 6.60 | 508 | Moderate | Quartizic |
| | 2012 | **0.041** | 59.74 | 0.67 | 4.98 | 332 | Moderate | Quartizic |
| | 2013 | **0.038** | 49.72 | 0.75 | 4.64 | 350 | Moderate | Quartizic |
| Nzihi | 2011 | **0.023** | 44.89 | 0.77 | 6.60 | 508 | Moderate | Quartizic |
| | 2012 | **0.012** | 59.74 | 0.67 | 4.98 | 332 | Moderate | Quartizic |
| | 2013 | **0.007** | 49.72 | 0.75 | 4.64 | 350 | Moderate | Quartizic |
| Nyamihuu | 2011 | **0.050** | 28.87 | 0.99 | 7.80 | 772 | Moderate | Lateritic |
| | 2012 | **0.037** | 17.37 | 0.99 | 7.96 | 792 | Moderate | Lateritic |
| | 2013 | **0.007** | 25.38 | 0.82 | 6.46 | 526 | Moderate | Lateritic |
| Kidete | 2011 | **0.025** | 32.95 | 0.99 | 7.53 | 743 | Moderate | Quartz pebbles |
| | 2012 | **0.009** | 40.01 | 0.99 | 6.88 | 678 | Moderate | Quartz pebbles |
| | 2013 | **0.004** | 47.74 | 0.91 | 6.05 | 549 | Moderate | Quartz pebbles |
| Mapinduzi | 2011 | **0.007** | 27.31 | 0.94 | 5.84 | 551 | Moderate | Quartz pebbles |
| | 2012 | **0.005** | 38.51 | 0.95 | 4.97 | 474 | Moderate | Quartz pebbles |
| | 2013 | **0.005** | 41.38 | 0.95 | 5.55 | 527 | Moderate | Quartz pebbles |
| Mapinduzi-Kilendu | 2011 | **0.038** | 27.31 | 0.94 | 5.84 | 551 | Moderate | Quartz pebbles |
| | 2012 | **0.008** | 38.51 | 0.95 | 4.97 | 474 | Moderate | Quartz pebbles |
| | 2013 | **0.009** | 41.38 | 0.95 | 5.55 | 527 | Moderate | Quartz pebbles |
| Muhunga | 2011 | **0.058** | 44.9 | 0.33 | 2.32 | 77 | Dry | Ferruginous siltstone |
| | 2012 | **0.024** | 48.87 | 0.48 | 3.32 | 161 | Dry | Ferruginous siltstone |
| | 2013 | **0.003** | 52.32 | 0.51 | 2.37 | 121 | Dry | Ferruginous siltstone |
| Kimalanongwa | 2011 | **0.063** | 19.75 | 0.72 | 5.01 | 362 | Dry | Lateritic |
| | 2012 | **0.007** | 23.84 | 0.67 | 5.40 | 363 | Dry | Lateritic |
| | 2013 | **0.027** | 29.74 | 0.66 | 5.55 | 365 | Dry | Lateritic |
| Mkwambilenga | 2011 | **0.068** | 54.59 | 0.75 | 6.10 | 457 | Dry | Limestone + Quartizic |
| | 2012 | **0.056** | 59.76 | 0.81 | 4.98 | 404 | Dry | |
| | 2013 | **0.043** | 57.37 | 0.85 | 4.67 | 396 | Dry | |
| Pawaga SS | 2011 | **0.088** | 52.18 | 0.62 | 3.24 | 200 | Dry | Quartizic |
| | 2012 | **0.077** | 54.38 | 0.53 | 2.51 | 133 | Dry | Quartizic |
| | 2013 | **0.055** | 55.26 | 0.52 | 2.47 | 128 | Dry | Quartizic |
| Tagamenda | 2011 | **0.049** | 72.36 | 0.43 | 0.85 | 36 | Moderate | Quartizic |
| | 2012 | **0.038** | 69.18 | 0.46 | 1.44 | 66 | Moderate | Quartizic |
| | 2013 | **0.025** | 70.14 | 0.68 | 1.01 | 69 | Moderate | Quartizic |
| Kitayawa | 2011 | **0.022** | 57.71 | 0.47 | 3.11 | 146 | Moderate | Quartizic |
| | 2012 | **0.018** | 74.22 | 0.54 | 2.12 | 115 | Moderate | Quartizic |
| | 2013 | **0.020** | 69.74 | 0.69 | 2.35 | 161 | Moderate | Quartizic |

**Table 50: Continued**

| Test section | Year | Variables | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **GL (m)** | **CI** | **DR** | **PM** | **PP** | **Climate** | **Material Geology** |
| Igula | 2011 | **0.039** | 57.71 | 0.47 | 3.11 | 146 | Moderate | Quartizic |
| | 2012 | **0.041** | 74.22 | 0.54 | 2.12 | 115 | Moderate | Quartizic |
| | 2013 | **0.023** | 69.74 | 0.69 | 2.35 | 161 | Moderate | Quartizic |
| Ndiwili | 2011 | **0.012** | 47.94 | 0.68 | 3.34 | 226 | Wet | Quartizic |
| | 2012 | **0.008** | 49.79 | 0.80 | 3.57 | 285 | Wet | Quartizic |
| | 2013 | **0.014** | 41.36 | 0.69 | 6.73 | 464 | Wet | Quartizic |
| Italula/ Utengule | 2011 | **0.010** | 47.94 | 0.68 | 3.34 | 226 | Wet | Quartizic |
| | 2012 | **0.008** | 49.79 | 0.80 | 3.57 | 285 | Wet | Quartizic |
| | 2013 | **0.009** | 41.36 | 0.69 | 6.73 | 464 | Wet | Quartizic |
| Itwanga | 2011 | **0.004** | 56.71 | 0.61 | 4.97 | 303 | Wet | Quartizic |
| | 2012 | **0.004** | 60.15 | 0.59 | 4.93 | 289 | Wet | Quartizic |
| | 2013 | **0.003** | 57.35 | 0.56 | 4.42 | 248 | Wet | Quartizic |
| Amani | 2011 | **0.002** | 24.79 | 0.70 | 7.88 | 549 | Wet | Quartizic |
| | 2012 | **0.002** | 26.6 | 0.56 | 7.55 | 426 | Wet | Quartizic |
| | 2013 | **0.004** | 32.05 | 0.75 | 10.06 | 753 | Wet | Quartizic |
| Ilamba | 2011 | **0.004** | 24.79 | 0.70 | 7.88 | 549 | Wet | Quartizic |
| | 2012 | **0.003** | 26.6 | 0.56 | 7.55 | 426 | Wet | Quartizic |
| | 2013 | **0.003** | 32.05 | 0.75 | 10.06 | 753 | Wet | Quartizic |
| Don Bosco | 2011 | **0.029** | 39.15 | 0.83 | 4.72 | 392 | Moderate | Quartizic |
| | 2012 | **0.025** | 30.56 | 0.74 | 4.30 | 317 | Moderate | Quartizic |
| | 2013 | **0.027** | 36.7 | 0.79 | 4.65 | 366 | Moderate | Quartizic |

### 7.3.6 Gravel loss modelling

The modelling exercise of gravel loss is based on the methodology as explained in section 4.4.9. The final modelling Equation was the results of Equation 14 as per Cameron and Trivedi (2010:257).

#### 7.3.6.1 Descriptive statistics

Descriptive statistics assists in understanding the variation within and between the variables in question. The properties of interest are the variables' mean, minimum value, maximum value, and standard deviation. These descriptive statistics are presented in Table 51.

**Table 51: Descriptive statistics for variables used in formulation of the gravel loss prediction model**

| Variable | Relation | Mean | Std. Dev. | Min | Max | Observations |
|---|---|---|---|---|---|---|
| GL | overall | 0.0224697 | 0.0204565 | 0.002 | 0.088 | N = 66 |
| | between | | 0.0176109 | 0.0026667 | 0.0733333 | n = 22 |
| | within | | 0.0108566 | -0.002864 | 0.0531364 | T = 3 |
| ADT | overall | 184.7424 | 227.5077 | 15 | 1213 | N = 66 |
| | between | | 230.1757 | 17.33333 | 1146.333 | n = 22 |
| | within | | 20.2259 | 67.40909 | 251.4091 | T = 3 |
| PF | overall | 6.59803 | 2.789556 | 0.74 | 12.72 | N = 66 |
| | between | | 2.478208 | 1.823333 | 10.13 | n = 22 |
| | within | | 1.352436 | 2.56803 | 11.93803 | T = 3 |
| DR | overall | 0.7039394 | 0.1590344 | 0.33 | 0.99 | N = 66 |
| | between | | 0.1465065 | 0.44 | 0.9633333 | n = 22 |
| | within | | 0.0669941 | 0.5406061 | 0.8706061 | T = 3 |
| PM | overall | 4.888485 | 2.013313 | 0.85 | 10.06 | N = 66 |
| | between | | 1.889154 | 1.1 | 8.496667 | n = 22 |
| | within | | 0.7709342 | 3.681818 | 7.071818 | T = 3 |
| PP | overall | 360.6818 | 189.8288 | 36 | 792 | N = 66 |
| | between | | 178.634 | 57 | 696.6667 | n = 22 |
| | within | | 71.46116 | 190.0152 | 537.6818 | T = 3 |
| D1 | overall | 0.2272727 | 0.4222815 | 0 | 1 | N = 66 |
| | between | | 0.428932 | 0 | 1 | n = 22 |
| | within | | 0 | 0.2272727 | 0.2272727 | T = 3 |

Since the data have both cross-sectional and time series characteristics, then the variables varied both over time and over individuals. The variation over time of a given individual is termed as within variation while variation across individuals is termed as between variations. The time invariant variables have zero within variation while the individual invariant variables have zero between variations. Thus, from Table 51, DI is the climate dummy, which is time invariant and there are no individual invariant variables.

### 7.3.6.2 Correlation coefficient analysis

The direction as well as the strength of the relationship between the variables can be obtained through calculating their correlation coefficients. A correlation coefficient indicates the strength of a relationship between two or more variables (Koutsoyiannis 2001:31-32). He further asserts that correlation coefficient may be linear or nonlinear. Table 52 shows the correlation between the variables used in formulation of the gravel loss prediction model. The correlation between variables may be positive, negative, or zero. When the correlation is positive, the variables tend to be both high or be both low. When the correlation is negative, one tends to be high and the other low (Schmidt 2005:47). As shown in Table 52, only the average daily traffic has a positive relationship with gravel loss. All other variables show negative relationship with gravel loss. Correlation coefficient does not distinguish independent from dependent variables, and is not affected by changes in the unit of measurement of either or both variables (Moore and McCabe 1989:199). The existence of a strong correlation does not imply a causation effect. It only indicates the tendencies present in the data (Levine *et al.*2008:130)

**Table 52: Correlation between the variables used in formulation of the gravel loss prediction model**

| Variables | GL | ADT | PF | DR | PM | PP | D1 |
|---|---|---|---|---|---|---|---|
| GL | 1.0000 | | | | | | |
| ADT | 0.0264 | 1.0000 | | | | | |
| PF | -0.3367 | -0.0495 | 1.0000 | | | | |
| DR | -0.1835 | 0.0444 | 0.6556 | 1.0000 | | | |
| PM | -0.3479 | -0.1461 | 0.8225 | 0.5297 | 1.0000 | | |
| PP | -0.2735 | -0.1170 | 0.8428 | 0.7837 | 0.9259 | 1.0000 | |
| D1 | -0.4400 | -0.2200 | 0.3019 | -0.1006 | 0.3484 | 0.1604 | 1.0000 |

### 7.3.6.3 Empirical findings and discussion

The model adopted to explain marginal gravel loss was based on panel data, whereby the data to explain the gravel loss was collected across roads and over time.

To start with, the gravel loss was estimated using RE estimation and the result is as shown in the second column of Table 53. The RE model was preferred to the FE model based on the results of the Hausman test.

**Table 53: Regression results for random effect, population average and SPSS**

| Variables | Random effect | Population average | SPSS |
|---|---|---|---|
| ADT | 0.000000897 | 0.000000694 | 0.0000159 |
| PF | 0.0000268 | 0.0000135 | -0.001 |
| DR | -0.127*** | -0.124*** | -0.121*** |
| PM | -0.0174*** | -0.0169*** | -0.023*** |
| PP | 0.000236*** | 0.000229*** | 0.0002*** |
| D1 | -0.0142 | -0.0144* | -0.014** |
| Constant | 0.115*** | 0.113*** | 0.127*** |
| N | 66 | 66 | 66 |

Notes: *** denotes significant at 1%, ** denotes significant at 5%, and
* denotes significant at 10%

From the Hausman test, the probability value was 0.8637, which was greater than the significance level at 5% (Appendix 12). The result implied that the estimators were not significantly different and therefore, one could be better off using the RE model. However, according to Cameron and Trivedi (2010:257), if the Hausman test rejects the FE model and accepts the RE model, the best method to obtain consistent estimators is to use population average (PA) regression. The estimation results of the PA are shown in the third column of Table 53. The fourth column present the SPSS estimates.

#### 7.3.6.4 Estimated gravel loss model

The estimates results in Table 54 column three are summarized by the regression in Equation 23.

**Equation 23:** $$GL = [0.113 + 0.000000694\,ADT + 0.0000135\,PF - 0.124DR - 0.169PM + 0.000229PP - 0.0144D_1]\ mm$$

Where GL is the annual gravel loss in mm, ADT is average daily traffic in both directions, PF is plasticity factor in percentage, DR is dust ratio, PM is plasticity modulus in percentage, PP is plasticity product in percentage, and $D_1$ is a dummy variable which represents climatic condition. $D_1$ = wet climate, and $D_0$ = dry or moderate climate.

**Table 54: The GL analysis of variation**

| Model | Sum of squares | Degree of freedom | Mean square | R square | F Statistic | Significance |
|---|---|---|---|---|---|---|
| Regression | 0.008 | 6 | 0.001 | 0.300 | 4.112 | 0.002 |
| Residual | 0.019 | 59 | 0.000 | | | |
| Total | 0.027 | 65 | | | | |

From table 54 it is noted that, the model is statistically significance at 1% and coefficient of determination ($r^2$) is 0.3.

### 7.3.6.5 Interpretation of the results

From Table 53, Variables DR, PM, PP are highly significant at 1% significance level, whereas climatic dummy variable (D1) is significant at 10% level.

The value of the constant term ($\beta_0$) is 0.113 implying that when the independent variables ADT, PF, DR, PM, PP and $D_1$ are not contributing to gravel loss, the loss will be equal to 0.113mm. This can be attributed to variables not related to those addressed by an error term, such as erodibility characteristics of soil and weathering effects. The ADT and PF parameters are not significant in explaining the gravel loss, but their presence is vital so as to avoid bias due to omitted variables. It is noted further that GL decreases by 0.124 mm and 0.0169 mm for each unit increase in DR and PM respectively. However, GL increases by $6.94 \times 10^{-7}$ mm, $1.35 \times 10^{-5}$mm, and $2.26 \times 10^{-4}$ mm for every unit increase in ADT, PF and PP respectively.

Gravel roads located in wet area experiences a GL of about 0.0144 mm less than the roads located either in moderate or dry areas if all other factors remain constant. The GL is statistically significant at 1% and its coefficient of determination ($r^2$) is 0.3.

Except fro the signs of ADT, PM and $D_1$ parameters which tally with those hypothesized in Chapter 4, the signs for PF, DR, and PP did not tall with those hypothesized. These differences in signs do not invalidate the model, but only tells the relationship between dependent and independent variables.

#### 7.3.6.6 Statistical significance

A significance test is a procedure by which sample results are used to verify the truth or falsify a null hypothesis (Moore and McCable 1989:465; Gujarati 2014:132). It is based on a test statistic that indicates whether or not the data set give evidence against the null hypothesis. The actual probability of obtaining a value of the test statistic is termed p-value (probability value) which is defined as the lowest significance level at which a null hypothesis can be rejected (Gujarati 2014:140). Significance in statistical sense implies that the evidence against the null hypothesis has reached the standard set by α (Moore and McCable 1989:468). If the p-value is as small as or smaller than α, we say that the data are statistically significant at level α (Moore and McCable 1989:468). Thus a formulated gravel loss prediction model depicted in Equation 23 is statistically highly significance at 1% level, as p which is equal to 0.002 is less than α at 1% level.

#### 7.3.6.7 Coefficient of determination ($r^2$)

The coefficient of determination ($r^2$) measures the proportion of variation in gravel loss that is explained by the independent variables in the regression model (Levine *et al*. 2008:526). $r^2$ is fundamentally a property of the linearity of the data, it measure how well the regression line predicts the data (Schmidt 2005:111). $r^2$ will always lie between 0 and 1 no matter what the units of dependent variable may happen to be. The coefficient of determination does not say anything about how close the estimated values of parameters are to their true values, and it cannot be used to say whether parameters are good estimates or not. According to Schmidt (2005:112) there are regressions with very high $r^2$ but very poor estimates of parameters, and conversely, there are regressions with very low $r^2$ but with excellent estimates of parameters.

Schmidt is of opinion that dependent variables which has many explanatory variables are hard to predict as their have very large error terms and residuals, which results in small $r^2$**.** The changing nature of gravel roads performance under the influence of natural and human made variables affects the predictability of the defects significantly. It is thus expected that gravel loss models will have a significant variability and consequently relatively low regression coefficients. This was the case with Brazilian and New Zealand gravel loss models which had a very low $r^2$ as were noted in Chapter 2. From the above discussion, it follows that the model formulated by this study can be used to predict the gravel loss for Iringa region condition inspite of its low $r^2$.

### 7.4 Conclusion and recommendations

This chapter tried to relate the physical characteristics and geology of gravel materials employed to surface tests sections under study with prevalent distress noted during the condition survey. The study noted that marginal materials employed for surfacing gravel roads, particular in Iringa region, all passed the 37.5 mm sieve criteria at 100%. This was the case too for SP, which has a wide range to accommodate marginal gravel materials. But most of these materials do not meet the criteria of GC. Apart from this anomaly, these materials are being used in surfacing gravel roads, disregarding TZ-MoW (1999) and TZ-MoW (2000) manual and specification on GC, and still perform relatively well.

There is total disregard of specification on particle size distribution, as the nominal particle size noted at test sections varied with the source borrow pit. Test sections with stoniness embedded or loose materials reflect the type and characteristics of gravel materials employed as wearing course.

The riding quality/safety for gravel roads alignment in the study ranged from 70 to 20 km/h, where 70 is very good, 60 good, 50 average, 30 poor, and 20 very poor. The aforementioned riding quality/safety range, as proposed by this study, are based on the fact that gravel roads geometrical features which govern the safety speed, e.g. curves, super-elevation, and safe sight distances are either not designed to cater for speed above 70 km/h or are not designed at all.

It is not always that the maintenance funds available are inadequate, but sometimes even the calculation of the funds required for adequate maintenance is not being done professionally. This may be due to the fact that condition survey and performance studies are not being properly conducted. From the condition survey visit conducted on unsealed roads under question, it was clear that:

- The surface conditions of the tests sections and the entire stretch of road network may change from 0 to 5 degree of severity within three months. This is a clear indication that maintenance being conducted does not adhere to the proper methodology and is inadequate to the need.
- Apart from material characteristics, terrain, surrounding vegetation and alignment play a role in influencing negatively or positively the degree and extent of distress. In general, vegetation impedes flow of rainwater and hence controls erosion.

The sections for performing the condition and gravel loss surveys should be randomly selected to cover the entire stretch of gravel road network and be permanent. This will aid in understanding and predicting the performance of network segments and vary maintenance activities. Furthermore, it will aid in producing realistic maintenance budget. Any changes on gravel material sources or improvement in construction technology, alignment and maintenance activities necessitate a new test site selection and condition or gravel loss survey.

Seasonal effect on the rate of gravel loss was not noticed in this study, although this observation does not imply that it should not be taken into consideration during scheduling gravel loss surveys. Negative gravel loss, which implies an increase in gravel road height, was attributed to raveling. The study noted that gravel loss was higher in dry climates, followed by moderate and wet climates. The climate factor was in turn modified by traffic and marginal material characteristics.

The study did not reveal a consistent range of gravel loss. This might be attributed to either gravel material characteristics or inconsistent quality in construction and maintenance procedures.

In using econometric principles of modeling, it is not the number of profile height surveyed, which matter most. It is the duration of study and number of test sections randomly selected which give the number of observations. In this study the number of observations (N) was 66 as noted in Table 51 and 53.

The term pavemetric as introduced in this study is synonymous with econometric when it comes to statistical or mathematical methods employed in modelling. Pavemetrics is the study of the application of statistical methods to pavement problems, while econometrics is the study of the application of statistical methods to economic problems.

# CHAPTER 8

# SUMMARY OF FINDINGS, CONCLUSION, AND RECOMMENDATIONS

## 8.1 Summary of findings

This study recommends a change in the GC range to 23-72 inclusive for marginal materials, as it is more accommodating for gravel roads covered by the study. The current range, as provided by TZ-MoW (1999:11.3), is 12-34. This recommendation is based on the fact that despite the said materials deviating from the specification, they performed relatively well. This was observed during the condition survey.

The results of GM for sampled gravel materials in the Iringa region have shown that the grading modulus of below 2.0 indicates that the dominate particle size distributions are fine, and above 2.0 are coarser

The gravel loss study has a small window frame in which it will register positive changes of elevation with each subsequent visit, until its profile is approaching flat. Then it will either register a negative or positive gain in elevation depending on the position to which the levelling staff is positioned and the condition of gravelling materials. Hence a gravel loss study is not a long-term study, unless the road in question is receiving timely maintenance. In such cases, the best practice is to start afresh after grading or re-gravelling has been performed, and stop once the condition survey, register 3 degree of severity for any gravel loss associated distress on any of the gravel roads under study.

The study has proven further that a modelling exercise can be performed locally by using variables obtained or derived from materials test results, such as consistency and particle size distribution.

This study proposes gravel loss threshold values at which the quality of construction and maintenance activities can be judged as shown in Table 47. The application of these thresholds necessitates setting a liability period of one year after construction or major maintenance of gravel road wearing course, which hitherto is set at three months. During this period the road will be visited four times in three-month intervals to conduct gravel loss surveys and at the end of the year the rate of gravel loss per annum will be pegged with the threshold valued to judge the quality of work performed. This will also go a long way to curb corruption which involves cheating regarding the quality of finished thickness of gravelling layer.

This study has formulated a model for predicting gravel loss as shown in Equation 23. The model is appropriate for Iringa region condition and is stastistically significant at 1%.

## 8.2 Summary of the conclusion

For any pavement type or network, a proper inventory of the pavement conditions must be kept and effectively put into use to determine the time and order in which the different sections should be maintained or rehabilitated. The reasons behind this are that: there are not enough funds for maintaining all the roads in a network at the same time, road segments deteriorate at different rates and the consequence of this is they are in different conditions at any one specific time, and it is paramount to catch the pavement at the most appropriate conditions for remedial action to be effective and economical.

A gravel loss prediction model is effective when accompanied by a dynamic GRMS, and MMS; short of this, other distress such as ruts and erosion gullies will accelerate the gravel loss beyond the models predicting capacity. The model has to tally with the local road organisations and social economic power. There is a need for political will to be ready to allocate funds and sincerely implement the budget for these models to become an effective tool in predicting the future condition needs and the nature of remedial actions.

It has been stressed that the use of a gravel loss prediction model developed from different geographical, climate, economic and political environments can not adequately address the local condition. During the formulation of gravel loss prediction model, there is a need to study the interaction between the local climatic condition, the traffic characteristics, construction and maintenance standards which are specific to individual localities and which change across space. Furthermore, for GRMS software to be successful during its implementation, it is highly advised to localise the exercise during its formulations as far as this is practicable. Where there is a strong desire to look for external expertise, it has to be combined with the local team at the ratio of one external expert to three local engineers.

The capacity of each road organization, in terms of knowledge and skills, should equal the task and working environment in which they are operating GRMS. There is a strong urge for pavement engineers to lobby politicians in the concerned areas so as for them to create interest in matters affecting gravel road performance.

Even though the allocation of funds to the road sector has not improved and is grossly inadequate in relation to the needs that should not be an excuse not to:

- Implement maintenance management system,
- Use better and effective road construction and maintenance machinery,
- Adopt better and locally appropriate pavement maintenance techniques, and
- Ensure accountability on the part of road agency involved with the supervision of road construction and maintenance.

Quality of data being collected during empirical research on the performance of gravel roads should not be a variable to contend with for results to be valid.

It is further advised that in order to make the effective utilization of available funds, there is a need to improve institutions looking after gravel roads in terms of: planning and design practices, construction and maintenance methods, and contract administration. Private sector has to be encouraged to participate in highway maintenance and expenditure controls. Without an adequate road conservation system appropriate to local condition, significant natural resources are wasted, and the environment is damaged.

The design life concept is purely a probability phenomenon. It has a number of variables which have to be fulfilled for the designated design life to be attained. Instead of having a generalised concept that all gravel roads will have the same designated design life, there is a need for modelling exercise to determine what shall be a predicted design life of the gravel road in question. The actual design life can be hypothesized during design stage and determined after construction stage.

Challenges still exist in attempting to convince local road agencies to participate in any endeavour to improve the GRMS locally. This force one to conclude that implementing or adopting a new formulated gravel loss predicting model or maintenance policy for most sub Saharan African countries will remain academic exercise until there are government commitment, management ability, staff quality, accountability, and incentives.

## 8.3 Recommendations

The following recommendations are offered for consideration and implementation.

- For gravel loss prediction models to be effective and efficient in maintenance management of gravel roads, they have to be dynamic and reflect local material's characteristics, traffic characteristics, user behaviour, climatic changes, and advances in gravel road design, construction, and maintenance technology.

- Survey team and equipment, and methods of collecting and data analysis used for formulating gravel loss prediction models have to be consistent.

- Empirical studies should address areas of similar geographical features and climate to address the characteristic variation within marginal gravel and sub grade materials. The study should reflect as far as it is practical the variability within the same local materials used in surfacing the unsealed roads.

- The quality of work at the construction stage and subsequent maintenance operations has to be standardized through a working document for them to be consistently implemented and be reflected in the gravel loss prediction models.

- Transparency in addressing the root causes of gravel road deterioration is a necessary condition for an optimal allocation of maintenance funds.

- Changes in road user behaviour associated with the vehicle technological innovation and the effect of vehicle manoeuvres resulting in shearing movements of granular wearing course materials have to be independently studied and quantified to be incorporated in either gravel loss models or condition surveys.

- The capacity of road organization in question to collect data on gravel road performance, which are relevant to the model in question, should be reflected in the gravel road deterioration prediction models for them to be effective management tools.

- The collection of rainfall data should be localised in order to maximise the reliability of rainfall data for specific localities, for its influence on gravel roads performance in affected areas to be studied and incorporated in gravel road deterioration models or to be noted during the condition survey. At the same time compilation of statistics on gravel road condition is essential if countrywide trends are to be detected and reliable judgements made about the relative performance of each region gravel road network.

- Road organizations should constantly study the environment in which they work to improve and maintain the quality of the performance of the gravel road networks under their management within their financial limitations.

- The modelling exercise for prediction of pavement performance has been simplified by the numbers of modelling software package currently in existent, such as Microsoft Excel, SPSS and STATA, just to mention a few. This study encourage local road agencies in sub Sahara countries to model the distress data they collect annually through gravel road condition survey so as to improve further the GRMS of their gravel road networks.

- Despite unsealed roads being the earliest roads in the history of humankind, and despite vast accumulated experience in their construction and maintenance, the provision of surface layer gravel materials is still largely based on thumb rule. Thus, research is required to provide consistency and scientifically sound policy regarding the design thickness of unsealed roads for sub-Sahara Africa countries. Only describing the required CBR for subgrade so as to provide a cover of 150 or 200 mm thickness gravelling material does not take into account the different physical characteristics of gravel materials and their performance under the expected traffic volume and climate as has been noted by this study.

- Further research work should look at the effects of vertical and horizontal curves and horizontal grades on the rate of marginal gravel loss. Research also should be directed in launching and promoting pavemetric to a level enjoyed by econometric.

- More local based research needs to be conducted to map the type of GRMS appropriate for the current environment in sub-Sahara Africa. In addition, research to identify factors influencing gravel road deterioration and the effects of different maintenance processes should be substantially strengthened and refined.

# REFERENCES


*Advanced learner`s dictionary of current English*. 2000. 6th ed. Oxford: Oxford University Press.

*Dictionary of contemporary English for advanced learners*. 2009. 5th ed. Harlow: Pearson Education.

Aggarwal, S., Jain, S. S. and Parida, M. 2003. *Development of pavement management system for Indian national highway network*. Roorkee: Roorkee Institute of Technology.

Alzubaidi, H. and Magnusson, R. 2002. *Deterioration and rating of gravel roads. state of art* (online). Available: www.tandfonline.com. (Accessed 15 September 2014).

American Association of State Highways and Transportation Officials. 2009. *Standard specification for transportation materials and method of sampling and testing*. 29th ed. Washington D.C.: AASHTO.

Anastasopoulos, P. C., Mannering, F. L. and Haddock, J. E. 2009. *Effectiveness and service lives/survival curves of various pavement rehabilitation treatments*. West Lafayette, Indiana: Indiana Department of Transportation and Purdue University.

Anderson, C., Beusch, A., and Miles, D. 1996. *Road maintenance and re-gravelling (ROMAR) using labour-based method*. London: Intermediate Technology Publications.

Austin, L. M. and Burns, J. R. 1985. *Management science: an aid for managerial decision making*. New York: Macmillan Publishing.

AUSTROADS. 1987. *A guide to the visual assessment of pavement condition*. Sydney: AUSTROADS.

Awadhi, A., and Starkey, P. 2007. *A rapid assessment of rural transport services in Iringa region, Tanzania*. Dar es Salaam: Practical Action Consulting.

Beenhakker, H. L., Carapetis, S., Crowther, L., and Hertel, S. 1987. *Rural transport services: A guide to their planning and implementation*. London: Intermediate technology publications.

Bless, C. and Smith, C. H. 2013. *Fundamentals of social research methods: An African perspective*. 5th ed. Johannesburg: Juta Education.

Brazilian Transportation Planning Agency (GEIPOT) and United Nations Development Programme (UNDP). 1981 (Digitised in 2012). *Research on the interrelationships between the cost of highway construction, maintenance and utilization – Study of pavement maintenance and deterioration*. Brasilia: GEIPOT.

Buckley, J. W., Buckley, M. H., and Chiang, H. 1976. *Research methodology and business decisions*. New York: National Association of Accountants.

Byers, H.R. 1974. *General meteorology*. 4th ed. New York: McGraw Hill.

Cameron, A. C. and Trivedi, P. K. 2010. *Micro econometrics using Stata*. Texas: Stata press.

Department of Transport, Republic of South Africa. 1989. Draft urban transport guidelines (UTG) 6: Maintenance management for large municipalities. Pretoria: Department of Transport-Committee of Urban Transport Authority.

Dierks, K. 1992. Technical aspects for appropriate low-volume roads in Namibia.PhD thesis, Technical University of Berlin.

Dawson, A. 2011. Unsealed highway construction. In: Walsh, I.D., Hunter, R.N., Darral, L., Matthews, P., Jameson, P. and Thorp, J. ed. *Institution of Civil Engineer manual of highway design and management.* London: ICE Publishing, 395-406.

Durban University of Technology (DUT). 2014. Post graduate student guide. Durban: Research and postgraduate support.

Ele International. 2009. *Construction materials testing equipment* 12th ed. England: Ele International.

Ellis, C. I. 1979. *Pavement engineering in developing countries.* Crowthorne: Transport and Road Research Laboratory.

Fay, Spofford and Thorndike Engineers- Planners- Scientists. 2009. *Pavement management system Spencer, Massachusetts*: Town of Spencer office of Utilities and Facilities.

Fellows, R. and Liu, A. 2008. *Research methods for construction*. 3rd ed. Oxford : Wiley- Blackwell Science.

Garber, N.J. and Hoel, L.A. 2014. *Traffic and highway engineering*.5th ed., Canada: Cengage Learning.

Geweke, J., Horowitz, J. and Pesaran, H.P.2008. *Econometrics* (online). Available: http:// en.wikipedia.org/wiki/econometric (Accessed 20 October 2013).

Gichaga, F. J. and Parker, N. A. 1988. *Essentials of highway engineering with reference to warm climates*. London: Macmillan Publishers.

Giummarra, G. J., Martin, T. C. and Choummanivong, L. 2004. Establishing deterioration models for local roads in Australia, In: *6th International Conference on Managing Pavements*. Sydney, 2004. Sydney: Australian Road Research Board.

Government of Western Australia. Australia, M. R. W. 2008. *Statistically based quality control for density in road construction*. Western Australia: Materials Engineering Branch.

Green, W. H. 2012. *Econometric analysis*.7th ed. Upper Saddle River, New Jersey: Pearson Education.

Greenberg, E. 2013. *Introduction to Bayesian econometrics*. 2nd ed. New York: Cambridge University Press.

Greening, T., Sahle, D., Morosiuk, G., Mukura, K. and Elsworth, N. 2006. *Increased application of labour-based methods through appropriate engineering standards: Uganda country report*. Mauritius: International Labour Organization.

Gujarati, D. N. 2014. *Basic econometrics*.5th ed. New York: McGraw.

Harral, C. and Faiz, A. 1988. *Road deterioration in developing countries: causes and remedies*. Washington D.C: The International Bank for Reconstruction and Development/The World Bank.

Hassing, J. M. 1996. Hydrology. In: Thagesen, B. ed. *Highway and traffic engineering in developing countries*. London: E&FN Spon, 167-180.

Henning, T., Giummarra, G. and Brass, J. 2007. Development of gravel loss and other condition performance models for unsealed roads. In: *Low Volume Roads Workshop*. 18th -20th July. Road Engineering Association of Asia and Australasia (NZ).

Henning, T. F. P., Giummarra, G. J. and Roux, D. C. 2008. *The development of gravel deterioration models for adoption in a New Zealand gravel road management system*. Wellington: Land Transport New Zealand.

Henrrink, M., Hutter, I. and Bailey, A. 2011. *Qualitative research methods*. Los Angeles: Sage.

Holt, D. G. 1998. *A guide to successful dissertation study for students of the built environment.* 2nd ed. West midlands: The Built Environment Research Unit, University of Wolverhampton.

Huang, Y.H. 2012. *Pavement analysis and design*. 2nd ed. Upper Saddle River, New Jersey: Pearson Education International.

Jones, D. and Paige-Green, P. 2011. *TMH 12: Pavement management systems: Standard visual assessment manual for unsealed roads (SANS 3012).* Pretoria: CSIR Transportek.

Jones, T. E. 1984. *The Kenya maintenance study on unpaved roads: Optimum maintenance strategies*. Crowthorne: Transport and Road Research Laboratory.

Katula, J. and Toole, T. 2000. Road Management System-The development of the Road Mentor System in Tanzania.In: *Annual Roads Convention*. Dar es Salaam, 2000. Dar es Salaam: Tanzania Roads Association.

Kendrick, P., Copson, M., Beresford, S. and McCormick, S. 2004. *Roadwork: theory and practice*. 5th ed. Oxford: Heinemann.

Kenny, C. 2007. Construction, corruption and developing countries. World Bank: Policy Research Working Paper, (1) 1. Report No. WPS 4271.

Kerlinger, F. N. 2007. *Foundations of behavioural research*. 4th ed. Chicago: Holt, Rinehart and Winston.

Khanna, S. K. and Justo, C. E. G. 1982. *Highway material testing: Laboratory manual.* 3rd ed. Roorkee: Nem Chand & Bros.

Kothari, C.R. 2013. *Research methodology: methods and techniques.* 2nd rev. ed. New Delhi: New Age International Publishers.

Koutsoyiannis, A. 2001. *Theory of econometrics: an introductory exposition of econometric method*. 2nd ed. Hampshire: Palgrave Publisher.

Kuennen, T. 2009. Manage your unpaved roads for best value, performance. *Road science, better roads* (online). Available: www.americanbusinessmedia.com/images/abm/pdfs/events/neal_library/Better Roads—Class A lot 5.pdf (Accessed 06-August 2014).

Larsen, H. J. E., Hildebrand, G. and Macdonald, R. A. 2002. *Economic evaluation of pavement maintenance*. Denmark: Danish Road Institute.

Lay, M. G. 2009. *Handbook of road technology: Planning and Pavements*.4th ed. Amsterdam: Gordon and Breach Science Publications.

Leedy, P. D. and Ormoud, J. E. 2014. *Practical research: Planning and design*. 10th ed. Upper Saddle River, New Jersey: Prentice Hall.

Levine, D. M., Stephen, D.F., Krehbiel, T.C., and Berenson, M.L. 2008. *Statistics for managers using Microsoft Excel*. 5th ed. Upper Saddle River, New Jersey: Pearson Prentice Hall.

Madanat, S. 1987. Predicting pavement deterioration. *Institute of Transportation Studies*, 20 (3): 2.

Mallick, R.B. and El-Korchi, T. 2009. *Pavement engineering: principles and practice.* Parkway New York: CRS Press.

McCarthy, D.F. 2007. Essential of soil mechanics and foundation: basic geotechnics. 7th ed. Upper Saddle River, New Jersey: Pearson Prentice Hall.

McKinlay, D. G. 1988. Soils In: Jackson, N. and Dhir, R. K. eds. *Civil engineering materials*. 4th ed. Basingstoke: Macmillan Education.

Michigan Technological University. 2014. *Pavement condition survey*: *module 5* (online). Available: www.cce.mtu.edu/ce 504/Lec 4A.pdf (Accessed 01-October 2014).

Moore, D.S. and McCabe, G.P. 1989. Introduction to the practice of statistics. New York: W.H. Freeman.

Morris, J.M. 1990. *Earth roads: A practical manual for the provision of access for agricultural and forestry projects in developing countries*. Bedford: Canfield Press.

Morse, A. A. and Green, R.L. 2012. Pavement design and rehabilitation. In: Brockenbrough, R. L. and Boedecker JR, K.J. ed. *Highways Engineering Handbook; The building and rehabilitating the infrastructure*.3rd ed. New York: McGraw-Hill, 3.50-3.53.

Murphy, K.J. 2014. *Econometrics* (online). Available www.referencefor business. com/encyclopedia/Dev-Eco/Econometrics.html (Accessed 30-October-2014).

Mwaipungu, R. R. and Allopi, D. 2011. The use of longitudinal roughness data as a tool for effective maintenance management of gravel roads. In: *30th Annual Southern African Transport Conference*. CSIR, Pretoria, July 11-14 2011. Pretoria: Southern African Transport Conference (SATC).

Mwaipungu, R.R. and Allopi, D. 2012a. Review of sub-Sahara Africa gravel roads management system: Tanzania case study. In: Longhurst, J.W.S. and Brebbia, C.A. ed. *18th International conference on urban transport and the environment; urban transport and the environment in 21st century*. La Coruna, Spain. 11-12 May 2012. Southampton: WIT, 629-640.

Mwaipungu, R. R. and Allopi, D. 2012b. The use of gravel loss prediction models for effective management of gravel roads. In: *31st Annual Southern African Transport Conference*. CSIR, Pretoria, 9-12 July 2012. Pretoria: SATC.

Mwaipungu, R. R. and Allopi, D. 2014. The sustainability of gravel roads as depicted by sub Saharan Africa`s standard specification and manuals for road works: Tanzania case study. In: Brebbia, C. A. ed. *20th International conference on urban transport and the environment*. The Algarve, 28-30 May 2014. Southampton: WIT, 581-593.

Mwaipungu, R. R. W. 1999. The use of pavement longitudinal roughness data for maintenance management of gravel roads. M.Sc. (Highway Engineering) dissertation, University of Dar es Salaam.

Naidoo, K. and Purchase, R. B. 2001. Managing unpaved roads in urban areas. In: *20th Annual Southern African Transport Conference*. CSIR, Pretoria 16-20 July 2001 Pretoria: SATC.

National Institute for Transport and Road Research (NITRR). 1984. *Technical Recommendations for Highways (TRH) 12; Bituminous pavement rehabilitation design.* Pretoria: National Institute for Transport and Road Research - CSIR.

National Institute for Transport and Road Research (NITRR). 2009. *Technical Recommendations for Highways (TRH) 20; The structural design, construction and maintenance of unpaved roads.* Pretoria: CSIR.

O`Flaherty, C. A. 2002. Soils for roadworks. In: O'Flaherty, C. A. ed. *Highways; The location, design, construction and maintenance of road pavements.* Oxford: Butterworth-Heinemann, 66-117.

Oliver, J. E. 2002. Basic road maintenance operations. In: O'Flaherty, C. A. ed. *Highways; The location, design, construction and maintenance of road pavements.* Oxford: Butterworth-Heinemann, 452-477.

Paige-Green, P. 1989. The influence of geotechnical properties on the performance of gravel wearing course materials. PhD thesis, University of Pretoria.

Paige-Green, P. 1995. Re-evaluation of Southern African Unpaved Road Deterioration Models. In: *6th International Conference on Low Volume Roads*. Minneapolis. 25-29 June 1995 Minneapolis: TRB, 208-220.

Paige-Green, P. 1999. Materials for sealed low-volume roads. Transportation Research Record 1652: 163-173.

Paige-Green, P. 2006. Appropriate roads for rural access. In: Proceedings of *the 3rd Gulf Conference on Roads*. Muscat, 6-8March 2006.Muscat: Gulf Conference on Roads, 1-10.

Paige-Green, P. 2007a. New perspective in unsealed roads in South Africa. In: *International Conference on Low Volume Roads*. Nelson, 18-20 July 2007. Nelson: International Conference on Low Volume Roads.

Paige-Green, P. 2007b. *South African highway technology practice: Unsealed and sealed low volume road technology in South Africa. TRB workshop 153*. (online). Available: www.nra.co.za/content/TRB2.pdf. Accessed 12 March 2014 (Accessed 12 March 2014).

Paige-Green, P. and Visser, A. T. 1991. Comparison of the impact of various unpaved road performance models on management decisions. Transportation Research Record 1291: 137-142.

Papagiannakis, A.T. and Masad, E.A. 2008. *Pavement design and materials*. Hoboken, New Jersey: John Wiley & Sons.

Paterson, W. D. O. 1987. *The Highway Design and Maintenance Standards Model (HDM-III),*. Washington, D.C.: Transport Department. World Bank.

Paterson, W. D. O. 1991. Deterioration and maintenance of unpaved roads: Models of roughness and material Loss. Transportation Research Record 1291: 143-156.

Pearson, D. 2012. *Deterioration and maintenance of pavements.* London: Institute of Civil Engineering (ICE) (Thomas Telford).

Permanent International Association of Road Congresses (PIARC), Transport Research Laboratory (TRL) and Intech Associates. 2002. *Draft guidelines to rural road surfacing*. Intech Associates.

Permanent International Association of Road Congresses (PIARC). 1994. *Maintenance of unpaved roads: practical guidelines for rural road maintenance*. Wiltshire: Transport Research Laboratory.

Pesaran, M.H.1987. *Econometrics* (online). Available: http://en.wikipedia.org/wiki/econometric (Accessed 20 October 2013).

Phillips, E. M. and Pugh, D. S. 2010. *How to get a PhD; A handbook for students and their supervisors*.5th ed. Berkshire: McGraw-Hill Education.

Pinard, M. I. 1999. Managing SADC roads agencies in the new millennium: The role of road asset management systems. In: *Annual Roads Convention*. Dar es Salaam,1999. Dar es Salaam: Tanzania Road Association, 138-148.

Robinson, R. and Thagesen, B. 1996a. Maintenance management. In: Thagesen, B. ed. *Highway and traffic engineering in developing countries*. London: E&FN Spon, 385-408.

Robinson, R. and Thagesen, B. 1996b. Training of staff. In: Thagesen, B. ed. *Highway and traffic engineering in developing countries*. London: E&FN Spon, 452-475.

Robinson, R., Danielson, U. and Snaith, M. 1998. *Road maintenance management: concepts and systems*. London: Macmillan Press.

Samwelson, P.A. Kopmans, T.C. and Stone, J.R.N. 1954. *Report on the evaluation committee for econometrica* (online). Available: http://en.wikipedia.org/wiki/ econometric (Accessed 20 October 2013).

Sargious, M. 1975. *Pavements and surfacings for highways and airports*. London: Applied Science.

Schliessler, A. and Bull, A. 1993. *Roads: New approach for road network management and conservation*. Santiago: Larrea Diseñadores e Impresores.

Schmidt, S.J. 2005. *Econometrics*. New York: McGraw-Hill.

Scott, C. R. 1980. *An introduction to soil mechanics and foundation*. 3rd ed. London: Applied science publishers.

Shahin, M. Y. 2005. *Pavement management for airports, roads and parking lots*.2nd ed. New York: Chapman & Hall.

South African Bureau of Standards (SABS). 1996. *Standardized Specification for Civil Engineering Construction*, SABS 1200 M.

StataCorp. 2011. *Stata: Release 12 Software package*. College station, Texas: StataCorp LP.

Steels, H.M. 2011. Initial professional development for civil engineers. London: Institution of Civil Engineers (Thomas Telford).

Tanzania National Roads Agency (TANROADS). 2010a. *Road Maintenance Management Systems (RMMS) Version 5: Data Collection Manual, Inventory and Condition Data*. Dar es Salaam: TANROADS.

Tanzania National Roads Agency (TANROADS). 2010b. *Road Maintenance Management Systems (RMMS); Operational Manual*. Dar es Salaam: TANROADS.

Tapper, M.S.P., Henning, T.F.P., Dunn, K.D. 2013. *Improvement on visual condition data* (online). Wellington, NZTransport Agency research report 528. Available: www.nzta.govt.nz/resources/research/reports/528/docs/528.pdf (Accessed 02/10/2014).

Taseni, E. 2000. Performance of materials used for gravel roads construction in Tanzania. M.Sc. (Highway Engineering) thesis, University of Dar es Salaam.

Tembo, S. and Blockhuis, F. 2004. *Manual for supervision of labour based road rehabilitation work*. Harare. International Labour Office, Advisory, Support, Information Service and Training.

The United Republic of Tanzania. 2007. *The Road Act of 2007 [No. 13 of 2007]*. Dar es Salaam: Printed by the Government Printer.

The United Republic of Tanzania; Ministry of Works. 1999. *Pavement and materials design manual*. Skjetten: Novum Grafisk AS.

The United Republic of Tanzania; Ministry of Works. 2000a. *Central materials laboratory: Laboratory testing manual*. Skjetten: Novum Grafik AS.

The United Republic of Tanzania; Ministry of Works. 2000b. *Standard Specification for Road Works*. Skjetten, Norway: Novum Grafisk AS.

The United Republic of Tanzania; Prime Minister's Office Regional Administration and Local Government (PRO-RALG). 2004. *Annual district road inventory and condition survey and District road management system*. Dodoma: Prime Minister's Office Regional Administration and Local Government.

Thorne, B. M. and Giesen, J. M. 2000. *Statistics for the behavioural Sciences*. 3rd ed. Mountain View, California: Mayfield Publishing.

Underwood, R. T. 1995. *Road engineering practice*. South Melbourne: MacMillan Education.

United States Department of Transportation and Federal Highway Administration. 2000. *Variability of pavement distress data from manual surveys*. Georgetown Pike: Federal Highway Administration.

Uys, J. R. 2008. The effect of improved design and construction practices on gravel loss deterioration. M.Sc. thesis, University of Pretoria.

van Zyl, G., Henderson, M. and Uys, J. R. 2007. Applicability of existing gravel road deterioration models questioned. *Transportation Research Record*, 1989(1): 217-225.

Veeraragavan, A. 1995. Contract level pavement maintenance management: Prospects for future change in India. In: Proceedings of *ICORT-95*. University of Roorkee, Civil Engineering Department, University of Roorkee.

Verbeek, M. 2012. *A guide to modern econometrics*.4th ed. West Sussex: John Wiley & Sons.

Visser, A. T. and Hudson, W. R. 1983. Design and maintenance criteria for unpaved roads. *The Civil Engineer in South Africa*, 25 ( 3): 141-152.

Visser, A. T. and Queiroz, C. A. V. 1979. *Research on the interrelationship between costs of highway construction, maintenance and utilization*. Brasilia.

Walker, D. H. T. 1997. Choosing an appropriate research methodology for construction management and economics. *Journal of construction management and economics*,15(2): 149-159.

Watson, D. K. and Rajakapse, R. K. N. D. 2000. Seasonal variation in materials properties of a flexible pavement. *Canadian Journal of Civil Engineers,7(1)*: 44-54.

Whight, P.W., Lai, J.S., Parsonson, P.S. and Meyer, M. 1996. *Highway engineering*.6th ed. Singapore: John Wiley& Sons.

Wright, P.H., Dixon, K.K., and Meyer, M. 2004. *Highway engineering*. 7th ed., Hoboken, New Jersey: John Wiley& Sons.

World Bank. 2000. *Highways Development and Management - HDM-4*. Washington, D.C.: World Bank.

Yoder, E.J. and Witczak, M.W. 1975. Principles of pavement design. 2nd ed. New York: A Wiley Interscience.

## Appendix 1: Typical questionnaire covering letter

P.O. Box 1493,
Iringa,
Mob: 0754 292426
Fax: 026-2702751
E-mail: rrmwaipungu@gmail.com

To:
District Engineer,
Dodoma Municipality Council,
P.O. Box 1249,
Dodoma**.**

Dear Sir/Madam,

**Re: Questionnaire on the maintenance management practice of gravel roads**

My name is Eng. Richard R. Mwaipungu, an employee of Mkwawa University College of Education. Currently I am a Doctorate student in Civil Engineering at Durban University of Technology, and I am doing a research on “the formulation and application of gravel loss models in management of gravel roads in the Iringa region-Tanzania.

The purpose of this questionnaire is to collect information on the maintenance management of gravel roads under your organization, and your response to this questionnaire is important in realizing the objectives of this research, which are to:

- Formulate statistically accurate gravel loss predicting model through investigation of marginal gravel material's geotechnical properties and physical characteristics, and the interaction over time between these properties with prevailing traffic characteristics and climatic conditions for Iringa region;

- Determine a rational method of quantifying quality of gravel road construction and subsequent maintenance operation, based on visual assessment of the condition and performance of gravel roads and measured rate of gravel los; and
- Stimulate the culture of formulating gravel loss predicting models through empirical studies.

The questions in this questionnaire are close and open ended and are set to obtain the following information: statistics of unsealed roads; climatic condition; experience in gravel road management; level of technical education of management team; and current status of construction and maintenance techniques of gravel roads.

Your response will enable us to understand the challenges being faced to achieve the optimum management of gravel roads to suit local condition, and realizing the objectives of this research.

We would very much appreciate if you could answer the attached questionnaire and return to the undersigned at your earliest convenience

Yours Sincerely

Eng. Richard R. Mwaipungu

## Appendix 2: Questionnaire

1. **Management team of Gravel Roads**

a. How large is your gravel roads management team in terms of the number of technical personnel and supporting staff?

Technical Personnel ____________________________________________

Supporting Staff ____________________________________________

b. What is the level of experience of your team in supervising the construction and maintenance operation of gravel roads? Circle the appropriate answer, among the answers provided below. You can have a team fitting all three categories of experience, just circle them and indicate the quantity at the end of the answer you have circled.

i. Less than three years

ii. Three to five years

iii. More than five years

c. Indicate the number of staff you have in your organization in terms of the following level of technical education

i. Vocational training =

ii. Secondary education with vocational training =

iii. Technician =

iv. Engineer =

d. Do you have a system in place for providing training to your maintenance team? Yes/No (circle the answer). If the answer is yes, can you please explain briefly how the system function,

______________________________________________________________

e. Are the funds for providing training to your management team donor based or from your own resources?

______________________________________________________________

**2. Local Climatic Condition**

a. What is the common climatic condition prevalent in your areas? Circle the appropriate answer.

   i. Wet

   ii. Dry,

   iii. Moderate

b. Is there any location/area which is unique and experience the different climatic condition from the three options in question 2 a? If yes, name the location/area

   ______________________________________________________________

**3. Statistical data of Gravel Road Networks**

a. Do you have an inventory of gravel surface roads under your management? Yes/No

b. What is the total length (km)) of gravel roads under your management?

   ______________________________________________________________

c. What is the total length (km) of earth roads under your management?

   ______________________________________________________________

d. What is the total length (km) of recognized tracks under your management?

   ______________________________________________________________

e. How frequent do you collect data on the condition of your unsealed road networks? Circle the appropriate answer.

   i. We don't have a data bank

   ii. Once per year

   iii. Once per two years

   iv. Data collection is infrequent

   v. Other (Indicate)____________________________________________

f. Which data do you collect? Circle the appropriate answer/answers

   i. Traffic volume

   ii. Axle loads

iii. Distress survey

iv. Other (Indicate)_____________________________________________

g. How is the data put to use after analysis?

_________________________________________________________________

h. Have you ever measured the longitudinal roughness of the gravel road networks in your area? Yes/No. If the answer is yes which method/s has been employed? Circle the appropriate answer.

i. Towed bump integrator

ii. Vehicle mounted bump integrator

iii. MERLIN

iv. Other (indicate) _____________________________________________

**4. Gravel Road Materials**

a. How many gravel material borrow pits are active in your area?

_________________________________________________________________

b. Please name geological types of gravel material (e.g. laterite, volcanic, etc) and provide brief properties of these borrow pits, by indicating, the common range of PI, anticipated CBR, and percentage passing the 0.075 mm sieve.

_________________________________________________________________

c. Do you test the gravel materials in established and accredited materials laboratory to determine the optimum moisture content and maximum dry density to be used in specifying the field density to be achieved by the contractor during construction and maintenance exercise? Yes/No. If no please explain

_________________________________________________________________

d. How do you address variation in test results when conducting quality control exercise during construction and maintenance operation of gravel roads?

_________________________________________________________________

e. Do you follow any procedure, like looking for approval from the responsible Ministry, or do environmental impact assessments, before opening new borrow pit/s? Yes/No

   If yes please explain briefly the procedure.

   ______________________________________________________________

**5. Construction and Maintenance Operation of Unsealed Roads**

a. Which types of compaction plants are available in your area of jurisdiction?

   ______________________________________________________________

b. What is the availability rate of construction and maintenance plants, namely Grader, Compactor, Excavator, and Dozer? Circle the appropriate answer

   i. Low (one plant per seven contractors)
   ii. Medium (one plant per four contractors)
   iii. High (one plant per two contractors)

c. What type of maintenance methodology is adopted on unsealed roads? (Self-propelled machines or dragged equipment), explain

   ______________________________________________________________

d. Have you ever considered labour intensive maintenance method in your area? If Yes indicates its frequencies. Circle the appropriate answer

   i. Low
   ii. Medium
   iii. High

e. What is the current situation of maintenance in rural areas? Circle the appropriate answer

   i. Labour based,
   ii. Mixed, Labour and Equipment based
   iii. Equipment based

f. When do you schedule the maintenance activities on unsealed roads? Circle the appropriate answer

   i. Immediately after the end of wet season.

ii. At the beginning of the wet season.

Please give reasons for the circled decision.

________________________________________________________

g. Do you measure the compactive effort achieved after compaction exercise has been completed during the maintenance operation? Yes/No. If the answer is yes, which method is commonly used? Circle the appropriate answer.

i. Qualitative method (Site based (proof rolling))

ii. Quantitative method (Laboratory based methods (sand replacement methods/Nuclear methods))

iii. Both

## Appendix 3: Letter requesting access to gravel roads under TANROADS management

P. O. Box 1493,
Iringa.
24th January, 2011

To: Regional Manager,
TANROADS Iringa,
P.O. Box 23,
Iringa.

Dear Sir

**Re: Performance study on gravel roads under your management**

Please be informed that we intend to start the performance study on the selected gravel roads under your management. Within those gravel roads, we shall establish test sections, which have to be representative of substantive amount of gravel materials borrow pits active in your area.

In the process of performance studies, we shall establish experimental design. The objective of the experimental design is to ensure that suitable data will be collected, that a systematic approach is followed and that the data could be used to formulate gravel loss models.

The following criterion will be used during the experimental design to identify the most suitable sections to be selected for the research study, namely:

- Start and end distance of the road section;
- Road widths;
- Topography;
- Traffic volumes;
- Material type and properties;
- Drainage conditions; and
- Climatic data.

The sections to be monitored shall be representative of the agency's road network, and will be selected accordingly.

**Test sections**

The selection of gravel road test sections for monitoring exercise will be based on the following geometric and material property, namely:-

- No steep longitudinal gradients (not more than 4%),
- No tight curves, and
- Acceptable drainage, (roads located on the self (better) drained parts of the terrain will be selected)

Each section will be 300 metres long.

## 1 Measurement of gravel loss

The measurement of gravel loss will be conducted on all test sections. The measurement shall be done in three stages, namely: i) the identification of the monitoring section; ii) the setting out of the monitoring section; and iii) the measurement of gravel loss at predetermined interval and periods.

### 1.1 Method statement

The identification of the monitoring sections shall be done only after a proper desktop study.

The selection of the monitoring section shall be done by taking the prevailing geometric and topographic conditions into consideration. The safety of the setting out or measurement team must also be considered. Access roads or junctions shall be avoided within the circumference of the test section, as they will have a negative influence on the gravel loss measurements. The test section should preferably be selected on a road segment with a uniform vertical and horizontal alignment.

The setting out of the monitoring sections shall be done in two stages, namely the installation of the reference benchmarks, and the installation of the monitoring pegs. Each monitoring section shall be based on a localized referencing system, where a height is allocated to the first reference benchmark, and heights are determined for the rest of the reference benchmarks and monitoring pegs. At least three references benchmarks shall be installed that missing or damaged pegs can be replaced effectively and accurately if needed.

## 1.2 Equipment

The following equipment will be needed for the installation of the reference benchmarks and monitoring pegs per monitoring section, namely:

i)  pick axle, bush knifes and shovels for bush and shrubs clearing, digging holes and mixing concrete; ii) 2 kg hammer for driving the steel rods into the ground; iii) cement; iv) aggregates; v) sand; vi) mixing water; vii) trowel for carrying and giving the concrete a smooth finish; viii) head pans or 10 litres buckets; ix) 15 x 300 to 600 mm Y 12 - 16 round steel rods; x) 12 x 150 to 300 mm x 200 mm diameter PVC pipes; xi) 50 m measuring tape; xii) 500 mm spirit level; xiii) dumpy level; xiv) tripod stand; and xv) survey staff.

## 2 Traffic volume count

During the performance study we shall conduct traffic volume counts at trial sections. Traffic volume counts are conducted using two basic methods, that is manual and mechanical. The basic form of manual count involves a person recording each vehicle by making tally marks on a field sheet, which may be used by an individual to conduct traffic volume counts.

The main disadvantages of the manual count method are that: i) it is subject to the limitations of human factors; and ii) it cannot be used for long periods of counting.

Regardless of the above mentioned disadvantages, traffic volume counts in this study shall be conducted manually, as it is affordable.

Yours sincerely

Eng. Richard Robert Mwaipungu

cc: Deputy Principal Administration, & Ag. Estates Manager: For information

**Appendix 4: The response letter from TANROADS Iringa Regional Manager`s office**

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# TANZANIA NATIONAL ROADS AGENCY

Tanzania National Roads Agency
TANROADS
Good roads for national development

Regional Manager's Office
P.O Box 23
IRINGA

**Date:** 1 July 2010

**Ref: No**. TRD/RM/IR/C.40/2 Vol. III/223

MKWAWA UNIVERSITY COLLEGE OF EDUCATION
RECEIVED
08 JUL 2010
SIGN..........................

Principal,
Mkwawa University,
College of Education,
Private Bag,
**IRINGA**.

**RE: REQUEST TO USE TANROADS IRINGA REGIONAL GRAVEL ROADS NETWORK AND MATERIAL LABORATORY FOR RESEARCH STUDY PURPOSE.**

Reference is made to captioned subject matter and your letter with Reference No. PF. EST/2/1/114 dated 29th June, 2010.

We are pleased to inform you that your request to allow Eng. Richard Mwaipungu to utilize sections of our roads network and Materials Laboratory for research purpose toward fulfilment of award of Doctor of Philosophy Degree in Pavement Engineering has been accepted. It is our understanding that the research findings shall be beneficial to our Agency and National at large.

Please let Eng. Maipungu contact our Eng. Bashir Rwesingisa Head of Planning Unit at our Office who shall accord him the necessary assistance on his study whenever possible.

Please be guided accordingly.

[redacted]

P L S Lyakurwa,
Regional Manager,
**TANROADS IRINGA.**

REGIONAL MANAGER
TANROADS
TANZANIA NATIONAL ROADS AGENCY
P. O. Box 23
IRINGA

**Tel:** + 255 26 2702121, **Fax:** + 255 26 2702596, **E-Mail:** tanroadsiringa@yahoo.com

**TANROADS** is an Executive Agency of the Ministry of Infrastructure Development, Tanzania, established under the Executive Agencies Act, 1997

**Appendix 5: Letter clarifying tests to be performed at TANROADS materials laboratory**

P.O. Box 1493,
Iringa.
08th February, 2011

To: Regional Manager,
TANROADS Iringa,
P.O.Box 23,
Iringa**.**

Dear Sir

**Re: Tests to be performed in your materials laboratory during my study**

Please refer to the subject above and the meeting we had with the Head of Planning Unit office on 20th January, 2011.

First of all I would like to thank the management TANROADS Iringa for giving me the opportunity to use your materials laboratory for testing soil materials and to conduct performance survey on gravel roads under your management.

Please be informed that my studies on the formulation and application of gravel loss prediction model in management of gravel roads in Iringa region will take three years. In those years I will be monitoring the performance of gravel roads under your management to establish the correlation between gravel material characteristics, traffic volume, and climatic condition prevailing in Iringa region.

The soil materials to be tested will be sampled from existing gravel material borrow pits used for surfacing the gravel road sections to be monitored, existing gravel roads surfacing materials, and subgrade materials. Following are the tests which shall be performed in your material laboratory:

i. Particle size distribution and ii. Atterberg limits tests.

Looking forward to your assistance in achieving the study objectives.

Yours sincerely

Eng. Richard Robert Mwaipungu

cc: Deputy Principal Administration, & Ag. Estates Manager: For information

## Appendix 6: The setting out details of a gravel road monitoring section to be used for conducting gravel loss survey

### Tools and materials

The following tools and materials are needed during the setting out of the sections and subsequent gravel loss survey (reference benchmarks and monitoring pegs per monitoring section), namely: Picks axle, Bush knives, and Shovels/Spades for bush and shrub clearing, digging holes and mixing concrete. Large hammer, of 2 kg weight, to drive the steel rods into the ground. Head pans or 10 litre bucket for transporting concrete. Trowel for giving the concrete a smooth finish. 3 x 300 to 400 mm Y 16 or 12 round steel rods, 12 x 250 to 350 mm Y 16 or 12 round steel rods, 12 x 200 to 400 mm x 100 mm diameter PVC pipes, 30 and 100 m measuring tape, 500 mm spirit level, and Dumpy level, tripod stand, and survey staff. Cement, aggregate, sand and mixing water.

### Reference benchmarks

The three reference benchmarks should be installed to suit the topography of the monitoring section, but should preferably be individually installed with one at the start, one near the centre and one at the end of the section (alternating from left to right over the entire length of the section if that is applicable, otherwise they can be all on one side). Three reference benchmarks will facilitate replacement of damaged pegs. The benchmarks must be installed as close as possible to the shoulder or far away from the road centre line to prevent damage or vandalism by road users, pedestrians or maintenance personnel and equipment. The exact position will depend on the road reserve width. The benchmarks must be installed at the same distance or further than the monitoring pegs.

### Installation exercise

The benchmark installation will start off with a hole dug approximately 400 mm deep, but not less than 200 mm, and with an approximate diameter of 300 mm. The

300 to 500 mm long Y 12 or 16 rods must be driven vertically into the ground at the centre of the hole for approximately 100 mm making use of the spirit level. The hole must be filled, by using the concrete mixture without disturbing the position of the rod. The concrete must be worked off at the top to any shape but preferably round or square by making use of the towel, leaving the benchmark rod approximately 10 to 20 mm proud of the top of the concrete. This process must be repeated for the other two benchmarks at predefined positions. Figure 34 shows a typical benchmark rod 20 mm proud of the top of the concrete.

**Figure 34: Typical temporary bench mark at one of test section**

**Installation of monitoring pegs**

The monitoring pegs must be installed along the 100 metre section from the start of the section at 20 metre intervals on both sides up to the end of this 100 metre section. The offsets from the centre line of the road and the 20 metre intervals over the length of the section must be carefully set out with a measuring tape.

The monitoring pegs should be positioned at the same distance from the centre line for all the intervals over the length of the monitoring section, depending on the prevailing topographical conditions, existing road width and storm water drainage structures.

The distance from the centre line will normally be a minimum of 7 metres, but may be increased if needed. Each monitoring peg must be installed at the centre of a 200 to 300 mm deep and approximately 200 mm wide hole. The 450 mm long Y12 to 16 rods must be driven vertically into the ground at the centre of the hole of approximately 100 mm, making use of the spirit level.

The 200 to 500 mm long, 200 mm diameter PVC pipe must be carefully placed over theY12-16 rod, ensuring that the rod is exactly in the centre of the pipe. The outside of the hole must be backfilled using the excavated material and the PVC pipe must be backfilled using the concrete mixture without disturbing the position of the rod. The concrete must be worked off at the top by using either a steel rod or with the point of the towel, leaving the monitoring rod approximately 10 to 20 mm proud of the top of the concrete. This process must be repeated for the other eleven monitoring pegs at the predetermined positions as described above. The reference height (first reference benchmark), the heights for the other two benchmarks and the heights of the twelve monitoring pegs in relation to the reference height, must be determined using the dumpy level and survey staff and must be carefully recorded for future use.

**Levelling Instrument setup and gravel loss measurements**

Only one setup may be required, but if the topography does not allow for this, two sets may be used to complete the level survey of the pegs. A class A (less than 10 mm difference) level survey is required.

After the installation of the reference benchmarks and the monitoring pegs an initial measurement of gravel loss must be done for each monitoring section. The initial assessment will be done at each 20 metre interval, measuring the height of the road at the centre line, as well as at 250 mm offset to the left and right of the centre line, up to a distance of at least 2.5 metres from the centre line. This could be increased if the road is wider than 5 metres.

A pre-marked builder’s gut line and thin masking tape to indicate the centre line and off-set positions must be used to ensure that the same positions will be measured each time the gravel loss is measured.

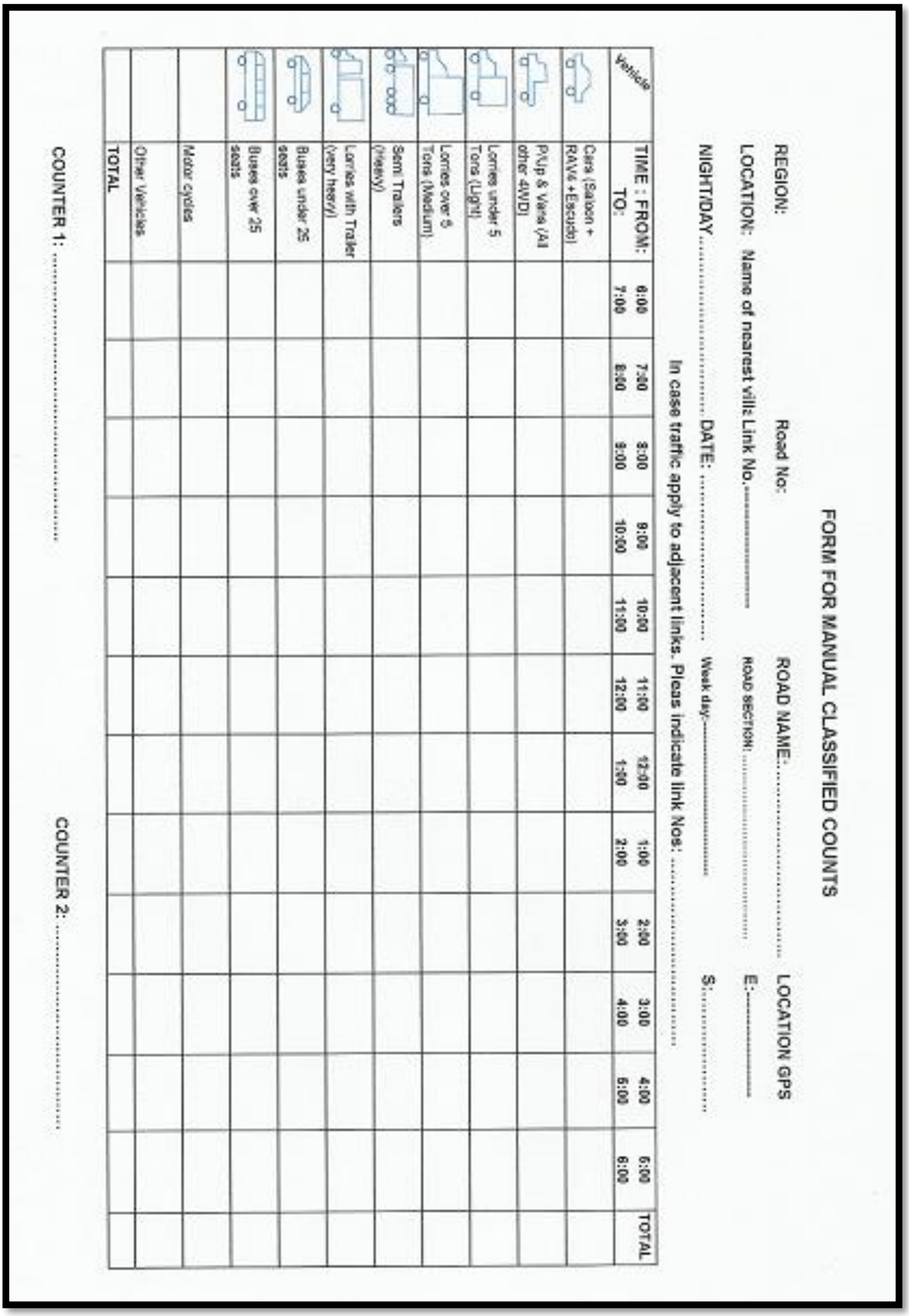
**Figure 35: Gravel loss survey at the start point**

The distances may be indicated on the masking tape by using a thin black permanent marking pen. Figure 35 shows a builder`s gut line around a nail, and a surveyor holding a dip stick at the start point of gravel loss survey. The gravel loss measurement intervals after the initial measurement must be done at predefined intervals to suit individual needs, but it is suggested that this be repeated at most every four months to obtain a clear indication of not only the rate of gravel loss, but also the effect of dry, cold and wet seasons of the year on the rate of gravel loss.

**Repeatability of the exercise**

The success of the gravel loss measurement is in creating a situation that can be repeated every time the gravel loss is measured with the greatest level of confidence possible. A well-defined referencing benchmark and monitoring pegs installation, good accurate record keeping and using reliable survey equipment is essential.

## Appendix 7: Traffic counting form



FORM FOR MANUAL CLASSIFIED COUNTS

REGION: Road No: ROAD NAME:.................................. LOCATION GPS

LOCATION: Name of nearest vill: Link No.---------------------- ROAD SECTION: .......................................... E:------------------

NIGHT/DAY.................................. DATE: .............................. Week day:-------------------------------- S:......................

In case traffic apply to adjacent links. Pleas indicate link Nos: ..................................

| Vehicle | TIME : FROM:<br>TO: | 6:00<br>7:00 | 7:00<br>8:00 | 8:00<br>9:00 | 9:00<br>10:00 | 10:00<br>11:00 | 11:00<br>12:00 | 12:00<br>1:00 | 1:00<br>2:00 | 2:00<br>3:00 | 3:00<br>4:00 | 4:00<br>5:00 | 5:00<br>6:00 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cars (Saloon + RAV4 +Escudo) | | | | | | | | | | | | | |
| | P/Up & Vans (All other 4WD) | | | | | | | | | | | | | |
| | Lorries under 5 Tons (Light) | | | | | | | | | | | | | |
| | Lorries over 5 Tons (Medium) | | | | | | | | | | | | | |
| | Semi Trailers (Heavy) | | | | | | | | | | | | | |
| | Lorries with Trailer (very heavy) | | | | | | | | | | | | | |
| | Buses under 25 seats | | | | | | | | | | | | | |
| | Buses over 25 seats | | | | | | | | | | | | | |
| | Motor cycles | | | | | | | | | | | | | |
| | Other Vehicles | | | | | | | | | | | | | |
| | TOTAL | | | | | | | | | | | | | |

COUNTER 1: ....................................................... COUNTER 2: .......................................

## Appendix 8: Typical unsealed road condition assessment form

| | |
|---|---|
| Evaluator: | Date: |
| Road Name: | Section: |

| General Performance | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | | 5 | |
| Gravel quantity | 1 | Plenty | 2 | Sufficient | 3 | Isolated exposure | 4 | Extreme exposure | 5 | None |
| Gravel quality | 1 | Very good | 2 | Good | 3 | Average | 4 | Poor | 5 | Very poor |

| Influencing factors | Clay | Sand | Gravel/Stones |
|---|---|---|---|

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Road profile/Shape | 1 | Very good - 4% | 2 | Good - 2% | 3 | Flat | 4 | Uneven | 5 | Very uneven |
| Drainage from road | 1 | Well above ground | 2 | Slightly above | 3 | Level with ground | 4 | Slightly below | 5 | Canal |
| Riding quality/safety | 1 | Very good - >100 km/h | 2 | Good - 100 km/h | 3 | Average - 80 km/h | 4 | Poor - 60 km/h | 5 | Very poor - 40 km/h |

| | | | | | |
|---|---|---|---|---|---|
| Influencing factors | Corrugation | Loose materials | Stoniness | Potholes | Ruts/Erosion |
| Maintenance action | Blading | Heavy blading | Regravelling | Reshaping | Drainage |

| **Defects** | **Degree** | | | | | | **Extent** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Potholes | 1 | 2 | 3 | 4 | 5 | | 1 | 2 | 3 | 4 | 5 |
| Rutting | 1 | 2 | 3 | 4 | 5 | | 1 | 2 | 3 | 4 | 5 |
| Transverse erosion | 1 | 2 | 3 | 4 | 5 | | 1 | 2 | 3 | 4 | 5 |
| Longitudinal erosion | 1 | 2 | 3 | 4 | 5 | | 1 | 2 | 3 | 4 | 5 |
| Corrugation | 1 | 2 | 3 | 4 | 5 | | 1 | 2 | 3 | 4 | 5 |
| Loose materials | 1 | 2 | 3 | 4 | 5 | | 1 | 2 | 3 | 4 | 5 |
| Stoniness-embedded | 1 | 2 | 3 | 4 | 5 | | 1 | 2 | 3 | 4 | 5 |
| Stoniness-loose | 1 | 2 | 3 | 4 | 5 | | 1 | 2 | 3 | 4 | 5 |
| Dustiness | 1 | 2 | 3 | 4 | 5 | | | | | | |

| | | |
|---|---|---|
| Slipperiness | Acceptable | Unacceptable |
| Skid resistance | Acceptable | Unacceptable |
| Trafficability | Acceptable | Unacceptable |

**Appendix 9: Acceptance letter on the request to participate in unsealed road condition survey**

**TANZANIA NATIONAL ROADS AGENCY**

TANROADS

Good roads for national development

P.O. Box 258,
Sabasaba Road
MBEYA
Tel: 055 025 2503285
Fax: 055 025 2502755
Email:Tanroads.rmmbeya@yahoo.com

**Our Ref:** TANROADS/RM/MBY/ CON/V.10/O1/Vol.II/111

1st October, 2010

Richard R. Mwaipungu,
P.O. Box 1493
**IRINGA**

**RE: REQUEST TO PARTICIPATE IN UNPAVED ROAD CONDITION SURVEY**

Reference is made to your letter dated 7th September, 2010.

Your request to participate in carrying out unpaved road condition survey as part of your research study topic has been accepted.

The condition survey exercise is scheduled to commence on 5th October 2010 and will take about two weeks.

The request has been accepted with the condition that you will bear all the costs of staying at site for the whole period of the condition survey exercise.

Yours faithfully.

[redacted]

Eng. L. H. Kilewo
Regional Manager
TANROADS-MBEYA

REGIONAL MANAGER
TANROADS
MBEYA

**Appendix 10: Letter from PRO-RALG accepting the request to use they unsealed road network for research work**

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**THE UNITED REPUBLIC OF TANZANIA**
**PRIME MINISTER'S OFFICE**

**Telegraphic Address:** "RALG"

**Phone No:** 026 – 2322848
026 – 2321607/ 026 – 2322681
**Fax No:** 026 – 2322116/2322168
E-mail: ps@pmoralg.go.tz

Regional Administration and Local Government,
P.O. Box 1923,
DODOMA.

**In reply please quote:**

Ref. No. GA: 98/415/01B/214

20th July, 2010

MKWAWA UNIVERSITY COLLEGE OF EDUCATION
RECEIVED
03 AUG 2010
PRINCIPAL
IRINGA

Regional Administrative Secretaries,
**IRINGA, MBEYA, MOROGORO AND DODOMA.**

Re:- **REQUEST TO USE GRAVEL ROADS NETWORKS UNDER THE MANAGEMENT OF LOCAL GOVERNMENT AND REGIONAL ADMINISTRATION FOR RESEARCH – ENGINEER RICHARD R. MWAIPUNGU**

Reference is made to the above captioned subject.

Engineer Richard R. Mwaipungu of Mkwawa University College of Education, is currently persuing his PHD in Pavement Engineering under the Durban/ University of Technology in South Africa.

He wants to do Research study in Tanzania as a partial fulfillment for his doctorate degree. He wants to use networks of gravel roads under the management of the Regional and Local Governments in your regions.

This Office requests you to provide him with all necessary assistance that he may require. Attached, please find a copy of the letter from his employer Mkwawa University, in case of a need for an inquiry.

I thank you for your continued cooperation.

[redacted]

G. K. Mwakilufi
**For: PERMANENT SECRETARY**

**Copy:** Mkwawa University College of Education,
**IRINGA.**

## Appendix 11: Questionnaire responses from TANROADS and Local government district, municipal, & city engineer`s offices

### Question 1: Management team of gravel roads

| Question 1a | Respondent | Responses | |
|---|---|---|---|
| | | **Technical Personnel** | **Supporting Staff** |
| How large is your gravel roads management team in terms of the number of technical personnel and supporting staff? **Objective** To learn how big is the gravel roads management team in terms of the size of technical personnel and supporting staff | TANROADS Coast | 16 | 15 |
| | TANROADS Bukoba | 14 | 18 |
| | TANROADS Rukwa | 16 | 14 |
| | TANROADS Mbeya | 10 | 71 |
| | TANROADS Iringa | 19 | 10 |
| | TANROADS Morogoro | 10 | 14 |
| | TANROADS Manyara | 13 | 20 |
| | TANROADS Dar es Salaam | 14 | 13 |
| | TANROADS Dodoma | 17 | 15 |
| | TANROADS Tabora | 11 | 25 |
| | TANROADS Tanga | 25 | 40 |
| | TANROADS Arusha | 28 | 67 |
| | District Council Serengeti | 5 | 1 |
| | District Council Chunya | 2 | 2 |
| | District Council Mbeya | 8 | 2 |
| | District Council Morogoro | 8 | 12 |
| | District Council Rungwe | 7 | |
| | District Council Kasulu | 16 | |
| | District Council Manyoni | 6 | |
| | Municipal Council Iringa | 5 | 7 |
| | Municipal Council Temeke | 16 | 10 |
| | District Council Mkuranga | 4 | |
| | District Council Njombe | 5 | 10 |
| | City Council Arusha | 7 | 4 |
| | District Council Bahi | 2 | 2 |
| | District Council Kyela | 11 | 2 |
| | District Council Mbozi | 5 | 2 |
| | District Council Iringa | 7 | 2 |
| | District Council Mvomelo | 4 | 2 |
| | District Council Arumeru | 6 | 7 |
| | District Council Kilolo | 8 | 2 |
| | Municipal Council Dodoma | 7 | 10 |

| Question 1b | Respondent | Responses | | |
|---|---|---|---|---|
| | | **< 3 years** | **3-5 years** | **> 5 years** |
| What is the level of experience of your team in supervising the construction and maintenance operation of gravel roads? | TANROADS Coast | √ (2) | | √ (14) |
| | TANROADS Bukoba | | | √ (14) |
| | TANROADS Rukwa | | | √ (16) |
| | TANROADS Mbeya | √ (3) | √ (1) | √ (12) |
| | TANROADS Iringa | | | √ (19) |

| Question 1b continued | Respondent | Responses | | |
|---|---|---|---|---|
| | | < 3 years | 3-5 years | > 5 years |
| **Objective**<br>To learn the level of experience the road authority has in supervising the construction and maintenance operation of gravel roads | TANROADS Morogoro | | | √ (14) |
| | TANROADS Manyara | | | √ (13) |
| | TANROADS Dar es Salaam | | | |
| | TANROADS Dodoma | √ (4) | √ (6) | √ (7) |
| | TANROADS Tabora | | √ (2) | √ (9) |
| | TANROADS Tanga | | | √ |
| | TANROADS Arusha | | | √ |
| | District Council Serengeti | | | √ (5) |
| | District Council Chunya | | √ (3) | |
| | District Council Mbeya | √ (2) | √ (3) | √ (11) |
| | District Council Morogoro | √ (1) | √ (2) | √ (5) |
| | District Council Tukuyu | √ (2) | √ (3) | √ (2) |
| | District Council Kasulu | | | √ (16) |
| | District Council Manyoni | √ (3) | | √ (3) |
| | Municipal Council Iringa | | √ | |
| | Municipal Council Temeke | √ (5) | √ (5) | √ (6) |
| | District Council Mkuranga | - | √ | - |
| | District Council Njombe | | | √ (15) |
| | City Council Arusha | | √ (3) | √ (4) |
| | District Council Bahi | √(3) | | √(1) |
| | District Council Kyela | | | √ |
| | District Council Mbozi | | | √ |
| | District Council Iringa | | √ | |
| | District Council Mvomelo | | √ | |
| | District Council Arumeru | | | √ |
| | District Council Kilolo | | √(4) | √(4) |
| | Municipal Council Dodoma | √ (2) | √ (3) | √ (2) |

| Question 1c | Respondent | Responses | | | |
|---|---|---|---|---|---|
| | | Eng. | Tech. | VT | SE with VT |
| Indicate the number of staff you have in your organization in terms of the following levels of technical education | TANROADS Coast | 10 | 6 | | |
| | TANROADS Bukoba | 5 | 9 | | |
| | TANROADS Rukwa | 8 | 8 | | |
| | TANROADS Mbeya | 6 | 4 | | |
| | TANROADS Iringa | 8 | 11 | | |
| | TANROADS Morogoro | 6 | 8 | | |
| | TANROADS Manyara | 5 | 9 | 1 | 5 |
| | TANROADS Dar es Salaam | 6 | 6 | | |
| | TANROADS Dodoma | 7 | 4 | | 6 |
| | TANROADS Tabora | 6 | 5 | | |
| | TANROADS Tanga | 9 | 16 | | |
| | TANROADS Arusha | 5 | 39 | 25 | 29 |

| Question 1c continued | Respondent | Responses | | | |
|---|---|---|---|---|---|
| | | Eng. | Tech. | VT | SE with VT |
| **Objective**<br>To learn the level of technical education the staff of the road authority possesses so as to know their capability on management of gravel roads | District Council Serengeti | 4 | 1 | 1 | |
| | District Council Chunya | 1 | 1 | | |
| | District Council Mbeya | 5 | 6 | 5 | |
| | District Council Morogoro | 2 | 2 | 4 | |
| | District Council Tukuyu | 2 | 5 | | |
| | District Council Kasulu | 2 | 2 | 12 | |
| | District Council Manyoni | 2 | 2 | 1 | 1 |
| | Municipal Council Iringa | 2 | 3 | | |
| | Municipal Council Temeke | 5 | 11 | 1 | 9 |
| | District Council Mkuranga | 1 | 3 | | |
| | District Council Njombe | 2 | 5 | 6 | 2 |
| | City Council Arusha | 6 | 10 | 4 | 2 |
| | District Council Bahi | 1 | 1 | 7 | 2 |
| | District Council Kyela | 3 | 1 | 4 | 2 |
| | District Council Mbozi | 1 | 2 | | 2 |
| | District Council Iringa | 2 | 6 | | 1 |
| | District Council Mvomelo | 2 | 3 | | 1 |
| | District Council Arumeru | 2 | 3 | | |
| | District Council Kilolo | 7 | 1 | | |
| | Municipal Council Dodoma | 6 | 1 | | |

Note: Eng. – Engineer; Tech – Technician; VT – Vocational Training
SE – Secondary Education

| Question 1d | Respondent | Responses | |
|---|---|---|---|
| | | Yes | No |
| Do you have a system in place for providing training to your maintenance team? If the answer is yes, can you please explain briefly how the system functions? | TANROADS Coast | | √ |
| | TANROADS Bukoba | Road Maintenance Management System (RMMS) for planning and monitoring of contracts, Bridge Maintenance Management System for records keeping of bridges like inventory and inspecting and costing for repair. In house and outside seminars & training | |

| Question 1d continued | Respondent | Responses | |
|---|---|---|---|
| | | Yes | No |
| **Objective**<br>To learn if there is a system in place for providing continuous training to the gravel roads management team for its sustainability | TANROADS Rukwa | Training in supervision of road/bridge maintenance works and Training in road/bridge maintenance management system mainly in contract monitoring and reporting | |
| | TANROADS Mbeya | On the job training by conducting short courses and seminars | |
| | TANROADS Iringa | Mostly it is on job training for a new member of staff. There is an ongoing programme for improving the road maintenance management system, whereby almost all involved staff are updated of new development from time to time | |
| | TANROADS Morogoro | | Training is organized by the Head Office in Dar es Salaam. However, it occurs in very few occasions |
| | TANROADS Manyara | √ | |
| | TANROADS Dar es Salaam | √ | |
| | TANROADS Dodoma | The need might originate from staff/Region/HQ and fund are sought or budgeted annually | |

| Question 1d continued | Respondent | Responses | |
|---|---|---|---|
| | | Yes | No |
| | TANROADS Tabora | No well defined system, however training is provided whenever the opportunity arises | |
| | TANROADS Tanga | In house and overseas training, including study tours is normally organized by TANROADS Head Office after assessing training needs among employees. On the job training is carried out on a routine basis while implementing road maintenance activities | |
| | TANROADS Arusha | A tailor made program in supervising, contracts managements and procurement (public) procedure and other related training as provided by the head office | |
| | District Council Serengeti | The Government funds the staff in each year to get trained for short and long periods | |
| | District Council Chunya | Permission is sought from the management, after getting an Institution which offers the desired knowledge and skills | |
| | District Council Mbeya | Facilitation of the staff member to attend short courses provided by ATTI , NCC, etc | |
| | District Council Morogoro | Technical staff are provided with training in short courses like Labour based technology course at ATTI Mbeya | |

| Question 1d continued | Respondent | Responses | |
|---|---|---|---|
| | | Yes | No |
| | District Council Tukuyu | | √ |
| | District Council Kasulu | | √ |
| | District Council Manyoni | | √ |
| | Municipal Council Iringa | The council has to set aside funds for short course training and attending professional seminars and workshops | |
| | Municipal Council Temeke | Internal training through ongoing activities, and attending training organized by CRB or ERB and other stakeholders | |
| | District Council Mkuranga | √ | |
| | District Council Njombe | √ | |
| | City Council Arusha | | √ |
| | District Council Bahi | | √ |
| | District Council Kyela | Application from staff concerned, confirmation from institute, and preparation of budget | |
| | District Council Mbozi | | √ |
| | District Council Iringa | Attending short courses provided by NCC and ATTI | |
| | District Council Mvomelo | Training of the maintenance team is only as per government requirements, meaning that, the staff goes to training based on the district council plan and budget for a particular year and not otherwise | |
| | District Council Arumeru | | √ |
| | District Council Kilolo | | √ |
| | Municipal Council Dodoma | √ | |

| Question 1e | Respondent | Responses |
|---|---|---|
| Are the funds for providing training to your management team donor based or from your own resources?<br><br>**Objective**<br>To learn the source of funds for providing training to the gravel roads management team so as to establish its sustainability | TANROADS Coast | - |
| | TANROADS Bukoba | From Government (Road Fund Board) |
| | TANROADS Rukwa | The funds for providing training are from TANROADS budget |
| | TANROADS Mbeya | Both government and donor funds |
| | TANROADS Iringa | Both from donor and within the resources of TANROADS |
| | TANROADS Morogoro | Own sources/Donor based |
| | TANROADS Manyara | Government Source |
| | TANROADS Dar es Salaam | Own sourced |
| | TANROADS Dodoma | Own sources/Donor based |
| | TANROADS Tabora | Funds for training are based at the TANROADS Headquarter in Dar es Salaam |
| | TANROADS Tanga | Mostly from Donors, DANIDA, African Development Bank, and International Development Agency (IDA). GoT contribution is very small. |
| | TANROADS Arusha | Own resources |
| | District Council Serengeti | From Government and own sources |
| | District Council Chunya | Donor and Government based |
| | District Council Mbeya | From Government grant and own sources |
| | District Council Morogoro | Own resources |
| | District Council Tukuyu | Not available |
| | District Council Kasulu | No provisional of money for training |
| | District Council Manyoni | Not applicable |
| | Municipal Council Iringa | Both, own sources and donor based |
| | Municipal Council Temeke | Mainly from own source and rarely from donors |
| | District Council Mkuranga | Donor based |
| | District Council Njombe | Own resources |
| | City Council Arusha | Own resources |
| | District Council Bahi | When it happens funds are donor based |
| | District Council Kyela | Donor and own resources |
| | District Council Mbozi | Donor based |
| | District Council Iringa | Both donor and Government grant (OC) |
| | District Council Mvomelo | Government source |
| | District Council Arumeru | Nil |
| | District Council Kilolo | Government source |
| | Municipal Council Dodoma | Both, own sources and donor based |

**Question 2: Local climatic condition**

| Question 2a | Respondent | Responses | | |
|---|---|---|---|---|
| | | Wet | Dry | Moderate |
| What is the common climatic condition prevalent in your areas?<br><br>**Objective**<br>To determine the common climatic condition prevalent in the district or regional in question so as to have a picture of its influence on gravel loss | TANROADS Coast | | | √ |
| | TANROADS Bukoba | | | √ |
| | TANROADS Rukwa | √ | √ | |
| | TANROADS Mbeya | √ | √ | |
| | TANROADS Iringa | √ | | √ |
| | TANROADS Morogoro | √ | | √ |
| | TANROADS Manyara | | | √ |
| | TANROADS Dar es Salaam | | | √ |
| | TANROADS Dodoma | | √ | √ |
| | TANROADS Tabora | | √ | √ |
| | TANROADS Tanga | | | √ |
| | TANROADS Arusha | | | √ |
| | District Council Serengeti | | | √ |
| | District Council Chunya | | | √ |
| | District Council Mbeya | √ | | |
| | District Council Morogoro | √ | √ | √ |
| | District Council Tukuyu | √ | | |
| | District Council Kasulu | | | √ |
| | District Council Manyoni | | √ | |
| | Municipal Council Iringa | | | √ |
| | Municipal Council Temeke | | | √ |
| | District Council Mkuranga | | | √ |
| | District Council Njombe | √ | | √ |
| | City Council Arusha | | | √ |
| | District Council Bahi | | √ | |
| | District Council Kyela | | | √ |
| | District Council Mbozi | | | √ |
| | District Council Iringa | √ | √ | |
| | District Council Mvomelo | | | √ |
| | District Council Arumeru | | | √ |
| | District Council Ilolo | √ | | |
| | Municipal Council Dodoma | | √ | √ |

| Question 2b | Respondent | Responses | |
|---|---|---|---|
| | | Yes | No |
| Is there any location/area which is unique and experience different climatic condition(s) from the three options in question 2 a? If yes, name the location/area | TANROADS Coast | | √ |
| | TANROADS Bukoba | | √ |
| | TANROADS Rukwa | | √ |
| | TANROADS Mbeya | | √ |
| | TANROADS Iringa | Along Iringa-Mtera and Iringa-Msembe Roads | |

| Question 2b continued | Respondent | Responses | |
|---|---|---|---|
| | | Yes | No |
| **Objective**<br>To determine if there is any location or area in the district or regional which experience different climatic condition from the three options in question 2a, as an indication of the need of a separate gravel loss model | TANROADS Morogoro | | √ |
| | TANROADS Manyara | | √ |
| | TANROADS<br>Dar es Salaam | | √ |
| | TANROADS Dodoma | | √ |
| | TANROADS Tabora | | √ |
| | TANROADS Tanga | | √ |
| | TANROADS Arusha | | √ |
| | District Council Serengeti | | √ |
| | District Council Chunya | | √ |
| | District Council Mbeya | Ikukwa, Songwe valley, and Inyala | |
| | District Council Morogoro | Mountainous terrain | |
| | District Council Tukuyu | | √ |
| | District Council Kasulu | | √ |
| | District Council Manyoni | | √ |
| | Municipal Council Iringa | | √ |
| | Municipal Council Temeke | | √ |
| | District Council Mkuranga | | √ |
| | District Council Njombe | | √ |
| | City Council Arusha | - | √ |
| | District Council Bahi | | √ |
| | District Council Kyela | | √ |
| | District Council Mbozi | | √ |
| | District Council Iringa | | √ |
| | District Council Mvomelo | | √ |
| | District Council Arumeru | | √ |
| | District Council Kilolo | | √ |
| | Municipal Council Dodoma | | √ |

**Question 3: Statistical data of gravel road networks**

| Question 3a | Respondent | Responses | |
|---|---|---|---|
| | | Yes | No |
| Do you have an inventory of gravel surface roads under your management?<br><br>**Objective**<br>To establish whether the respondent has an inventory of gravel road, which is an indicative of the existence of the gravel road management system | TANROADS Coast | √ | |
| | TANROADS Bukoba | √ | |
| | TANROADS Rukwa | √ | |
| | TANROADS Mbeya | √ | |
| | TANROADS Iringa | √ | |
| | TANROADS Morogoro | √ | |
| | TANROADS Manyara | √ | |
| | TANROADS Dar es Salaam | √ | |
| | TANROADS Dodoma | √ | |
| | TANROADS Tabora | √ | |
| | TANROADS Tanga | √ | |

| Question 3a continued | Respondent | Responses | |
|---|---|---|---|
| | | Yes | No |
| | TANROADS Arusha | √ | |
| | District Council Serengeti | √ | |
| | District Council Chunya | √ | |
| | District Council Mbeya | √ | |
| | District Council Morogoro | √ | |
| | District Council Tukuyu | √ | |
| | District Council Kasulu | √ | |
| | District Council Manyoni | √ | |
| | Municipal Council Iringa | √ | |
| | Municipal Council Temeke | √ | |
| | District Council Mkuranga | √ | |
| | District Council Njombe | √ | |
| | City Council Arusha | √ | |
| | District Council Bahi | √ | |
| | District Council Kyela | √ | |
| | District Council Mbozi | √ | |
| | District Council Iringa | √ | |
| | District Council Mvomelo | √ | |
| | District Council Arumeru | √ | |
| | District Council Kilolo | √ | |
| | Municipal Council Dodoma | √ | |

| Question 3b | Respondent | Responses |
|---|---|---|
| What is the total length (km)) of gravel roads under your management?<br><br>**Objective**<br>To establish the total length of gravel roads under respondent management so as to determine the average length each engineer or technician is managing, and whether they are able to manage | TANROADS Coast | 860 km |
| | TANROADS Bukoba | 1,564.66 km |
| | TANROADS Rukwa | 2,135 km |
| | TANROADS Mbeya | 1,688.66 km |
| | TANROADS Iringa | 670.8 km |
| | TANROADS Morogoro | 853 km |
| | TANROADS Manyara | 1,000 km |
| | TANROADS Dar es Salaam | 239.4 km |
| | TANROADS Dodoma | 560 km |
| | TANROADS Tabora | 1,025 km |
| | TANROADS Tanga | 1,802.49 km |
| | TANROADS Arusha | 870.01 km |
| | District Council Serengeti | 570 km |
| | District Council Chunya | 126.6 km |
| | District Council Mbeya | 175.08 km |
| | District Council Morogoro | 115 km |
| | District Council Tukuyu | 463.1 km |
| | District Council Kasulu | 148.9 km |
| | District Council Manyoni | 240.8 |
| | Municipal Council Iringa | 103.7 km |
| | Municipal Council Temeke | 440 km |

| Question 3b continued | Respondent | Responses |
|---|---|---|
| | District Council Mkuranga | 10 km |
| | District Council Njombe | 900 km |
| | City Council Arusha | 85 km |
| | District Council Bahi | 3,000 km |
| | District Council Kyela | 116 km |
| | District Council Mbozi | 109.1 km |
| | District Council Iringa | 490 |
| | District Council Mvomelo | 295.1 km |
| | District Council Arumeru | 109.175 km |
| | District Council Kilolo | 189.6 km |
| | Municipal Council Dodoma | 270 km |

| Question 3c | Respondent | Responses |
|---|---|---|
| What is the total length (km) of earth roads under your management?<br><br>**Objective**<br>To establish the total length of earth roads under respondent management so as to determine the average length each engineer or technician is managing, and whether they are able to manage | TANROADS Coast | 250 km |
| | TANROADS Bukoba | None |
| | TANROADS Rukwa | None |
| | TANROADS Mbeya | 186.30 km |
| | TANROADS Iringa | 164 km |
| | TANROADS Morogoro | 500 km |
| | TANROADS Manyara | 623 km |
| | TANROADS Dar es Salaam | 58 km |
| | TANROADS Dodoma | 180 km |
| | TANROADS Tabora | 527.8 km |
| | TANROADS Tanga | None |
| | TANROADS Arusha | None |
| | District Council Serengeti | 240 km |
| | District Council Chunya | 417.4 km |
| | District Council Mbeya | 514.69 km |
| | District Council Morogoro | 776 km |
| | District Council Tukuyu | 300 km |
| | District Council Kasulu | 795.7 km |
| | District Council Manyoni | 263 km |
| | Municipal Council Iringa | 237.27 |
| | Municipal Council Temeke | 340 km |
| | District Council Mkuranga | 745 km |
| | District Council Njombe | 100 km |
| | City Council Arusha | 163 km |
| | District Council Bahi | 444 km |
| | District Council Kyela | 280 km |
| | District Council Mbozi | 689.1 km |
| | District Council Iringa | 276 km |
| | District Council Mvomelo | 331.37 km |
| | District Council Arumeru | 471.555 km |
| | District Council Kilolo | 919.5 km |
| | Municipal Council Dodoma | 380 km |

| Question 3d | Respondent | Responses |
|---|---|---|
| What is the total length (km) of recognized tracks under your management?<br><br>**Objective**<br>To establish the total length of recognized tracks under respondent management so as to determine the average length each engineer or technician is managing, and whether they are able to manage | TANROADS Coast | 205 km |
| | TANROADS Bukoba | None |
| | TANROADS Rukwa | None |
| | TANROADS Mbeya | None |
| | TANROADS Iringa | None |
| | TANROADS Morogoro | None |
| | TANROADS Manyara | 212 km |
| | TANROADS Dar es Salaam | 592 km |
| | TANROADS Dodoma | None |
| | TANROADS Tabora | None |
| | TANROADS Tanga | None |
| | TANROADS Arusha | None |
| | District Council Serengeti | 891 km |
| | District Council Chunya | None |
| | District Council Mbeya | 185.15 km |
| | District Council Morogoro | 891 km |
| | District Council Tukuyu | None |
| | District Council Kasulu | 134 km |
| | District Council Manyoni | None |
| | Municipal Council Iringa | None |
| | Municipal Council Temeke | 780 km |
| | District Council Mkuranga | 400 km |
| | District Council Njombe | 5 km |
| | City Council Arusha | 123 km |
| | District Council Bahi | None |
| | District Council Kyela | None |
| | District Council Mbozi | None |
| | District Council Iringa | None |
| | District Council Mvomelo | 626.47 km |
| | District Council Arumeru | 585.08 km |
| | District Council Kilolo | None |
| | Municipal Council Dodoma | None |

| Question 3e | Respondent | Responses | | | | |
|---|---|---|---|---|---|---|
| | | No data | Once per year | Once per two years | Infrequent | Other |
| How frequent do you collect data on the condition of your unsealed road networks? | TANROADS Coast | | √ | | | |
| | TANROADS Bukoba | | √ | | | |
| | TANROADS Rukwa | | √ | | | |
| | TANROADS Mbeya | | √ | | | |

| Question 3e continued | Respondent | Responses | | | | |
|---|---|---|---|---|---|---|
| | | No data | Once per year | Once per two years | Infrequent | Other |
| **Objective** To establish the frequency in which data on the condition of the unsealed road network is being collected the knowledge which will assist in knowing their capability in running gravel loss model, in terms of data collection to run it. | TANROADS Iringa | | √ | | | |
| | TANROADS Morogoro | | √ | | | |
| | TANROADS Manyara | | √ | | | |
| | TANROADS Dar es Salaam | | √ | | | |
| | TANROADS Dodoma | | √ | | | |
| | TANROADS Tabora | | √ | | | |
| | TANROADS Tanga | | | | | Twice per year (Dry and Wet seasons) |
| | TANROADS Arusha | | √ | | | |
| | District Council Serengeti | | | √ | | |
| | District Council Chunya | | √ | | | |
| | District Council Mbeya | | √ | | | |
| | District Council Morogoro | | | | √ | |
| | District Council Tukuyu | √ | | | | |
| | District Council Kasulu | | √ | | | |
| | District Council Manyoni | | | √ | | |
| | Municipal Council Iringa | | √ | | | |
| | Municipal Council Temeke | | √ | | | |
| | District Council Mkuranga | | | | √ | |
| | District Council Njombe | | √ | | | |
| | City Council Arusha | | √ | | | |
| | District Council Bahi | | √ | | | |

| Question 3e continued | Respondent | Responses | | | | |
|---|---|---|---|---|---|---|
| | | No data | Once per year | Once per two years | Infrequent | Other |
| | District Council Kyela | | √ | | | |
| | District Council Mbozi | | √ | | | |
| | District Council Iringa | | √* | | | |
| | District Council Mvomelo | | √ | | | |
| | District Council Arumeru | | √ | | | |
| | District Council Kilolo | | √ | | | |
| | Municipal Council Dodoma | | √ | | | |

Note: * For those roads which will be included in budget for maintenance data will be collected twice a year for cost estimate.

| Question 3f | Respondent | Responses | | | |
|---|---|---|---|---|---|
| | | Traffic Volume | Axle Loads | Distress Survey | Other |
| What type of data do you collect?<br><br>**Objective**<br>To establish type of data being collected by each road authority the knowledge which will assist in knowing their capability in running gravel loss model, in terms of data collection to run it. | TANROADS Coast | √ | | √ | MCA |
| | TANROADS Bukoba | √ | | √ | |
| | TANROADS Rukwa | √ | | √ | |
| | TANROADS Mbeya | √ | | √ | Inventory & MCA |
| | TANROADS Iringa | √ | | √ | |
| | TANROADS Morogoro | √ | | √ | |
| | TANROADS Manyara | √ | | √ | |
| | TANROADS Dar es Salaam | √ | | √ | |
| | TANROADS Dodoma | √ | | √ | |
| | TANROADS Tabora | √ | | √ | |
| | TANROADS Tanga | | | √ | Bridge condition |
| | TANROADS Arusha | √ | | √ | |
| | District Council Serengeti | | | √ | |
| | District Council Chunya | √ | | | |

| Question 3f continued | Respondent | Responses | | | |
|---|---|---|---|---|---|
| | | Traffic Volume | Axle Loads | Distress Survey | Other (Indicate) |
| | District Council Mbeya | | | √ | |
| | District Council Morogoro | | | √ | |
| | District Council Tukuyu | | | | Not applicable |
| | District Council Kasulu | √ | | √ | |
| | District Council Manyoni | √ | √ | | |
| | Municipal Council Iringa | √ | | √ | |
| | Municipal Council Temeke | √ | √ | √ | |
| | District Council Mkuranga | √ | | | |
| | District Council Njombe | | | √ | |
| | City Council Arusha | √ | | √ | |
| | District Council Bahi | √ | | √ | |
| | District Council Kyela | √ | | √ | |
| | District Council Mbozi | √ | | √ | |
| | District Council Iringa | √ | | √ | |
| | District Council Mvomelo | √ | | | |
| | District Council Arumeru | √(ADRICS) | | √ (ADRICS) | |
| | District Council Kilolo | √ | | √ | |
| | Municipal Council Dodoma | √ | | √ | |

Note: MCA – Multi Criteria Analysis
ADRICS – Annual District Roads Inventory and Condition Survey

| Question 3g | Respondent | Responses |
|---|---|---|
| How are the data put to use after analysis? | TANROADS Coast | Selection of maintenance intervention,<br>Production of several reports,<br>Constrained budget prioritization of roads. |
| | TANROADS Bukoba | Budgeting for maintenance and Prioritising |

| Question 3g continued | Respondent | Responses |
|---|---|---|
| **Objective**<br>To establish the use in which data collected is being put into after analysis, the knowledge which will assist in knowing their capability in running gravel loss model, in terms of data needed to run it. | TANROADS Rukwa | Determination of maintenance needs |
| | TANROADS Mbeya | Planning of the maintenance needs and prioritization of the network to undergo maintenance using the available limited resources |
| | TANROADS Iringa | The data is used as input for Road Mentor of RMMS to produce budget for maintenance and sometime for input to HDM IV |
| | TANROADS Morogoro | Budgeting and for updating road management software (RMMs) |
| | TANROADS Manyara | Used to prioritize maintenance works |
| | TANROADS Dar es Salaam | For maintenance budget preparation |
| | TANROADS Dodoma | Maintenance and prioritization |
| | TANROADS Tabora | The data entry into the system is made for records and is also used in preparation of the Road annual budget for the subsequent fiscal year and maintenance prioritization |
| | TANROADS Tanga | Input for budget analysis and indicating data for design purposes |
| | TANROADS Arusha | Maintenance intervention, prediction and annual budgeting and upgrading proposals |
| | District Council Serengeti | The data enable us to estimate the cost of maintenance |
| | District Council Chunya | Budgeting needs for gravelling or regravelling |
| | District Council Mbeya | Prioritization of roads for maintenance |
| | District Council Morogoro | For budget preparation purposes |
| | District Council Tukuyu | Not applicable |
| | District Council Kasulu | We have a programme used for preparation of costs after fill in rates for different interventions depending on road condition |
| | District Council Manyoni | Used for planning of road maintenance and upgrading proposals |
| | Municipal Council Iringa | We use the data for the preparation of annual maintenance plan |
| | Municipal Council Temeke | For design purpose |
| | District Council Mkuranga | The data is put to help to identify the type and methodology of maintenance required on each road |

| Question 3g continued | Respondent | Responses |
|---|---|---|
| | District Council Njombe | In filling District Road Management Forms, which provide the guidelines on how to go about in management of roads |
| | City Council Arusha | The data are used in prioritizing maintenance/rehabilitation needs. Especially at budgeting and implementing stage |
| | District Council Bahi | In prioritizing maintenance/rehabilitation needs |
| | District Council Kyela | In prioritizing maintenance/rehabilitation needs |
| | District Council Mbozi | Road upgrading, Planning and Maintenance activities |
| | District Council Iringa | Preparation of Tender document, Budgeting and Planning |
| | District Council Mvomelo | This help to prioritize the roads based on the service requirement and budget |
| | District Council Arumeru | They do lead to maintenance program |
| | District Council Kilolo | Preparation of Tender document, for road maintenance |
| | Municipal Council Dodoma | Budget and Prioritization of maintenance |

| Question 3h | Respondent | Responses | | | |
|---|---|---|---|---|---|
| | | TBI | VMBI | MERLIN | Other |
| Have you ever measured the longitudinal roughness of the gravel road networks in your area? If the answer is yes, which method/s did you employ? | TANROADS Coast | No | No | No | No |
| | TANROADS Bukoba | No | No | No | No |
| | TANROADS Rukwa | No | No | No | No |
| | TANROADS Mbeya | No | No | No | No |
| | TANROADS Iringa | No | No | No | No |
| | TANROADS Morogoro | No | No | No | No |
| | TANROADS Manyara | No | No | No | No |
| | TANROADS Dar es Salaam | No | No | No | No |
| | TANROADS Dodoma | No | No | No | No |
| | TANROADS Tabora | No | No | No | No |
| | TANROADS Tanga | No | No | No | No |
| | TANROADS Arusha | No | No | No | No |
| | District Council Serengeti | No | No | No | No |
| | District Council Chunya | No | No | No | No |
| | District Council Mbeya | No | No | No | No |
| | District Council Morogoro | No | No | No | No |
| | District Council Tukuyu | No | No | No | No |
| | District Council Kasulu | No | No | No | No |
| | District Council Manyoni | No | No | No | No |
| | Municipal Council Iringa | No | No | No | No |

| Question 3h continued | Respondent | Responses | | | |
|---|---|---|---|---|---|
| | | TBI | VMBI | MERLIN | Other |
| **Objective**<br>To establish whether the respondent have ever measured the longitudinal roughness of the road gravel road network in his/her area, the knowledge which will assist in knowing their capability of road authority in conducting gravel loss survey. | Municipal Council Temeke | No | Yes | No | No |
| | District Council Mkuranga | No | No | No | No |
| | District Council Njombe | No | No | No | No |
| | City Council Arusha | No | No | No | No |
| | District Council Bahi | No | No | No | Visual |
| | District Council Kyela | No | No | No | No |
| | District Council Mbozi | No | No | No | No |
| | District Council Iringa | No | No | No | No |
| | District Council Mvomelo | No | No | No | No |
| | District Council Arumeru | No | No | No | No |
| | District Council Kilolo | No | No | No | No |
| | Municipal Council Dodoma | No | No | No | No |

Note: TBI – Towed Bump Integrator
VMBI – Vehicle Mounted Bump Integrator

**Question 4: Gravel road materials**

| Question 4a | Respondent | Responses |
|---|---|---|
| How many gravel material borrow pits are active in your area?<br><br>**Objective**<br>To determine the number of active gravel materials borrow pits in the area of respondent, so as to establish the capability each have in maintaining the gravel roads under their jurisdiction | TANROADS Coast | Approximately 30 (Thirty) |
| | TANROADS Bukoba | At least within 15 km of gravel roads there is a borrow pit |
| | TANROADS Rukwa | 31 (Thirty one) |
| | TANROADS Mbeya | At least 4, they are established per need |
| | TANROADS Iringa | 145 (One hundred forty five) |
| | TANROADS Morogoro | Numerous |
| | TANROADS Manyara | 127 (One hundred twenty seven) |
| | TANROADS Dar es Salaam | No specific borrow pits |
| | TANROADS Dodoma | Numerous |
| | TANROADS Tabora | 60 (Sixty) |
| | TANROADS Tanga | 125 (One hundred twenty five) |
| | TANROADS Arusha | Numerous |
| | District Council Serengeti | More than 20 borrow pits |
| | District Council Chunya | 11 (Eleven) |
| | District Council Mbeya | 6 (Six) |
| | District Council Morogoro | We do use those established by TANROADS |
| | District Council Tukuyu | 1 (One) |
| | District Council Kasulu | 18 (Eighteen) |
| | District Council Manyoni | 11 (Eleven) |

| Question 4a continued | Respondent | Responses |
|---|---|---|
| | Municipal Council Iringa | 3 (Three) |
| | Municipal Council Temeke | 1 (one) at Kigamboni |
| | District Council Mkuranga | 15 |
| | District Council Njombe | 20 (Twenty) |
| | City Council Arusha | We have one active borrow pit with suitable gravel material and another one with large deposit of gravel but not as suitable as the first one |
| | District Council Bahi | 34 (Thirty four) |
| | District Council Kyela | 2 (Two) |
| | District Council Mbozi | 26 (Twenty six) |
| | District Council Iringa | 8 (Eight) |
| | District Council Mvomelo | 4 (Four) |
| | District Council Arumeru | 4 (Four) |
| | District Council Kilolo | 8 (Eight) |
| | Municipal Council Dodoma | 6 (Six) |

| Question 4b | Respondent | Responses |
|---|---|---|
| Please name geological types of gravel material (e.g. laterite, volcanic, etc) and provide brief properties of these borrow pits, by indicating, the common range of PI, anticipated CBR, and the percentage passing the 0.075 mm sieve | TANROADS Coast | - |
| | TANROADS Bukoba | Granular, PI 8% - 20%, %passing 0.075 mm sieve 7 – 30%, and anticipated CBR is 45% |
| | TANROADS Rukwa | Laterite materials; PI 8% - 20%, CBR 25% - 60%, and % passing 0.075 mm sieve 8 -12% |
| | TANROADS Mbeya | - |
| | TANROADS Iringa | - |
| | TANROADS Morogoro | - |
| | TANROADS Manyara | Granite and Sedimentary Rocks, PI range from 10-21%, CBR ranges from 5 – 40% (most are less than 20%), and Percentage passing 0.075 mm sieve range between 10-60% |
| | TANROADS Dar es Salaam | CBR ranges from 7 – 60%, PI ranges from 10-40% |
| | TANROADS Dodoma | PI 10-26; CBR 18-58; > 0.075 12-28 |
| | TANROADS Tabora | Mostly Laterite soils with PI range of 6-20, CBR value of 4-25. The % passing 0.075 mm sieve ranges between 10-27 |
| | TANROADS Tanga | PI ≥ 20, CBR ≥ 30 and passing 0.075 mm sieve ≥ 18% |
| | TANROADS Arusha | Volcanic ash, PI range 0-23%, CBR ranges 3-45% |

| Question 4b continued | Respondent | Responses |
|---|---|---|
| **Objective**<br>To determine the geological type and properties of gravel materials used for surfacing gravel roads the knowledge will assist in establishing whether these parameters can be employed during gravel loss modelling | District Council Serengeti | Laterite |
| | District Council Chunya | - |
| | District Council Mbeya | Uyole B/P – LL = 34.3, PL = 31.4, LS =1.4, MDD = 1925 kg/m3, OMC = 13.1% |
| | District Council Morogoro | - |
| | District Council Tukuyu | PI < 6, CBR 25 -45, percentage passing 0.075 mm sieve is 25% |
| | District Council Kasulu | The gravel material is volcanic |
| | District Council Manyoni | Not yet done |
| | Municipal Council Iringa | Laterite |
| | Municipal Council Temeke | PI range between 30-35, CBR from 60 -80%, materials passing 37.5 mm sieve minimum 95% |
| | District Council Mkuranga | - |
| | District Council Njombe | There is no Laboratory test, we use visual observation |
| | City Council Arusha | PI range from 10-16, CBR from 45 -60%, and % passing the 0.075 mm sieve range from 10 -15% |
| | District Council Bahi | - |
| | District Council Kyela | - |
| | District Council Mbozi | - |
| | District Council Iringa | TANROADS Iringa |
| | District Council Mvomelo | - |
| | District Council Arumeru | Volcanic |
| | District Council Kilolo | - |
| | Municipal Council Dodoma | PI range from 10-26, CBR 18-58%, and % passing 0.075 mm sieve 12-28 |

| Question 4c | Respondent | Responses | |
|---|---|---|---|
| | | Yes | No |
| Do you test the gravel materials in established and accredited materials laboratory to determine the optimum moisture content and maximum dry density to be used in specifying the field density to be achieved by the contractor during construction and maintenance exercise?<br>If No, please explain<br><br>**Objective**<br>To determine whether the respondents use established and accredited materials laboratory to test the compaction properties of gravel materials. The knowledge will assist in establishing the number of laboratory testable variables to be included in gravel loss models | TANROADS Coast | √ | |
| | TANROADS Bukoba | √ | |
| | TANROADS Rukwa | √ | |
| | TANROADS Mbeya | √ | |
| | TANROADS Iringa | √ | |
| | TANROADS Morogoro | √ | |
| | TANROADS Manyara | √ | |
| | TANROADS Dar es Salaam | √ | |
| | TANROADS Dodoma | √ | |
| | TANROADS Tabora | √ | |
| | TANROADS Tanga | √ | |
| | TANROADS Arusha | √ | |
| | District Council Serengeti | | The Government does not provide such funds, and according to the nature of our maintenance we do not need such tests |
| | District Council Chunya | | √ |
| | District Council Mbeya | √ | |
| | District Council Morogoro | | We normally use the data obtained by TANROADS |
| | District Council Tukuyu | √ | |
| | District Council Kasulu | - | We normally use the data obtained by TANROADS |
| | District Council Manyoni | | √ |
| | Municipal Council Iringa | We normally do the tests using TANROADS Laboratory which are available within the locality | |
| | Municipal Council Temeke | √ | |

| Question 4c continued | Respondent | Responses | |
|---|---|---|---|
| | | Yes | No |
| | District Council Mkuranga | | The approved budget, we are receiving annually does not include material testing due to insufficient of funds |
| | District Council Njombe | | √ |
| | City Council Arusha | | The existing borrow pits we are using have been tested by TANROADS Regional Office. We normally use data readily available at TANROADS, for field density test |
| | District Council Bahi | √ | |
| | District Council Kyela | Done by the Consultant | |
| | District Council Mbozi | √ | |
| | District Council Iringa | √ | |
| | District Council Mvomelo | √ | |
| | District Council Arumeru | √ | |
| | District Council Kilolo | √ | |
| | Municipal Council Dodoma | √ | |

| Question 4d | Respondent | Responses |
|---|---|---|
| How do you address variation in test results when conducting quality control exercise during construction and maintenance operation of gravel roads? | TANROADS Coast | Joint inspection and testing is conducted and solution is obtained jointly |
| | TANROADS Bukoba | By using Ministry of Works Standard Specification for Road Works 2000 which gives guidelines for tests results and evaluation |
| | TANROADS Rukwa | Most of the test results pass the specified standards |
| | TANROADS Mbeya | - |
| | TANROADS Iringa | We address variation by referring technical specification requirements as set forth time to time for the specific material suitability to be incorporated into the works |

| Question 4d continued | Respondent | Responses |
|---|---|---|
| **Objective**<br>To determine how variation in test results is being addressed when conducting quality control exercise during construction and maintenance operation of gravel roads. The knowledge will assist in establishing whether laboratory test results are reliable and how disagreement in test results is being handled | TANROADS Morogoro | - |
| | TANROADS Manyara | The variations are normally small, that is within the range of ±5% |
| | TANROADS Dar es Salaam | - |
| | TANROADS Dodoma | Variations are dealt with in line with stipulations of AASHTO and BS standards and guidelines |
| | TANROADS Tabora | Variations are dealt with in line with stipulations of AASHTO and BS standards and guidelines |
| | TANROADS Tanga | Carry out joint tests (Contractor and Engineer) on disagreement results. If no consensus an independent third party is engaged to carry out similar test. |
| | TANROADS Arusha | In experienced staff and defective equipments |
| | District Council Serengeti | - |
| | District Council Chunya | We do not conduct tests |
| | District Council Mbeya | We do not normally encounter such variation in test results as most of test are being conducted externally |
| | District Council Morogoro | - |
| | District Council Tukuyu | - |
| | District Council Kasulu | - |
| | District Council Manyoni | Not applicable |
| | Municipal Council Iringa | In case of variations the contractors are instructed t repeat the works |
| | Municipal Council Temeke | - |
| | District Council Mkuranga | - |
| | District Council Njombe | No |
| | City Council Arusha | Test results of the gravel materials from same borrow pit when tested do not have much variation. But it does happen as a matter of fact that soils differ from one point to another, even if it is 5 or 10 m apart, in this case we do repeat the test in the same section. |
| | District Council Bahi | Any variation is addressed by repeating the test |

| Question 4d continued | Respondent | Responses |
|---|---|---|
| | District Council Kyela | - |
| | District Council Mbozi | - |
| | District Council Iringa | No variation because all tests rely on TANROADS Iringa Laboratory |
| | District Council Mvomelo | - |
| | District Council Arumeru | Contractor repeats the work |
| | District Council Kilolo | Not applicable |
| | Municipal Council Dodoma | Using established standards |

| Question 4e | Respondent | Responses | |
|---|---|---|---|
| | | Yes | No |
| Do you follow any procedure, like looking for approval from the responsible Ministry, or do environmental impact assessments, before opening new borrow pit/s? If yes, please explain briefly the procedure.<br><br>**Objective**<br>To determine whether any procedure is being followed before opening new borrow pits for example seeking approval from the Ministry responsible with mining rights or do an environment impact assessment | TANROADS Coast | | √ |
| | TANROADS Bukoba | We seek approval from their representative in the regional | |
| | TANROADS Rukwa | Consultation with the landowner/occupier in the case of the borrow pit being outside the road reserve area | |
| | TANROADS Mbeya | √ | |
| | TANROADS Iringa | | √ |
| | TANROADS Morogoro | √ | |
| | TANROADS Manyara | We do request the mining license from the responsible Ministry. Also, we consult the institution responsible with environmental issues | |
| | TANROADS Dar es Salaam | | √ |
| | TANROADS Dodoma | | √ |

| Question 4e continued | Respondent | Responses | |
|---|---|---|---|
| | | Yes | No |
| | TANROADS Tabora | | However, we have now been issued with guidelines through which we have to address the environmental impact assessment as per laid out regulations |
| | TANROADS Tanga | We normally consult environment management organization like National Environmental Management Council for necessary approvals. For national road development projects ESIA studies are carried out by consultants. The ToR for the ESIA studies requires them to obtain necessary approvals from NEMC and responsible Ministry | |
| | TANROADS Arusha | We do consult local government (District) councils whose environmentalists give guidelines on the proper way of operations | |
| | District Council Serengeti | | √ |
| | District Council Chunya | | √ |
| | District Council Mbeya | | √ |
| | District Council Morogoro | | We use borrow pits established by TANROADS |
| | District Council Tukuyu | | √ |
| | District Council Kasulu | | √ |
| | District Council Manyoni | | - |

| Question 4e continued | Respondent | Responses | |
|---|---|---|---|
| | | Yes | No |
| | Municipal Council Iringa | | √ |
| | Municipal Council Temeke | √ | |
| | District Council Mkuranga | | √ |
| | District Council Njombe | √ | |
| | City Council Arusha | | Normally we do not look for an approval from the Ministry responsible, or do EIA, instead we go direct to the owner and confirm ownership through the village/Street Government. Then we compensate and start using under condition that the Contractor should take into account all environmental issues when excavating the material |
| | District Council Bahi | | √ |
| | District Council Kyela | | No new site has been established |
| | District Council Mbozi | | √ |
| | District Council Iringa | | √ |
| | District Council Mvomelo | | √ |
| | District Council Arumeru | | No new BP has been identified recently, but we should seek approval in the case identified |
| | District Council Kilolo | | √ |
| | Municipal Council Dodoma | | √ |

**Question 5: Construction and maintenance operation of unsealed roads**

| Question 5a | Respondent | Responses |
|---|---|---|
| Which types of compaction plants are available in your area of jurisdiction? (Vibratory, Smooth-Wheeled, Pneumatic tyred, Tamping, or Sheep foot rollers). Please indicate its size in tonnage (dead weight).<br><br>**Objective**<br>To determine which types and weight of compaction plants available in the area of respondent jurisdiction | TANROADS Coast | Vibratory and Sheep foot Rollers (10 tons) |
| | TANROADS Bukoba | Vibrating Roller (10 Tons) |
| | TANROADS Rukwa | Vibratory – 1800 kg to 5000 kg (5 – 20 tons) |
| | TANROADS Mbeya | Our specification specifies a mass per metre width of vibrating roller of 700 kg to 5000 kg. But the common available ones are 8 to 10 tons total mass |
| | TANROADS Iringa | Vibrating steel roller |
| | TANROADS Morogoro | Vibratory + Sheep foot Rollers/Compactor (10 to 15 tons) |
| | TANROADS Manyara | Vibratory rollers (11 tons) |
| | TANROADS Dar es Salaam | Vibratory Steel rollers (12 to 16 tons) |
| | TANROADS Dodoma | Basically compaction plants are provided by contractors executing a road maintenance contract. The capacity of compaction plants is commonly above 15 tons |
| | TANROADS Tabora | Vibratory and Pneumatic tyred rollers with a tonnage of $\geq$ 5 tons |
| | TANROADS Tanga | Basically compaction plants are provided by contractors executing a road maintenance contract. The capacity of compaction plants is commonly above 15 tons |
| | TANROADS Arusha | Vibratory and smooth wheeled rollers 8-12 ton capacities |
| | District Council Serengeti | Vibratory roller compactors |
| | District Council Chunya | Drum compactor |
| | District Council Mbeya | Our specification specifies mass per metre width of vibrating roller of 700 kg to 5000 kg. But the common available ones are 8 to 10 tons total mass |
| | District Council Morogoro | Towed roller, Plate compactor, Pedestrian roller |
| | District Council Tukuyu | Vibrating roller (15 Tons) Single steel drum , Pedestrian roller and Plate compactors |
| | District Council Kasulu | Compactors, Vibratory, Smooth-Wheeled Roller |
| | District Council Manyoni | Contracted companies have steel rollers ranging from 7 tons, to 15 tons |

| Question 5a continued | Respondent | Responses |
|---|---|---|
| | Municipal Council Iringa | Vibrating Steel and sheep foot rollers |
| | Municipal Council Temeke | Normatic Compactor (more than 40 tons) |
| | District Council Mkuranga | Smooth wheeled roller (10 tons) |
| | District Council Njombe | - |
| | City Council Arusha | Mostly are drum rollers (vibrating) available in different capacities (tonnage) |
| | District Council Bahi | Vibrating roller , 10 to 15 tons |
| | District Council Kyela | - |
| | District Council Mbozi | Smooth-Wheeled Roller between 2.7 to 5.4 tons |
| | District Council Iringa | Vibratory, Smooth Wheeled and Pedestrian Rollers, above 10 tons |
| | District Council Iringa | Vibratory |
| | District Council Mvomelo | Vibratory |
| | District Council Arumeru | Sheep foot rollers, a minimum of 20 tons |
| | District Council Kilolo | Vibratory, Smooth Wheeled 7-15 tons |
| | Municipal Council Dodoma | Vibratory, Smooth Wheeled 7-15 tons |

| Question 5b | Respondent | Responses | | |
|---|---|---|---|---|
| | | Low | Medium | High |
| What is the availability rate of construction and maintenance plants, namely Grader, Compactor, Excavator, and Dozer?<br><br>**Objective**<br>To determine the availability rate of construction and maintenance plants in the area of respondent jurisdiction | TANROADS Coast | | √ | |
| | TANROADS Bukoba | | √ | |
| | TANROADS Rukwa | | √ | |
| | TANROADS Mbeya | √ | | |
| | TANROADS Iringa | | | √ |
| | TANROADS Morogoro | √ | | |
| | TANROADS Manyara | | √ | |
| | TANROADS Dar es Salaam | - | - | - |
| | TANROADS Dodoma | | √ | |
| | TANROADS Tabora | √ | | |
| | TANROADS Tanga | √ | | |
| | TANROADS Arusha | √ | | |
| | District Council Serengeti | √ | | |
| | District Council Chunya | √ | | |
| | District Council Mbeya | √ | | |
| | District Council Morogoro | | √ | |
| | District Council Tukuyu | √ | | |
| | District Council Kasulu | √ | | |
| | District Council Manyoni | √ | | |
| | Municipal Council Iringa | | √ | |

| Question 5b continued | Respondent | Responses | | |
|---|---|---|---|---|
| | | Low | Medium | High |
| | Municipal Council Temeke | - | - | - |
| | District Council Mkuranga | | √ | |
| | District Council Njombe | √ | | |
| | City Council Arusha | | | √ |
| | District Council Bahi | √ | | |
| | District Council Kyela | √ | | |
| | District Council Mbozi | - | - | - |
| | District Council Iringa | √ | | |
| | District Council Mvomelo | | √ | |
| | District Council Arumeru | | √ | |
| | District Council Kilolo | √ | | |
| | Municipal Council Dodoma | | √ | |

Note: Low – One plant per seven contractors
Medium – One plant per four contractors
High – One plant per two contractors

| Question 5c | Respondent | Responses | |
|---|---|---|---|
| | | Self- propelled | Dragged equipment |
| What type of grading methodology is adopted on unsealed roads? (Self-propelled machines or dragged equipment)<br><br>**Objective**<br>To determine the type of grading methodology adopted on unsealed roads in the area of respondent's jurisdiction | TANROADS Coast | √ | |
| | TANROADS Bukoba | √ | |
| | TANROADS Rukwa | √ | |
| | TANROADS Mbeya | √ | |
| | TANROADS Iringa | √ | |
| | TANROADS Morogoro | | However cannot give satisfactory performance |
| | TANROADS Manyara | √ | |
| | TANROADS Dar es Salaam | √ | |
| | TANROADS Dodoma | √ | |
| | TANROADS Tabora | Self propelled graders are normally used for grading operations | |
| | TANROADS Tanga | Self propelled motor graders and other related equipments are used to perform different grading operations. | |
| | TANROADS Arusha | Self propelled graders | |
| | District Council Serengeti | √ | |

| Question 5c continued | Respondent | Responses | |
|---|---|---|---|
| | | Self- propelled | Dragged equipment |
| | District Council Chunya | √ | √ |
| | District Council Mbeya | √ | |
| | District Council Morogoro | - | - |
| | District Council Tukuyu | √ | |
| | District Council Kasulu | | |
| | District Council Manyoni | √ | |
| | Municipal Council Iringa | √ | |
| | Municipal Council Temeke | √ | |
| | District Council Mkuranga | √ | |
| | District Council Njombe | √ | |
| | City Council Arusha | Self propelled machine are mainly used for unsealed roads (Gravel and Earth road) as well as dragging machines in rare case | |
| | District Council Bahi | - | |
| | District Council Kyela | Self propelled | |
| | District Council Mbozi | - | |
| | District Council Iringa | Self propelled and towed grade | |
| | District Council Mvomelo | - | |
| | District Council Arumeru | Self propelled | |
| | District Council Kilolo | Self propelled | |
| | Municipal Council Dodoma | Self propelled | |

| Question 5d | Respondent | Responses | | |
|---|---|---|---|---|
| | | Low | Medium | High |
| Have you ever considered labour intensive maintenance method in your area? If Yes indicates its frequencies<br><br>**Objective**<br>To determine whether the labour intensive maintenance have ever been considered in the area of respondent jurisdiction | TANROADS Coast | √ | | |
| | TANROADS Bukoba | | √ | |
| | TANROADS Rukwa | √ | | |
| | TANROADS Mbeya | √ | | |
| | TANROADS Iringa | √ | | |
| | TANROADS Morogoro | √ | | |
| | TANROADS Manyara | √ | | |
| | TANROADS Dar es Salaam | √ | | |
| | TANROADS Dodoma | √ | | |
| | TANROADS Tabora | √ | | |
| | TANROADS Tanga | √ | | |
| | TANROADS Arusha | | √ | |
| | District Council Serengeti | √ | | |
| | District Council Chunya | √ | | |
| | District Council Mbeya | √ | | |
| | District Council Morogoro | | √ | |
| | District Council Tukuyu | | | |
| | District Council Kasulu | √ | | |
| | District Council Manyoni | √ | | |
| | Municipal Council Iringa | √ | | |
| | Municipal Council Temeke | √ | | |
| | District Council Mkuranga | √ | | |
| | District Council Njombe | | √ | |
| | City Council Arusha | √ | | |
| | District Council Bahi | √ | | |
| | District Council Kyela | √ | | |
| | District Council Mbozi | √ | | |
| | District Council Iringa | | √ | |
| | District Council Mvomelo | | √ | |
| | District Council Arumeru | √ | | |
| | District Council Kilolo | √ | | |
| | Municipal Council Dodoma | √ | | |

| Question 5e | Respondent | Responses | | |
|---|---|---|---|---|
| | | Labour based | Mixed | Equipment based |
| What is the current situation of maintenance in rural areas? | TANROADS Coast | | √ | |
| | TANROADS Bukoba | | √ | |
| | TANROADS Rukwa | | √ | |
| | TANROADS Mbeya | | √ | |
| | TANROADS Iringa | | √ | |
| | TANROADS Morogoro | | √ | |
| | TANROADS Manyara | | | √ |
| | TANROADS Dar es Salaam | | | √ |

| Question 5e continued | Respondent | Responses | | |
|---|---|---|---|---|
| | | Labour based | Mixed | Equipment based |
| **Objective**<br>To determine the current situation of maintenance in the area of respondent jurisdiction | TANROADS Dodoma | | √ | |
| | TANROADS Tabora | | √ | |
| | TANROADS Tanga | | √ | |
| | TANROADS Arusha | | √ | |
| | District Council Serengeti | | √ | |
| | District Council Chunya | | √ | |
| | District Council Mbeya | | √ | |
| | District Council Morogoro | | √ | |
| | District Council Tukuyu | | | |
| | District Council Kasulu | | √ | |
| | District Council Manyoni | | | √ |
| | Municipal Council Iringa | | √ | |
| | Municipal Council Temeke | | √ | |
| | District Council Mkuranga | | √ | |
| | District Council Njombe | | √ | |
| | City Council Arusha | | | √ |
| | District Council Bahi | | √ | |
| | District Council Kyela | | √ | |
| | District Council Mbozi | | | √ |
| | District Council Iringa | | √ | |
| | District Council Mvomelo | | √ | |
| | District Council Arumeru | | | √ |
| | District Council Kilolo | | √ | |
| | Municipal Council Dodoma | | √ | |

Note: Mixed – Labour and Equipment based

| Question 5f | Respondent | Responses | |
|---|---|---|---|
| | | Immediately after the end of wet season | At the beginning of the wet season |
| When do you schedule the maintenance activities on unsealed roads? Please give reasons for the decision | TANROADS Coast | √ | |
| | TANROADS Bukoba | Most of gravel roads deteriorate much during rainy season, and Maintenance works will not be interfered by rains | |
| | TANROADS Rukwa | Availability of water, and Rectification of defects which developed during rainy season | |

| Question 5f continued | Respondent | Responses | |
|---|---|---|---|
| | | Immediately after the end of wet season | At the beginning of the wet season |
| **Objective**<br>To determine when the respondent schedule the maintenance activities on unsealed roads | TANROADS Mbeya | To avoid excessive moisture content which could lead to damage of the completed work | |
| | TANROADS Iringa | The road condition is normally poor after the rain, hence interventions need to be undertaken to improve the condition. Road maintenance during wet season could not yield a good result | |
| | TANROADS Morogoro | For surface maintenance (grading) and drainage | For cleaning drainage structure |
| | TANROADS Manyara | To make sure that the moisture content is enough to compact the road, and to rectify any damage done by rainfall | |
| | TANROADS Dar es Salaam | To rectify potholes and erosion caused by washout/rain | |
| | TANROADS Dodoma | Any maintenance done at the beginning of wet seasons the effort will be eradicated during the rainy period | |
| | TANROADS Tabora | We have two wet seasons, short rain (Nov-Dec) and annual rains (March – May). Most of Routine works are executed between July and March of the following year. Periodic maintenance and Rehabilitation takes place between November and March. This is to compromise the shortage and excessive availability of water | |

| Question 5f continued | Respondent | Responses | |
|---|---|---|---|
| | | Immediately after the end of wet season | At the beginning of the wet season |
| | TANROADS Tanga | Road condition survey is carried out during the wet season. The data obtained are used to determine maintenance interventions and associated budgets. Preparation of bidding document and procurement work activities followed immediately thereafter. Maintenance contracts are completed just before the end of the wet season (commencement of maintenance) | |
| | TANROADS Arusha | Is when the road need to be restored after damages during rain period | |
| | District Council Serengeti | To fix the destructed roads, which occurred during the wet season | |
| | District Council Chunya | | Due to scarcity of funds and equipment, at the beginning of the wet season is best for vehicles compaction |
| | District Council Mbeya | √ | |
| | District Council Morogoro | During wet season roads deteriorate, therefore we have to reinstate them immediately | |

| Question 5f continued | Respondent | Responses | |
|---|---|---|---|
| | | Immediately after the end of wet season | At the beginning of the wet season |
| | District Council Tukuyu | To make use of the available Moisture content within the road bed/gravel so as to enhance compaction. It is difficult to work on the road when it is too wet or dry | |
| | District Council Kasulu | This is due to the nature of the soil, which is clay | |
| | District Council Manyoni | We use soil moisture as much as possible, | |
| | Municipal Council Iringa | It is easier to determine a correct intervention after rain season because you can get the feedback of water course from road users | |
| | Municipal Council Temeke | The soil posses moisture content which is likely to be within the limit | |
| | District Council Mkuranga | To avoid excessive rain distraction during construction works | |
| | District Council Njombe | It is easy to find the hidden problem | |
| | City Council Arusha | We normally schedule the maintenance activities towards the end of rainy season, because we do not need heavy rains and we also avoid dry season since water becomes a problem | |

| Question 5f continued | Respondent | Responses | |
|---|---|---|---|
| | | Immediately after the end of wet season | At the beginning of the wet season |
| | District Council Bahi | For periodic maintenance | Spot improvement and routine maintenance |
| | District Council Kyela | All defects are easily identified | |
| | District Council Mbozi | Many projects are implemented during dry season | |
| | District Council Iringa | Wet areas | Dry areas |
| | District Council Mvomelo | √ | |
| | District Council Arumeru | Water availability is questionable in most part of the district | |
| | District Council Kilolo | To provide stability of the road formation so as to improve the life span of the road | |
| | Municipal Council Dodoma | To rectify any defects caused by rain | |

| Question 5g | Respondent | Responses | | |
|---|---|---|---|---|
| | | Performance Specification | Method Specification | Both |
| Do you measure the compactive effort achieved after compaction exercise has been completed during the maintenance operation? If the answer is yes, which method is commonly used? | TANROADS Coast | √ | | |
| | TANROADS Bukoba | √ | | |
| | TANROADS Rukwa | | | √ |
| | TANROADS Mbeya | √ | | |
| | TANROADS Iringa | √ | | |
| | TANROADS Morogoro | √ | | |
| | TANROADS Manyara | √ | | |
| | TANROADS Dar es Salaam | | | √ |
| | TANROADS Dodoma | | | √ |
| | TANROADS Tabora | | | √ |
| | TANROADS Tanga | | | √ |
| | TANROADS Arusha | √ | | |
| | District Council Serengeti | | | No |
| | District Council Chunya | | | √ |

| Question 5g continued | Respondent | Responses | | |
|---|---|---|---|---|
| | | Performance Specification | Method Specification | Both |
| **Objective** To determine whether the respondent do measure the compaction effort achieved during maintenance operations | District Council Mbeya | | | √ |
| | District Council Morogoro | | | No |
| | District Council Tukuyu | √ | | |
| | District Council Kasulu | √ | | |
| | District Council Manyoni | √ | | |
| | Municipal Council Iringa | | | √ |
| | Municipal Council Temeke | √ | | |
| | District Council Mkuranga | √ | - | - |
| | District Council Njombe | √ | | |
| | City Council Arusha | | | √ |
| | District Council Bahi | √ | | |
| | District Council Kyela | | | √ |
| | District Council Mbozi | - | - | - |
| | District Council Iringa | √ | | |
| | District Council Mvomelo | | | √ |
| | District Council Arumeru | | | √ |
| | District Council Kilolo | √ | | |
| | Municipal Council Dodoma | | | √ |

Note: Performance specification – Specifying the dry density to be achieved
Method specification – Specifying compaction method to be adopted

## Appendix 12: Hausman test for fixed and random effect models

```
. hausman fe re, sigmamore
```

| | Coefficients (b) fe | Coefficients (B) re | (b-B) Difference | sqrt(diag(V_b-V_B)) S.E. |
|---|---|---|---|---|
| adt | -8.29e-06 | 8.97e-07 | -9.19e-06 | .0000757 |
| pf | .0001713 | .0000268 | .0001445 | .0004375 |
| dr | -.140106 | -.126868 | -.013238 | .0229025 |
| pm | -.0203651 | -.0174155 | -.0029496 | .0041456 |
| pp | .0002802 | .000236 | .0000442 | .0000455 |

```
                     b = consistent under Ho and Ha; obtained from xtreg
      B = inconsistent under Ha, efficient under Ho; obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                  chi2(5) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =        1.89
                Prob>chi2 =      0.8637
```

## Appendix 13: List of publications and conference presentations

### 1. Publications

Mwaipungu, R.R. and Allopi, D. 2014. Corruption, construction industry and gravel roads in Tanzania. *Journal of Public Administration*, 49(3):756-769

Mwaipungu, R.R. and Allopi, D. 2014. The challenges of implementing gravel road management system in sub-Sahara Africa: Tanzania case study. *International Journal of Applied Research in Engineering and Science*, 1(3):1-10

Mwaipungu, R.R. and Allopi, D. 2014. The review of sub-Sahara Africa gravel roads maintenance management System`s monitoring and need assessment: Tanzania experience. *International Journal of Sustainable development and planning*, 9(1):74-89.

Mwaipungu, R.R. and Allopi, D. 2013. The review of Tanzania`s Pavement and materials design manual and Standard specification treatment of gravel roads. *Tanzania Roads Association (TARA), Year 2013 annual roads convention. Delivery of Quality and safer roads in Tanzania*, Karimjee Hall, Dar es Salaam, November 28-29, 2013.

Mwaipungu, R.R. and Allopi, D. 2012. The application of longitudinal roughness data as a tool for effective maintenance management of gravel roads. *The Tanzania Engineer*. 12(1).

Mwaipungu, R.R. and Allopi, D. 2012. Environmental and climatic challenges associated with gravel roads: Tanzania case study. *8th International conference on mitigation and adoption to climate change: Social, Economic and Engineering* *perspectives*. Naura Springs Hotel, Arusha, Tanzania. 6-8 December 2012. The Institution of Engineers Tanzania

Mwaipungu, R.R. and Allopi, D. 2012. The review of sub-Sahara Africa gravel roads management system: Tanzania case study. In: Longhurst, J.W.S. and Brebbia, C.A. ed. *18$^{th}$ International conference on urban transport and the environment; urban transport and the environment in 21$^{st}$ century*. La Coruna, Spain. 11-12 May 2012. Ashurst Lodge, Ashurst, Southampton SO407AA, UK WIT Press, 629-640.

**2. Conference Presentation**

Mwaipungu, R.R. and Allopi, D. 2015. The lessons gained from conducting a condition survey on unsealed roads surfaced with the marginal materials in Iringa region-Tanzania, Wessex Institute of Transport. *7$^{th}$ International conference on sustainable development and planning*. Faculty of Architecture, Istanbul Technical University, Turkey. 19-21 May 2015.

Mwaipungu, R.R. and Allopi, D. 2015. The formulation and application of a gravel loss model in management of gravel roads in Iringa region, Tanzania. *2015 Engineers without borders, 5$^{th}$ Bi Annuar conference: engineering knowledge creation, sharing and collaboration*. Zambezi Sun Hotel, Livingstone, Zambia. 30 April 2015 – 1 May 2015

Mwaipungu, R.R. and Allopi, D. 2014. The Challenges of collecting unsealed road conditions data as an input in maintenance management system in Tanzania. *9$^{th}$ International conference on attainment of UN millennium development goals in developing countries: lessons and challenges for engineers*. Naura Springs Hotel, Arusha, Tanzania. 4-5 December 2014.

Mwaipungu, R.R. and Allopi, D. 2014. The corruption practice in the construction industry and its effects on the performance of gravel roads: A Tanzanian perspective. University of Limpopo, *3rd SAAPAM Limpopo chapter annual conference*. The Park Hotel, Mokopane, Limpopo, South Africa. 29-31 October 2014.

Mwaipungu, R.R. and Allopi, D. 2014. The sustainability of gravel roads as depicted by sub-Saharan Africa`s Standard specification and manuals for road works: Tanzania case study. Wessex Institute of Transport, *20th International conference on urban transport and environment*. The Algarve, Portugal. 28-30 May 2014.

Mwaipungu, R.R. and Allopi, D. 2013. The review of Tanzania`s Pavement and materials design manual and Standard specification treatment of gravel roads. Tanzania Roads Association (TARA) . Year 2013 annual roads convention. Delivery of Quality and safer roads in Tanzania, Karimjee Hall, Dar es Salaam, November 28-29, 2013.

Mwaipungu, R.R. and Allopi, D. 2012. The appropriate material specification and manual is a key for effective gravel road design, construction and maintenance practice. *1st National conference on intermodal transportation. Eastern seaboard intermodal transportation application centre. Intermodal transportation: Problems, practice and policies*. Student centre, Hampton University, Hampton, Virginia, USA. 11-12 October 2012.

Mwaipungu, R.R. and Allopi, D. 2012. The use of gravel loss predicting models for effective management of gravel roads. *31st Southern African Transport Conference . Getting southern Africa to work*. CSIR International convention centre, Pretoria, South Africa. 9-12 July 2012.

Mwaipungu, R.R. and Allopi, D. 2012. The review of sub-Sahara Africa gravel roads management system: Tanzania case study. Wessex Institute of Transport, *18th International conference on urban transport and the environment in 21st century*. La Coruna, Spain. 11-12 May 2012.

Mwaipungu, R.R. and Allopi, D. 2011. The use of longitudinal roughness data as a tool for effective management of gravel roads. *30th Southern African Transport Conference. The Africa on the move*. CSIR International convention centre, Pretoria, South Africa. 11-14 July 2011.