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**SCHOOL OF GRADUATE STUDIES**  
**SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**  
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**Modeling of Gravel Loss for Unsealed Roads**

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**The School of Civil and Environmental Engineering**  
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**MSc. Thesis on**

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**List of Abbreviation**

FDRE	Federal Democratic Republic Of Ethiopia
ERA	Ethiopian Roads Authority
URRAP	Universal Rural Road Accesses Program
ILO	International Labour Organization
ARRB	Australian Rural Road Board
ADT	Average Daily Traffic
MMP	Mean Monthly Precipitation
PI	Plasticity Index
G	Gradient
LVR	Low Volume Roads
DC	Design Class
RSDP	Road Sector Development Programm
VOC	Vehicle Operation Cost
AASHTO	American Association of State Highways and Transport Organization
ASTM	American Standard Test Manual
USCS	Unified Soil Classification System
VPD	Vehicle per Day
PMS	Pavement Management System
PIARC	Permanent International Association of Road Congress
TRRL	Transport and Road Research Laboratory
HDM	Highway Development and Management
SPSS	Statistical Package for the Social Sciences
USAID	United Sates Aid
IS	International Standard
BMTS	British Material Test Standard
GLM	General Linear Modeling
MLR	Multiple Linear Regression

## Abstract

Gravel loss is the reduction in thickness of the surfacing course of gravel road. It can be caused by many factors. Traffic as average daily traffic (ADT), climate in terms of mean monthly precipitation (MMP), geometric design parameters of the roads represented by absolute gradient (G), surface material of the road in terms of plasticity index (PI) and the duration of observation (D) was used as the model independent variable.

The dependent variable of the model, gravel loss, was collected by observing the selected gravel roads in three month interval. The selected roads were D/Birhan-Kasima, D/Birhan-Ankober and Chacha-Tsgerada –Ginager. The samples were prepared in to a grid of 15m of which divided into 5m interval. Elevation, across the width of the road, was observed using total station. Independent variables included in the model were gathered using standard procedure and methods.

Two models were developed using SPSS 15.0. The first model used multiple linear regression (MLR) model and it had a prediction power of 87.9% ( $R^2$  of 0.879). The second model used general linear modeling (GLM) and it had a prediction power of 99.4% ( $R^2$  of 0.994).

The model helps the parties involved in managing gravel roads. It can be used in gravel roads management system; in determination of maintenance and rehabilitation requirement and in predicting the residual life of gravel roads.

## Chapter 1: Introduction

### 1.1. Background of the study

In Ethiopia, the transport sector is a large working environment in which the road transport, air transport, marine transport and rail transport are functional. However, the dominant mode of transport is road transport, having a share of 90% in transporting passenger and cargo transports across the country [1]. In Ethiopia, Federal and regional road authorities manage the entire road asset. The federal road authority is responsible in constructing and maintaining of the roads that connect region to region and sometimes it may manage the roads that have higher volume which starts and ends with in one region. The regional road authorities only have low volume road which are gravel roads that connect Zones and Woreda's in the region. According to ERA [2], from the total road network in the country which was 56,100 km of both gravel and asphalt road asset, federal road authority (ERA) had 24,550 km and the regional road authorities had 31,550km. Considering gravel roads network that was managed by both authorities, it was 82% of the country's road network.

Access is the key determinant of poverty and gravel roads give access for the rural societies to different areas so that they become involved in social, economical and political movement which is exercised in the country. Rural roads improve rural access, which facilitates marketing, schooling and health services. Better access provides the opportunity for increased income and employment opportunities and can also contribute to the alleviation of poverty.

Although there are many definitions of unsealed roads, gravel roads are the concerns of this study. According to Theuns Henning [3], unsealed roads are, the roads that have no permanent surface proofing of water in contrast to sealed roads. There are three classes of unsealed roads.

1. **Unengineered Roads or Earth Roads:** have no drainage, cross fall, added granular material or other features that would ensure all-weather access.
2. **Engineered Roads:** have a reasonably well defined cross section, including drainage. They usually consist of locally available earth material with no added surfacing material.
3. **Graveled Roads:** are built and designed to certain engineering principles, including the supply, where warranted, of gravel wearing surface. Construction of these roads also involves a defined cross section, drainage and structures (bridges, culverts).

Gravel roads are heavily affected by their environment. Road environment can be classified in to two. Man-made environment includes traffic, historical events, political decision, and economics and natural environment includes; topography, climate, and geology. Topography to which the gravel road constructed on, can be related to alignment of the roads, drainage and gravel loss. Gravel roads in contrast to sealed roads, when they are designed and constructed, they tend to follow the natural contour. In highly contoured terrain, gravel roads are likely to be steeper and more sharply curved than their paved counterpart. The effects of topography on gravel roads alignment therefore are higher. Topography also affects the drainage capability of the roads. If the roads have flat terrain water may be accumulated on the road and facilitate the deterioration of the road. If the roads have mountainous terrain, since it increases the flow

of water, the consequence become erosion and gravel loss of the surfacing material. Traffic in terms of composition, volume and axle load, should be considered to identify the defects on gravel roads [4].

Gravel roads can be deteriorated by different factors. Understanding the factors that influence gravel loss could be significant for two reasons: (i) to decide and plan upgrading at the appropriate time and (ii) to reduce gravel loss through alternative maintenance approach [5]. Traffic, climate, quality of surfacing material and geometric design of the roads etc., are the major variables that should be considered to investigate the kind of deterioration on gravel roads. Due to those factors that cause deterioration, corrugation, potholes, ruts, dust loose gravel, loss of gravel, stoniness and cracking will be the final out put on gravel roads [6][4][7].

Most of the deteriorations observed on gravel roads are caused by the combination of those factors. It is rare that the particular type of defects to be caused by the single deteriorating agent. Traffic, for example, in combination with other factors, can be the cause of corrugation, potholes, ruts, dust, loose gravel, loss of gravel and stoniness [7]. But, from the maintenance point of view the most expensive type of defect is loss of surfacing material of the gravel roads. Since the lost gravel should be replaced, it becomes the challenge of many road agencies regarding the amount of gravel to be replaced and the limited budget allocation for maintaining the whole road network [8].

Maintenance, according to C.H. Donges [9], is to ensure that the road remains serviceable throughout its design life. It is important because it:

1. prolongs the life of the road by reducing the rate of deterioration, thereby safeguarding previous investments in construction and rehabilitation
2. lowers the cost of operating vehicles on the road by providing a smooth running surface
3. Keeps the road open for traffic and contributes to more reliable transport services; sustains social and economic benefits of improved road access.

Maintenance can be classified in to routine, periodic and emergency depending on their interval of application, machinery, labor usage and type of defects to be maintained. Gravel loss, for example is maintained by resurfacing and this activity is periodic maintenance [10] [11]. Among the three types of maintenance, obviously the emergency maintenance is the most important as it relates directly to keeping the roads open to traffic. In terms of non-emergency related works, it is the regular or routine maintenance activities which have the most significant effect in terms of extending the lifetime of a road. These works do not involve any sophisticated technology or skills. They can be carried out using manual labor and simple hand tools. The activities are inexpensive. Despite this, they still require a sound management organization to ensure that works are carried out at the right place and time. Periodic maintenance is the most expensive types of maintenance and gravel loss is mitigated by this.

However, all road work agencies need to factor in budgetary limitations when planning their maintenance program. Every engineer responsible for road maintenance faces the additional challenge that available funds are never sufficient. It is therefore necessary to assess the

importance of the various work interventions to ensure that available resources are utilized in the most effective manner [9].

Gravel loss is defined as the change in thickness of gravel roads surfacing over a period of time. The rate of gravel loss is recorded as the vertical loss in mm of material from the road surface. The loss of material for different types of material is not the same [8]. Using the above definition at hand, gravel roads are designed having two kinds of layer. The first one, which is directly in contact with traffic, is designed considering the loss of surface material due to traffic, rain fall or precipitation and others. The second layer is designed to protect the subgrade from excessive compressive strain. Therefore, the thickness of the gravel road is the combination of or assumption of consideration of gravel loss and protection of the subgrade from damage [13].

If the surfacing material of the roads is lost, the remedy to this will be to resurface or regravell the roads. The task consists of the complete resurfacing of existing gravel roads by the application of uniform thickness course of shaped, compacted natural or crushed gravel surfacing material. As the task is mechanized and periodic maintenance, it shares a significant amount of maintenance budget [10] [11] According to the World Bank [14], loss of surface material is particularly critical for gravel roads, where the loss or replacement of the lost gravel represents substantial costs. Rates of loss depend on material quality, traffic, rainfall, gradient and maintenance regime. For example, rates of loss can typically be 2 to 5 cm per year in a medium to high rainfall tropical environment. Replacement of the lost surface gravel can be as much as 60% of the total maintenance costs [15]. In table 1.1, in periodic maintenance of the particular road, the cost of resurfacing gravel roads by selected material (which was not include the cost of excavation to embankments) was 58.1% of the total expenditure of the road.

To be cost effective in resurfacing of gravel roads, the operation should be properly planned and managed. Estimation of resurfacing interval is important to adequately manage scarce resource allocated to maintenance. By predicting the gravel loss, road authorities can be benefited in managing their road assets. According to Richard R. Mwaipungu et.al [16], to conserve the gravel materials borrow pits and gravel materials deployed as surfacing layer of unsealed roads, there is a need to reduce regravelling cycles to optimum level by predicting the loss of surfacing material from gravel roads.

In this research there were two types of variables, i.e., dependent and independent variables. The dependent variable was gravel loss measured from the road by the use of optical survey method. The independent variables were average daily traffic (ADT), mean monthly precipitation (MMP), plasticity index (PI), absolute gradient (G) and duration of observation (D).

Table1.1: Activities of Periodic Maintenance

Source: Periodic maintenance road project under Shashemane district [17]

Item NO.	Description	Unit	provisional unit rates(Birr)	Total Used	
				Qty	Amount
Pavement					
1	Clearing and Grubbing	Ha	12,208.86		
2	Detour Construction	lm	32.38		
3	Road Bed Preparation	m	66.94	26,000	1,740,440
4	Gravel Resurfacing (Resurfacing )	m <sup>3</sup>	162.99	24,570	4,004,664.3
5	Common Excavation To Embankment	m <sup>3</sup>			
6	Embankment Placing				
Minor Drainage Works					
7	Culvert Cleaning	m <sup>3</sup>	67.27	32.16	2,163.4
8	Ditch Cleaning	Km	4,064.92	52	211,375.84
9	Mortar Masonry Repair	m <sup>3</sup>	549.59		
10	Selected Granular Backfill	m <sup>3</sup>	133.95		
11	Pipe Production	lm	862.5		
12	Pipe Installation	lm	1,344.96		
13	Paved Water Way	m <sup>2</sup>	185.36		
14	Structural Excavation	m <sup>3</sup>	52.75		
day works					
15	Other Routine Maintenance	DWs	1,012.5		56,842.75
16	Betterment	DWs			
Haulage					
17	Overhauling	m <sup>3</sup> km	5.01	174,622.5	874,858.73
Sub Total					6,890,345.02
Material Production					
1	Selected Material Production	m <sup>3</sup>			
2	Borrow Material Production	m <sup>3</sup>			
Sub Total					
Grand Total					6,890,345.02
Total Including 15% VAT					7,923,896.77
Hageremariam –Burji (28km) Periodic Maintenance Road Project (100% complete)					

The method followed to conduct gravel losses record was longitudinal observational study. According to Abiy Zegeye, et.al, [18], observation refers to the process of observing and recording events or situations. The technique is particularly useful for discovering how individuals or groups of people or animals (and in some instances inanimate objects) behave, act or react. Gravel loss data of each sample gravel road was collected from the 15m long

sample and this was divided in to 5m interval. The width of each sample road was variable but the data was collected at 1.0m interval along the width of each sample roads selected. For independent variables, different mechanism was followed to collect data. Traffic count of each sample road was conducted using observation of the flow of traffic (in both direction) and it was to obtain average daily traffic (ADT). Climatic condition of the area through which the gravel road passes, especially rainfall or precipitation, was obtained from Ethiopian Metrological Agency. The data regarding the behavior of the material was obtained from the test of the material in the laboratory. Test was conducted to have the plasticity index of each sample gravel roads. Geometrical condition of the sample road was represented by gradient of the road. The data regarding the gradient of the sample was obtained by optical survey method simultaneously with gravel loss data measurement. The last independent variable, which is the duration of observation, was obtained by counting the days between the two observations (initial and final).

The study area was located in Semen Shewa parts of Amhara region, around D/Birhan Town. Totally three roads was selected for the study of gravel loss. The two roads, D/Birhan – Kasima, Chacha –Tsgerada-Ginager, are authorized by Amhara Rural Road Authority and the third one, D/Birhan-Ankober, is mandated by Ethiopian Road Authority. From roads in the rural road authority, the first one was given periodic maintenance and the other one was newly constructed gravel road. Therefore, there was no maintenance activities executed in these roads during the observation period. The third road was maintained by routine maintenance and had a plenty of surface material.



Figure1.1: map of the Amahara region and zone of the study area

Source: Amhara regional states -Finance and Economic Development Biro

## 1.2. Statement of the problem

After the surface material is lost, resurfacing or regravelling, which is more expensive, is one of the remedial measures that will be executed to make the roads serviceable throughout the year. Some road agencies in Ethiopia maintain their roads by conducting condition survey. This kind of operation never tells about the future demand of maintenance. It is found necessary to devise some mechanism which can help the road agencies to manage their roads asset properly. Modeling of gravel loss is one of the methods that can help the managements of the roads. It was emphasized that several gravel loss models have been proposed over the years but, many of these models were developed for application in a particular region or country under specific traffic and climatic conditions. Gravel loss model should be developed to consider our countries specific conditions [5].

## 1.3. Research question

The major questions that the research tried to answer include the following:

1. What were the major variables that caused gravel loss in Ethiopia?
2. What were the relationships between gravel loss and individual variables that cause gravel loss in Ethiopia?
3. Could gravel loss be modeled?

## 1.4. Objective of the study

Modeling of gravel loss helps to predict the gravel loss in the specific road and makes the management of gravel roads easy. In order to properly manage the deterioration of gravel loss, the factor that causes the defect should be investigated. The prediction model contains the factor that can affect the road vigorously. This research contains two kinds of objectives i.e. general and specific objectives. The general objectives of the research were:

- to identify the major variables or factors that caused gravel loss
- to develop models that best represent gravel loss of observed gravel roads

The specific objectives were:

- ✓ to select the major variables that can affect the behavior of gravel roads from many options .i.e. environmental and man-made factors
- ✓ to identify the major defects on gravel roads that leads to gravel loss
- ✓ to propose the method and procedure in developing gravel loss model
- ✓ to propose alternative gravel loss models

## 1.5. Scope of the Research

The model developed summarized the factors that can cause gravel loss and only the most critical factors that affect the gravel road were included.

The model was intended to show the gravel loss from those specific gravel roads. Samples taken from the roads were too insignificant to generalize the behavior of gravel road in Ethiopia. It is not recommended to use the developed model for the road section other than the observed gravel roads.

The aim of the research is to show the way to further studies in gravel road deterioration and especially on gravel loss. The methodology followed and the measurement executed can be duplicated for further use. Factors that are included in the study may not be comprehensive. Therefore, it is the responsibility of the researcher to select the major variable that cause gravel loss.

It is obvious that the readings observed on the sample roads were affected by various types of defects that are created after the initial reading was taken. Although the model should consider such kinds of effects, it becomes difficult to include them in addition to the factor that causes them. Therefore, only the factor that cause deterioration of gravel roads that leads the roads to loss its wearing surface was included in the model.

### **1.6. Significance of the study**

The developed model can be used for many purposes. Modeling of gravel loss can benefit road agencies in:

- gravel road management system
- in determining maintenance and rehabilitation requirement
- in predicting the effects of proposed policies
- in predicting the residual life of gravel roads
- in evaluating the trade-offs between different maintenance and construction policies
- in establishing an economically defensible grading cycle
- in inhibiting gravel loss
- in determining regravelling frequency and gravel materials characteristics and specification [16].

Gravel loss was the concern of the study. To mitigate the problem caused by this defect, modeling should be conducted by considering the factor that causes it. Modeling of gravel loss benefits the road parties that involve in maintenance gravel loss. Different types of methods and procedures were followed to do the task. The model developed can be used to predict the gravel loss on the sample roads selected.

## Chapter 2: Literature Review

### 2.1. Introduction

Ethiopia is a country of great geographical, geological and climatic diversity. Altitudes range from the highest peak at Ras Dashen (4,620m above sea level) down to the Afar Depression (110m below sea level). The high plateaus and mountain, ranges usually above 1500m are characterized by precipitous edges and dissection by numerous rivers and streams. These areas constitute about 45 percent of the total area and are inhabited by close to 80 percent of the population [19].

In Ethiopia road transport plays a significant role in every aspect of activities. It facilitates economic development by benefiting the population of the country. The benefits can be observed in economic, social and political activities with in the country. In early modernization theory, roads were considered to be the important catalysts of economic development. Although the theory that building a road leads to development becomes the controversial issue, the modernization theory still works to the present time [2] [20].

Gravel roads are considered as low volume roads in Ethiopia. Low volume roads are defined as those roads carrying up to about 300 vehicles per day and Less than about 1 million equivalent standard axles. These roads contain mainly collector and feeder roads in Ethiopia. Low volume roads (LVR) are categorized in design code (DC) of 4 up to 1 [19]

Table2.1 Road classes in Ethiopia

Source: ERA, Low volume road design, [19]

Road Functional Classification					Geometric Standards	Level of Service	AADT	
			LINK	TRUNK	HIGH VOLUME	A	>10,000	
							DC8	3,000 - 10,000
						DC7	B	1,000 - 3,000
						DC6		300 - 1,000
	COLLECTOR	MAIN ACCESS			LOW VOLUME	C	150 - 300	
							DC4	75 - 150
							DC3	25 - 75
							DC2	<25
FEEDER					LOW VOLUME	D	<25	
							Track	

Table 2.2 shows that, the growth of each type of roads in the region and in the country was different. In the federal road network, asphalt road has grown in average of 6% and the gravel road has grown in average of 3%. This shows that the federal road authority was mostly concentrated on construction of asphalt roads than gravel roads. Observing the gravel road

growth in the region, since it is the only types of their road asset, the network has grown higher than the gravel roads in the federal road network (7.65%).

Table 2.2: Road network development in Ethiopia

Source: 15 year assessment of RSDP [2].

Federal Road Network (km)							Regional roads	
year	Asphalt (km)	Growth rate in (%)	Gravel (km)	Growth rate in (%)	total (km)	Growth rate in (%)	Gravel (km)	Growth rate in (%)
1997	3708		12162		15870		10680	
1998	3760	1.38	12240	0.81	16000	1	11737	10
1999	3812	1.36	12250	0.39	16062	0.4	12600	7
2000	3824	0.31	12250	0.07	16074	0.1	15480	23
2001	3924	2.55	12467	1.93	16391	2	16480	6
2002	4053	3.18	12564	1.36	16617	1	16680	1
2003	4362	7.08	12340	0.51	16702	1	17154	3
2004	4635	5.89	13905	9.91	18540	11	17956	5
2005	4972	6.78	13640	0.39	18612	0.4	18406	3
2006	5002	0.60	14311	3.63	19313	4	20164	10
2007	5452	8.25	14628	3.82	20080	4	22349	11
2008	6066	10.12	14363	1.71	20429	2	23930	7
2009	6938	12.57	14234	3.51	21172	4	25640	7
2010	7476	7.20	14373	3.10	21849	3	26944	5
2011	8295	9.87	14136	2.59	22431	3	30712	14
2012	9875	16	14675	8.63	24550	9	31550	2.7
% age	40	6.21	60	2.82		3		7.65

## 2.2. Gravel Roads

According to William B. A. et.al [21], the term gravel road is generally used to refer to all unpaved roadways. A true gravel road is a roadway whose surface layer is constructed of mineral aggregate materials (such as sand, gravel, pebbles or crushed stone) that are generally obtained from gravel pits and quarries. In line to this definition, Theuns Henning [3]), defines unsealed roads as a road that has no permanent surface proofing of water in contrast of sealed roads.

Gravel roads are built and designed to certain engineering principles, including the supply, where warranted, of gravel wearing surface. Construction of these roads also involves a defined cross section, drainage and structures (bridges, culverts). Good gravel road is constructed of three different layers. The subgrade or roadbed is the bottom layer made up of the native

material (clay, silt or sand) found along the roadway alignment or fill to level a depression. The aggregate base is placed on top of the subgrade and is ideally 45cm to 60cm depth. It should be constructed from free draining and easily compactable aggregate material (gravel or crushed stone) that produces a strong and stable layer. Such aggregate base materials should contain a minimal amount of fines (materials with a very small particle size such as clay or silt) since they tend to inhibit the free drainage of water, which could reduce the strength of the aggregate base. Finally, the surface layer (uniformly graded gravel or crushed stone) is placed on top of the aggregate base and it is at least 20cm in depth. Gravel roads can also be known as unpaved roads. This definition is clearly defined in the book [10] which says, "An unpaved road is a road with a soil or gravel surface."

The materials for gravel wearing course should satisfy the following requirements that are often somewhat conflicting. They should have sufficient cohesion to prevent raveling and corrugation (especially in dry conditions) and the amount of fines (particularly plastic fines) should be limited to avoid a slippery surface under wet conditions and dust in dry conditions. For an aggregate road surface to shed rain water, it must have an at least 10% fines in the material [6] [8] [13].

According to ERA [23], great care should be taken in using gravel as a road surface in some circumstances. It is unlikely that it will be suitable due to high costs of replacing the surface material that will be lost due to rainfall or traffic, or dust nuisance in the locations; where

- Traffic is more than 200 motor vehicles per day
- Annual Rainfall is greater than 2,000mm
- Longitudinal slope of road surface is more than 6%
- Through community settlements
- The haul distance from the quarry/pit to the road site is more than 10km
- The road section experiences flooding
- The gravel is of poor quality.

Gravel roads, due to their nature of construction, are prone to deterioration by different factors. These factors are traffic (speed, volume and axle loads), environmental factors especially climate (temperature and precipitation), surfacing material (type and nature) and geometrical design of gravel roads. Due to these factors, gravel roads deteriorated early than anticipated by their design. Defects on gravel road are potholes, corrugations, ruts, erosion (longitudinal and transversal), dust, loose material, stoniness and last but not least gravel loss [4] [6] [7] [8].

### **2.3. Deterioration of gravel roads**

Deterioration on gravel roads are determined by the behavior of the roads and the drainage capacity under the combined action of traffic and climate and the sufficiency of maintenance activities. Generally a problem begins slowly and progressively become serious. Slight defect

will grow to moderate faults and become severe conditions. As the condition become worse and worse, the distress show up on the surface [24].

According to ERA [19],” In determining cost-effective solutions for the provision of low volume roads, it is important to understand the mechanics of how the road deteriorates in the first place. Deterioration of the existing unpaved low volume roads in Ethiopia is governed by the type of material used on the surface (gravel to soil); the strength of the underlying soil (soft, erodible and/or expansive), the type and action of traffic (heavy vehicle to pedestrian) and probably most importantly, the influence of the “road environment”. The term “road environment” includes both the natural or bio-physical environment and the human environment. It includes the interaction between the different environmental factors and the road structure. Some of these factors are uncontrollable, such as those attributable to the natural environment, including the interacting influence of climate (e.g. wind, rainfall and intensity), local hydrology and drainage, terrain and gradient.”

Gravel road deterioration types are many and can be identified to their type of deterioration, degree and extent. The types of deterioration on gravel road are Loss of gravel, potholes, rutting, erosion, corrugations, loose material, stoniness, dust and cracking. Degree and extent of the distress are explained in tables 2.3 and 2.4.

Table 2.3: General description of degree class

Source: Standard visual assessment manual for unsealed roads [7]

<b>Degree</b>	<b>Severity</b>	<b>Description</b>
0	None	No distress visible
1	Slight	Distress difficult to discern. Only the first signs of distress are visible.
2	Between slight and warning	
3	Warning	Distress is distinct. Start of secondary defects. (Distress notable with respect to possible consequences. Maintenance might be required in near future e.g. potholes can be removed by blading)
4	Between warning and severe	
5	Severe	Distress is extreme. Secondary defects are well-developed (high degree of secondary defects) and/or extreme severity of primary defect. (Urgent attention required e.g. potholes require manual repair).

Table 2.4. General Description of extent class

Source: Standard visual assessment manual for unsealed roads [7]

Extent	Description	Estimate (%)
1	Isolated occurrence, not representative of the segment length being evaluated. They are usually associated with localised changes in the material, subgrade or drainage conditions. Intersections, steep grades or sharp curves may also result in isolated occurrences.	< 5
2	Intermittent occurrence, over most of the segment length, or extensive occurrence over a limited portion of the segment length. When occurring over most of the segment length, problems are usually associated with the material quality or maintenance procedures. When occurring over limited portions, the problem is usually a result of local material variations or drainage problems.	5 – 20
3		20 – 60
4		60 – 80
5	Extensive occurrence. This is usually a result of poor quality or insufficient wearing course material, or inadequate maintenance.	80 - 100

From the above two tables, the degree of a particular type of deterioration is a description of the magnitude of the individual deterioration type in specific area on the roads. The extent of the deterioration is the measure of how much of the road is covered by the particular type of distress. Condition survey should be conducted to know the actual maintenance needs of the roads using the above tables.

Figure 2.1 shows that in the life time of gravel roads, after the start of service, deterioration on the roads starts to be shown. In case of gravel loss, it is higher when the road is new and resurfaced. But at the time progresses, the reduction in the amount of surface material loss will be observed. On the contrary to gravel loss, other defects on gravel roads become increase in their impact and magnitude as the time progress. Heavy bladding operation to maintain the rough surface of the road can also increase the thickness of the roads and again gravel loss become higher after maintenance is done.

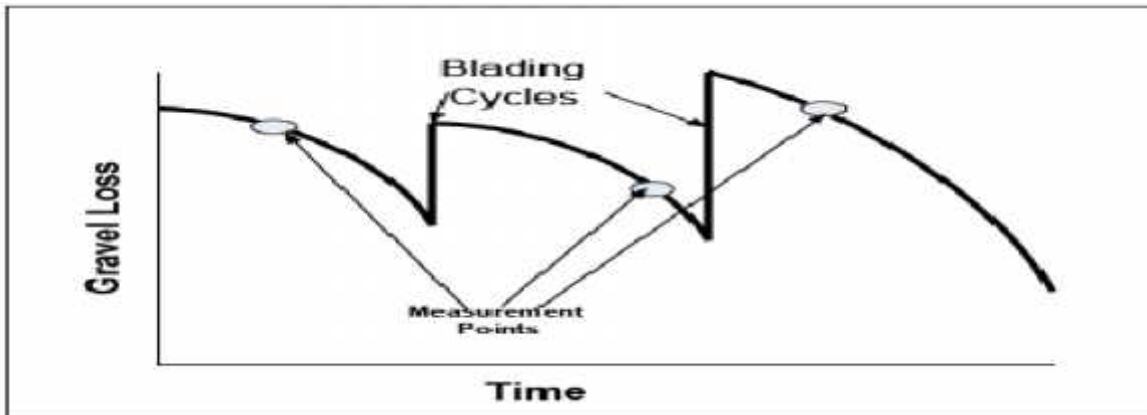


Figure 2.1: Loss of material from the road consideration of blading

Source: The development of gravel deterioration models [8]

Although gravel loss is the single output, it is related to various kinds of deterioration types. It is important to look deeply the types of deterioration of gravel roads which finally resulted to the loss of surfacing gravel. It is also significant to consider, in observation of the sample road for gravel loss, the cause of the observed loss. Potholes, ruts, corrugation, erosion, dusting, corrugation and etc., can vary the result of observed gravel loss. If reading was conducted on potholes, the values of gravel loss will be higher. But, in the case of corrugation the values can be positive i.e. it makes the second time reading to have higher values of heights than the first readings. This will lead to the rejection of the specific readings [8].

### 2.3.1. Potholes

Potholes are bowl-shaped, round or elongated depressions in gravel road surface. They may develop singly or in cluster. A group of potholes often ends up interconnecting as each expands. Potholes may also develop in conjunction with other surface distress, especially corrugation [4].

Potholes on the roads can be caused by due to:

- poor road shape and drainage
- poor grader operation practice (e.g. plucking of oversize material and destruction of the crown)
- compaction of material behind oversize stones under wheel loads
- poor compaction
- material and moisture variability
- enlargement of corrugation troughs
- deformation of weak subgrade and wearing courses
- subsidence or excavation of animal and insect burrows
- disintegration of highly cracked roads (i.e. excessive plasticity)
- disintegration of soft oversize materials
- dispersive soils [7].

Once the potholes are developed in the roads they become enlarged by the accumulation of water and this makes the surfacing material loose and detached by the vehicles riding on it. It enlarges in depth and in diameter. From the perspective of driving on potholed surface, they create difficulty and can damage the parts of the vehicle if not the driver manage the vehicle properly when reaching to them. Potholes in gravel roads can make vehicle operation cost become higher [24] [25] [26].

Although the degree or severity and the extent are varied through out the deteriorated gravel roads, maintenance should be in place after the roads shows some allowable ratings. The degree and extent of the pothole formation on road dictates the maintenance activity. Isolated potholes, which are created in dispersed manner on the length of the roads, has different maintenance approach than the roads that has extensive potholes through most of the length of the roads. [4] [11].



Figure 2.2: Potholes filled with water  
Source: Donald Walker [25].

### 2.3.2. Corrugation

Corrugation is one of the most disturbing defects of unpaved roads causing excessive roughness and poor vehicle directional stability. Corrugation or Washboard are rhythmic undulation that normally extends to the whole width of the roads and run perpendicular to the movement of traffic.

Corrugations can be either loose or fixed. Loose corrugations consist of parallel alternating crests of loose, fine-sandy material and troughs of compacted material at right angles to the direction of travel. Fixed corrugations on the other hand consist of compacted crests and troughs of hard, fine sandy-gravel material. Loose corrugations are easily removed by blading, whereas fixed corrugations need cutting or even tining with the grader before the material is re-spread. The wavelength of the corrugations is dependent on the modal speed (i.e. most frequently occurring speed) of the vehicles using the road, with longer wavelengths formed by faster traffic.

Although it is believed that the major contributor to corrugation formation on road is traffic, the behavior of the material in the structural parts of the road becomes a possible cause of corrugation [4] [7][25],

Gravel roads consist of coarse and fine aggregates. The coarse aggregate is gradually broken down by wear and sand is formed. When the road contains a lot of sand it is susceptible to corrugation [24]. Vehicle acceleration, deceleration and turning, increases the abrasive effects of tires and their tendency to corrugate the road surface. Accelerating quickly from a dead stop, decelerating suddenly to zero, or turning sharply at high speed, all heightens the effects even more. The parts of the road to which the road surface mostly corrugated are intersections, drive ways, curves grade of the roads [4].



Figure2.3: Severe Corrugation Type

Source: Gravel roads maintenance and design manual, [27]

### 2.3.3. Rutting

Ruts are types of deterioration that are longitudinal depression which are caused by permanent deformation of the road surface or subgrade by the loads of the traffic. They are parallel to the wheel tracks. They generally form as a result of loss of gravel from the wearing course by traffic abrasion and less commonly by deformation (compaction) of the subgrade and compaction of the wearing course [4] [7].

In general the causes of ruts are:-

- inappropriate aggregate composition
- wearing course of insufficient thickness
- inadequate compaction
- insufficient drainage
- high fine content [24].

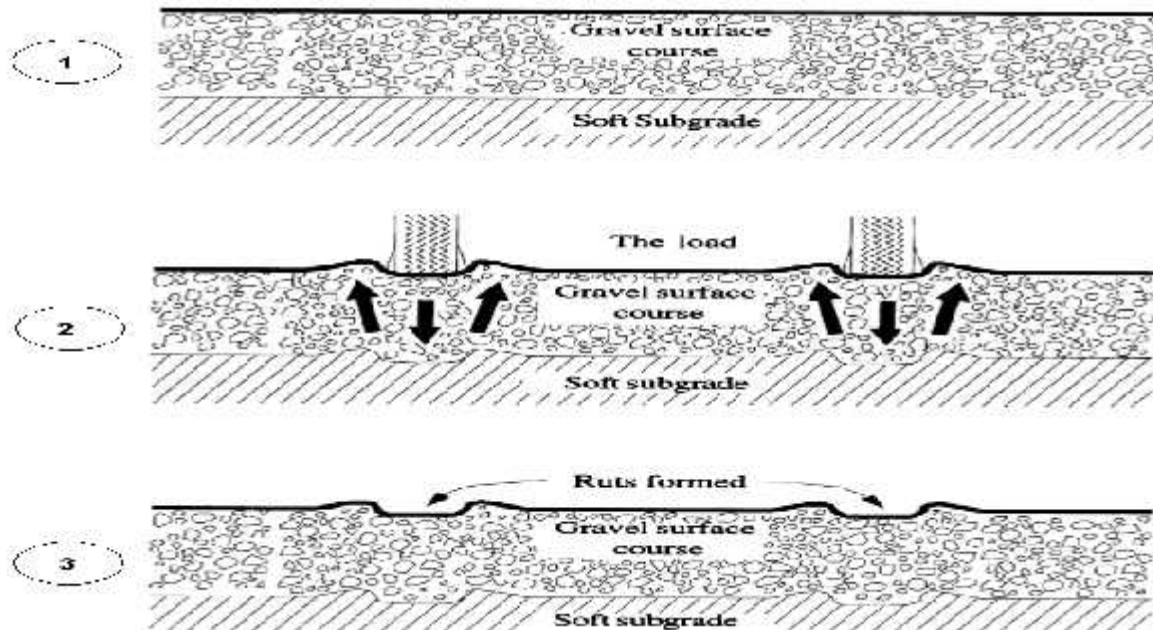


Figure 2.4: The Development of Ruts  
Source Federal Highway Administration, 1998, [4]

Ruts create difficulty in transportation. First the road that has ruts become filled by water and make the structural parts weak to support the loads of the vehicle and aggravate the deterioration of the road. If the severity becomes high enough, the driver may lose control of their vehicle. The most devastating effect is that it can create temporary break ups of the road transportation if the rutting becomes severe [4] [7].

#### 2.3.4. Erosion

Erosion is defined as the natural process by which wind, moving water, ice, and gravitational forces displace the solid and particulate materials of the land [28]. Concerning gravel roads, erosion of surfacing material is caused by the flow of water over the road and by the action of traffic and wind. The ability of a material to resist erosion depends on the shear strength (equal to the cohesion, as the normal stress is zero) under the conditions at which the water flow occurs. If the shear strength of the material is less than the tractive forces induced by the water flowing over the materials, grains will become detached and erosion will occur.

Erosion can be created longitudinally and transversally. The longitudinal erosion is occurred most of the time in grades and deep gullies will be created on the road. Transversal erosion is formed in horizontal curves and in tangents that lacks proper slopes. This creates difficulty in driving on them and leads in higher vehicle operation cost [7]. The characteristics of the surfacing material are crucial in reducing erosion. Some of the behaviors of the material that are related to erosion are:-

- soil texture (particle size and gradation)
- percentage of organic content

- soil structure
- soil permeability [29].



Figure 2.5: Transversal erosion



Figure 2.6: longitudinal erosion

Source:-Standard Visual Assessment Manual for Unsealed Roads [7].

Remedial measures to reduce the impacts of eroded gravel road should be in place. The activities that should be executed to maintain the roads are various but the most preventive measure is to develop the drainage capacity of the roads. This will ensure that the road will eroded slightly and maintenance cost would be minimized [11].

### 2.3.5. Loose material

Loose aggregate or unstable surface gravel condition can be developed by the action of traffic and poor material usage. Loose material (material less than 26 mm in size) is formed by the raveling of the wearing course gravel under traffic. This is due to when the original surfacing aggregate had improper gradation, lack cohesion and inadequate compaction, for example gap

graded surfacing material. This may be distributed over the full width of the road but more frequently, it is concentrated in windrows between the wheel tracks, or alongside the travelled portion of the road.

The major problem concerning of loose materials are stated as follow:-

- the windrows are a safety hazard
- stones from the loose material may damage vehicles or windscreens
- the rolling resistance of the vehicle is increased by loose material due to this it leads to increases in fuel consumption and vehicle operating costs
- windrows of loose material adjacent to the trafficked portion of the road impede surface drainage and become the cause of creation of secondary channel [7].



➤ Figure 2.7: Loose Material along the side of gravel road  
Source: Gravel roads maintenance and design manual [27].

### 2.3.6. Stoniness

Stoniness is the relative percentage of material embedded in the road that is larger than a recommended maximum size (usually 37.5 mm). This is one of the few defects that can be controlled, but usually it is not. Stoniness of the roads is classified in two: embedded and loose stones on the roads.

Excessively stony roads result in the following problems:

- unnecessarily rough roads
- difficulty with grader maintenance
- poor compaction of areas adjacent to stones (leading to potholes and raveling)
- the development of corrugations
- loose stones left after blading are likely to cause vehicle damage and potentially unsafe conditions [7].



Figure 2.8: Severe embedment of stones

Source: Standard Visual Assessment Manual for Unsealed Roads [7].

### 2.3.7. 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. Skid resistance is affected by an excess of loose, fine gravel that accumulates on the road surface through raveling under traffic or poor blading practices during dry conditions. This behaves like a layer of ball bearings and the skid resistance is reduced to practically zero. This is especially a problem on corners and at intersections. The main problems with slipperiness and skid resistance are the safety implications for road users.

Slipperiness can often be evaluated by observing wheel tracks formed during wet weather that are retained in the road after drying and other indicators. Slipperiness is rated as either acceptable or unacceptable [7]



Figure 2.9: unacceptable type of slipperiness on the roads

Source: Standard Visual Assessment Manual for Unsealed Roads [7].

### 2.3.8. Cracks

Cracking is not a usual deterioration type on gravel roads but in some circumstances it is observed on the surface of the roads. These defects are due to highly plastic surface material and the percentage of fines material become higher than the allowable range. Cracks can be the cause of pothole formation in dry season.



Figure 2.10: Severely Cracked Gravel Road Surface

Source: Source: Standard Visual Assessment Manual for Unsealed Roads [7].

### 2.3.9. Dust

All gravel roads will give off dust under traffic. After all these roads are typically used by low volume traffic, dust is usually an inherent problem. The quality and type of gravel material also has some effect on the amount of dust [27]. Road dust is the dry solid matter consisting of clay and silt-sized particles. Dust is created by wind, the wind shear forces created by vehicles and the interaction of vehicle tyres with the road. And this disperses and remains in suspension for a period before eventually falling back to the earth's surface [7]. Dusting is rated as viewed by the driver after the vehicle is passed before the next one.

Dust on gravel roads creates several problems. Visibility can be severely restricted under heavy dust conditions, creating traffic safety hazards. Dust is a form of air pollution and can be very objectionable to nearby property owners. The loss of the fine material from a well-graded gravel surface can eventually lead to a loss of stability. Without the fine binder material, the larger particles become unstable and are dislodged by traffic.



Figure2.11: Dust created by traffic on Chacha –Tsgerada -Ginager road

### 2.3.10. Gravel road roughness

Roughness is the term used to describe the relative degree of comfort or discomfort experienced by a road user when using a road. It is one of the most important aspects of a road network to monitor, since it directly relates to the experience of road users. As such, roughness serves as a collective measure of several aspects of road condition, including rutting, cracking, potholes, local failures and undulations [30]. The other term of roughness used is riding quality of the roads. According to D Jones and P Paige-Green [7], the riding quality of the road is probably the major performance parameter affecting driver and passenger comfort and safety. It also has a significant impact on the overall vehicle operating cost associated with the road. Road roughness is best quantified using one of the many items of equipment dedicated to roughness evaluation. However, for the purposes of network assessment, it is usually acceptable to rate the riding quality subjectively.

The roughness or riding quality of the road is influenced primarily by maintenance frequency, quality of grader maintenance and material properties. Other factors such as intensive rainfall and heavy seasonal traffic will also have an influence. Certain pavement defects are the direct result of deficiencies in the material properties. Defects influencing riding quality are:

- Corrugation
- Loose material
- Stoniness
- Potholes
- Ruts
- Erosion

Roughness on the road can be easily measured using the comfort of the occupant in the vehicle in different speed. Accordingly, the road that has less deterioration on the surface has a good riding quality. Rating of riding quality for different speed is shown in table 2.5.

Table 2.5: Rating of riding quality

Source: Standard Visual Assessment Manual for Unsealed Roads [7].

Rating	Descriptor	Description
1	Very good	Estimated comfortable/safe speed in excess of 100 km/h
2	Good	Estimated comfortable/safe speed between 80 and 100 km/h
3	Average	Estimated comfortable/safe speed between 60 and 80 km/h
4	Poor	Estimated comfortable/safe speed between 40 and 60 km/h
5	Very poor	Estimated comfortable/safe speed less than 40 km/h

In figure 2.12, roughness is the inverse of gravel loss. After the road is constructed or maintained, it starts to be deteriorated by different factors. Defects on the road will be shown on the road surface. The roughness of the road becomes more and more and finally it reaches on the stage in which the road requires maintenance (blading). This operation improves the condition of the roads and it reduces the roughness on the roads [31].

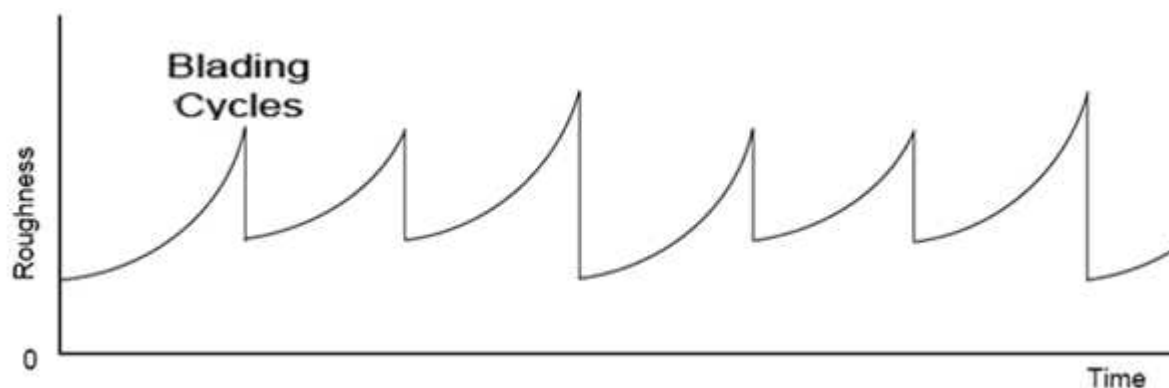


Figure 2.12: illustrative pavement life cycle with rehabilitation and reconstruction

Source: ATC (2006)

In general there are different kinds of roughness models developed in the world. The uses of those models are for different purpose. Maintenance and vehicle operation cost determination is very significant. With regards to gravel road maintenance, roughness index determination of the deteriorated road is useful for, most of the time, routine maintenance of the road. It is not significantly allow the managers to manage those works because these types of maintenance are easily observed by the technician to be maintained. Compared to gravel loss model, which is a powerful tool to manage gravel roads, model development of roughness for gravel roads are less important due to their complexity and expensiveness [8].

## 2.4. Causes of gravel loss

Considering gravel loss from the surface of gravel roads, factors that cause it can be traffic, climate, quality and behavior surfacing material, geometrical design of the roads and etc. The combination of those factors cause gravel loss. It is important to consider only major factor

because it is difficult to state all the factors that cause gravel loss. The factors that were used to model the gravel loss were reviewed as follow:-

#### **2.4.1. Traffic**

According to Hubendick and Lindth, referred by Hossein Alzubaidi (24), confirms that traffic is the greatest cause of wear of the road. Soil erosion or gravel loss by traffic comprises two active mechanisms. These are the slipstream and mechanical abrasion due to the torque developed by driving wheel. When the wheel of the vehicle rolls along the roads, the particles on the aggregate in the surface are subjected to considerable forces. Underneath the wheel load, the carriage way deformed to some extent. This gives rise to certain movement between the particles a little lower down in the wearing course. The particles grind against one another and abraded. Gradually, large particles become smaller. As the vehicle travelled along the roads, some particles inevitably thrown to the sides and vanishes. They are carried along by tailwind and are also spread out by wheels as they thrown in to the air. As regards of gravel loss, dusting is much more serious.

Hossein Alzubaid [24], states that the wearing course is continuously broken down by the vehicle wheels crushing the larger particles. The result is the shortage of aggregate and an excess of sand. Dust is the fine material released from the road surface under the wheels of moving vehicles and the turbulence caused by vehicles. Silt-sized particles (2 – 75  $\mu\text{m}$ ) are the predominant elements in dust and the quantity of dust generated by a vehicle is a function of its aerodynamic shape, speed of travel and the surfacing material properties [6].

According to Donald Walker [25], traffic on dry gravel road can generate dust. Good quality gravel used in the construction of gravel roads has a combination of large aggregate, sand and fine material or binder. These fines can be picked up under the action of traffic and become airborne. Dust on gravel roads creates several problems. Visibility can be severely restricted under heavy dust condition, creating traffic safety hazards. Dust is a form of air pollution and can be very objectionable to the nearby property owners. The loss of fine material from a well-graded gravel surface can eventually lead to a loss of stability. Without the fine binder material, the larger particles become unstable and are dislodged (raveled) by traffic.

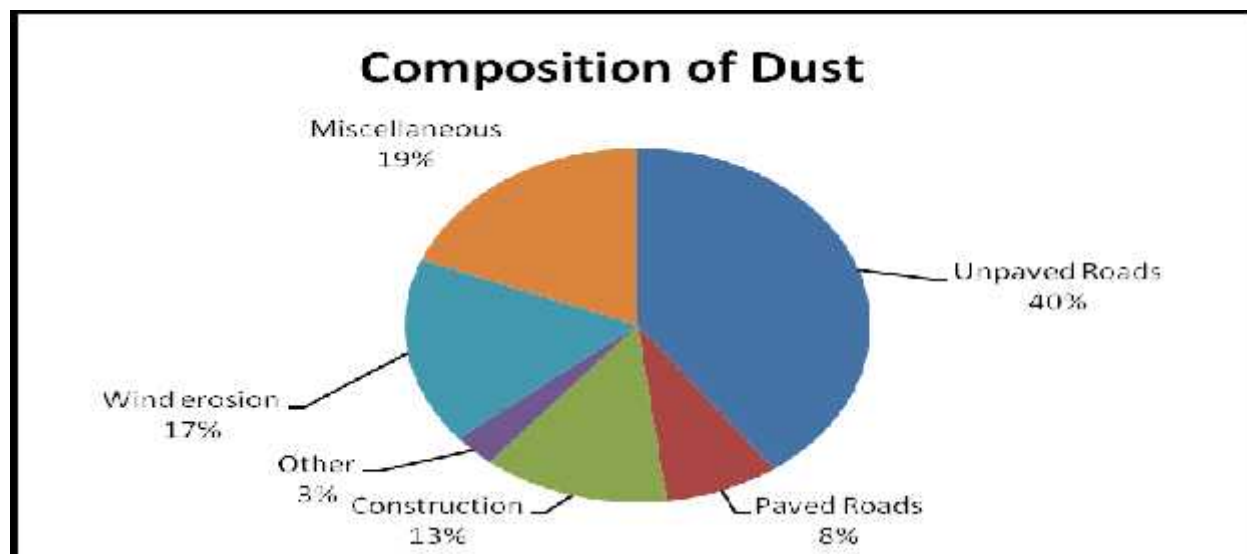


Figure 2.13: The Shares of Different Activities for the Dust Generation

Source: University of Missouri Extension [32]

Not only the axle load exerted by the vehicle cause dust, high speed is also the cause of dust generation. According to Nicholson et.al referred by Tony Greening [32], high vehicle speed is an important factor in generating dust due to the increased transfer of energy disturbing the dust from the surface of the road and the greater turbulence which transfers a greater amount of dust into the air.

ERA [13], states that, the mechanism of deterioration of gravel roads differs from that of paved roads and is directly related to the number of vehicles using the road rather than the number of equivalent standard axles. Traffic levels across Ethiopia vary considerably from region to region. In a 2010 traffic survey carried out by the Ethiopian Road Authority (ERA) on a 14,272 km sample of federal roads, AADT (Annual Average Daily Traffic) counts were taken for cars, small buses, large buses, land rovers, light trucks, medium trucks, heavy trucks and trailer trucks. Across all districts, heavier vehicles tended to account for a large proportion of the total traffic, with buses and trucks being the most common type of vehicle [33]. Table 2.6 shows the growth of volume in each type of vehicle yearly.

Table 2.6: Increasing AADT across Ethiopia

Source: ERA [33]

Year	AADT for each type of vehicle across all districts				Total
	Car	Bus	Truck	Truck and Trailer	
1998	13,680	12,291	20,198	4,909	51,078
1999	12,996	14,210	22,582	6,135	55,923
2000	13,403	13,205	22,585	6,479	55,672
2001	17,910	16,318	29,923	8,316	72,467
2002	18,299	17,955	31,049	11,383	78,686
2003	19,653	19,126	34,574	9,650	83,003
2004	21,488	22,760	38,280	10,178	92,706
2005	22,823	25,339	43,268	13,228	104,658
2006	25,862	31,050	48,411	13,734	119,057
2007	31,219	37,091	56,164	17,788	142,262
2008	33,231	42,345	60,464	18,321	154,361
2009	38,145	48,492	73,896	22,286	182,819
2010	39,782	53,986	79,885	22,886	196,539

It is obvious that vehicle on the road has grown in terms of volume and vehicle type that have higher axle load which is greater than from the design limit of the gravel roads. This should be considered in the design and construction of new projects. But, it is a little bit in line with the growth of vehicle of both volume and axle load [34]. Table 2.7 shows the relative traffic volume growth in Ethiopia. Addis Ababa, Dire Dawa and Harar had higher traffic volume growth on their roads. Tigray and Amhara regions had the lowest traffic volume growth.

Table 2.7: National and Regional Traffic Growth Rate

Source: ERA

Region	Low	Medium	High
Addis Ababa	5.7	7.1	8.5
Dire Dawa	5.7	7.1	8.5
Harar	6.0	7.5	9.0
Benishangul-Gumuz	4.5	6.0	7.0
Gambella	4.5	6.0	7.0
SNNPR	4.5	6.0	7.0
Oromiya	4.0	5.5	6.5
Afar	3.6	5.0	6.0
Somalia	3.6	5.0	6.0
Amhara	3.2	4.5	5.5
Tigray	3.2	4.5	5.5
<b>Ethiopia</b>	<b>4.5</b>	<b>6.0</b>	<b>7.5</b>

Figure 2.14 shows that gravel loss values for the roads that have the same percentage of heavy vehicle (HV) and had different volume of traffic. The road that had higher traffic volume had the highest gravel loss on the road and vice versa.

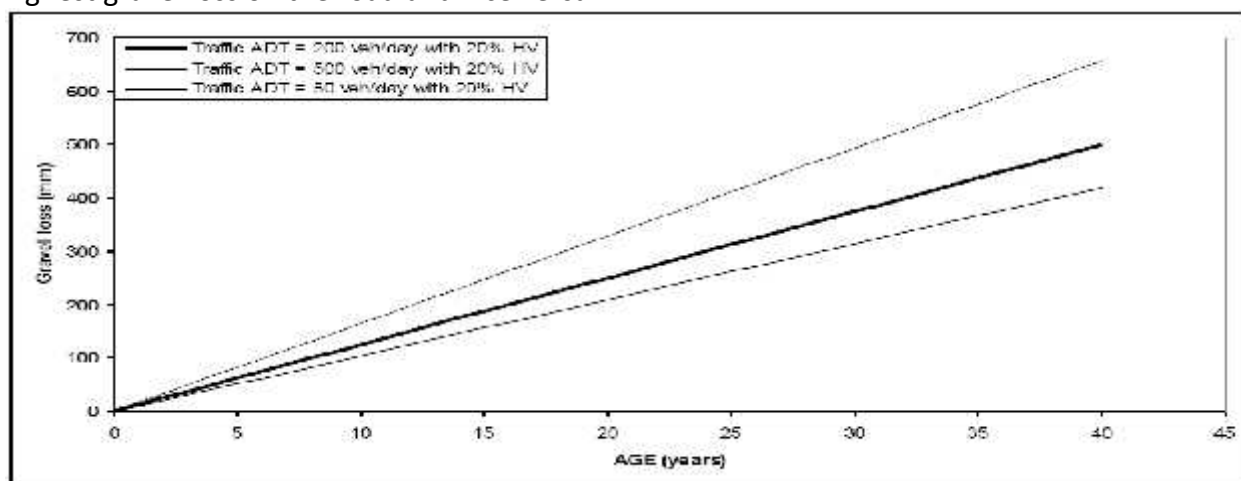


Figure 2.14: Gravel loss prediction for changes in traffic loading, ADT

Source: Dims Asset Management Tool User Documentation [35]

### 2.4.2. Climate / Precipitation

Although water may be the life-giving liquid of our planet, it has long been recognized as the arch-enemy of our gravel roads [36]. One of the major determinants of gravel loss is climate. Precipitation plays a significant role in eroding the surfacing material. According to Hossein Alzubaidi [24], during heavy rainfall, fine particles are dislodged, suspended in the water and are carried by the water in to the ditch. The condition of gravel roads varies greatly from season

to season. In spring and autumn the carriage way is generally softened by water. During summer, gravel roads are often corrugated, potholed and dusty.

A gravel road is susceptible to variations in climatic condition of the area to which the road located. In rainy season, the moisture content in the road become higher and due to this bearing capacity of the gravel road in general reduces and this leads the roads to rutting. In dry season the moisture content of the gravel roads reduces and this leads the roads to be corrugated and dusty. Never underestimate the force of a drop of rainwater. It is that water drop exploding when it impacts bare soil that starts the erosion process. If water passes through a road and fills the native soil, the road, whatever may be its thickness, loses its support and goes to pieces [36].

To understand the significance of water existence on gravel roads surface, three characteristics of water should be examined. Water acts as a lubricant, Water expands upon freezing and Water runs downhill. Water's presence allows materials to move more freely by decreasing the friction between particles. When a road gets wet, aggregates are more likely to move or become displaced under traffic loads. This in turn causes surface depressions that collect more water and result in even more weakened areas and soft spots.

The simplest and most obvious characteristic of water is that it runs downhill, subject to the relentless force of gravity. But we do not maintain our roads with this in mind. How many roads have ponding problems on the surface? We ignore this obvious characteristic at our roads peril. Like gravity, the effects of water are devastating and relentless [36]. In the figure below shows the relationships between gravel loss and rainfall for each type of traffic (vehicle per day, Average daily traffic, ADT).

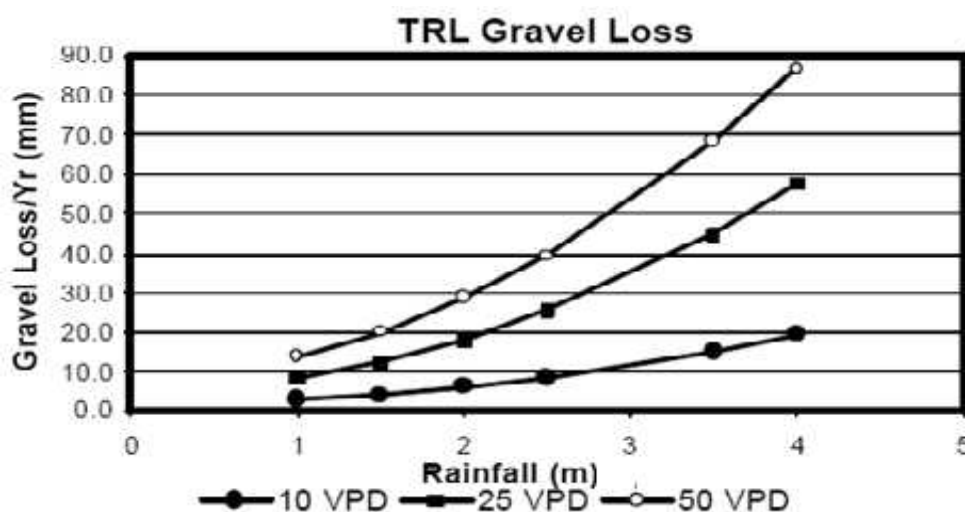


Figure 2.15: gravel loss with respect to rain fall

Source: Vietnam Rural Road Gravel Assessment Program [37]

### 2.4.3. Surfacing material of gravel roads

Low-volume road surfaces and structural sections are typically built from native materials that must support light vehicles and may have to support heavy commercial truck traffic.

In addition, low-volume roads should have a surface that, when wet, will not rut and will provide adequate traction for vehicles [38]. Roadway materials, and particularly roadway surfacing materials, such as aggregate or paving, can be half the cost of a road. Selection of materials directly affects the function, structural support, rider comfort, environmental impact and safety of the road user.

The classification systems for gravels used in road construction are generally depends on some measure of grading, maximum particle size, plasticity and bearing capacity [39]. AASHTO M 145, Classification of Soil-Aggregate Mixtures for Highway Construction Purposes, divides soils into the two major groups, namely granular and silt-clay materials. The granular materials are those soils with 35% or less passing the 75  $\mu\text{m}$  (No. 200) sieve. ASTM D 2487, divides soils into three major groups of coarse-grained soils (sands and gravels), fine-grained soils (silts and clays), and highly organic soils (peat and other highly organic soils).

Gravel surfacing material should contain the appropriate blend of material. Coarse aggregate, sand and fine aggregate parts of the surfacing material should be to their intended mix. The proper blend of different size aggregate on the road produces a surface that can be used in all types of weather [29]. From the perspective of gravel surfacing material, the material should satisfy some important criteria. According to ERA [40], the surfacing material should have sufficient cohesion to prevent raveling and corrugating (especially in dry conditions) and the amount of fines (particularly plastic fines) should be limited to avoid a slippery surface under wet conditions.

The specifications identify the most suitable materials in terms of two basic soil parameters; shrinkage product (SP) and grading coefficient (GC), which are determined from particle size distribution and linear shrinkage. An alternative to using linear shrinkage and the shrinkage product is to use the plasticity index and the associated plasticity product. For the range of materials likely to be used for gravel wearing course, the plasticity index can be assumed to be 2 x linear shrinkage. The linear shrinkage (shrinkage product) is recommended as it is based on one relatively simple test which has good precision limits in the shrinkage ranges of acceptable gravel wearing course material [41].

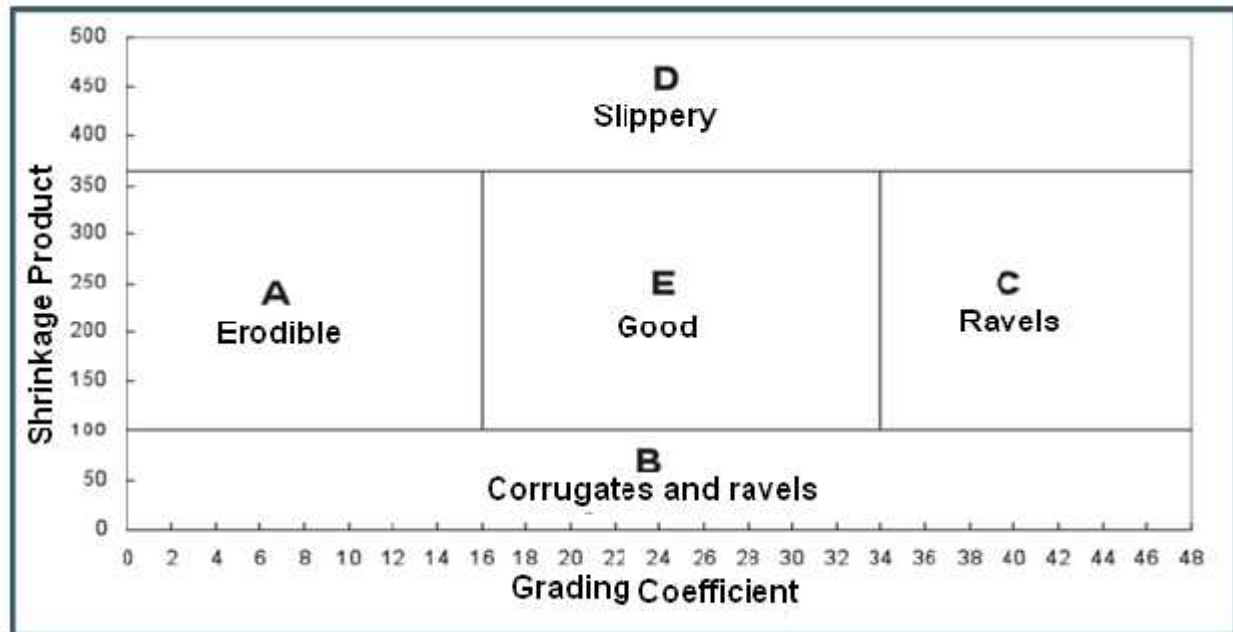


Figure 2.16: Material Quality Zone

Source: ERA [41]

Note:  $SP = (\text{Linear Shrinkage}) \times (\% \text{ passing } 0.425 \text{ mm})$

$GC = ((\% \text{ passing } 28 \text{ mm}) - (\% \text{ passing } 2 \text{ mm}) \times (\% \text{ passing } 5 \text{ mm}))/10$

The characteristics of materials in each zone are as follows:

1. Zone A material are generally perform satisfactorily but are finely graded and particularly prone to erosion. They should be avoided if possible, especially on steep grades and sections with steep cross-falls and super-elevations. Roads constructed from these materials require frequent periodic and labor intensive maintenance over short lengths and have high gravel losses due to erosion.
2. Zone B material are materials that generally lack cohesion and are highly susceptible to the formation of loose material (raveling) and corrugations. Regular maintenance is necessary if these materials are used and the road roughness is to be restricted to reasonable levels.
3. Zone C materials are generally comprised of fine, gap-graded gravels lacking adequate cohesion and resulting in raveling and the production of loose material.
4. Zone D materials with a shrinkage product in excess of 365 tend to be slippery when wet.
5. Materials in zone E perform well in general, provided the oversize material is restricted to the recommended limits [44]

In calculating the amount of dust from the surface of gravel roads, clay and silt content (% surface material < 0.075mm), average vehicle weight in tones and surface material moisture content should be considered [32]. Some of the factors that are the causes for erosion of

surface materials of gravel roads are soil type and condition. Coarse textured sands and gravels are the least erodible, because they are comprised of bigger and heavier particles that are harder to move. Water percolates in sand and gravel at a faster rate, which means there is less storm water to run off. Silts and fine sands are generally the most erodible soils, due to their large part to their small particle size. Smaller particles are lighter and more easily carried away by surface water runoff [42].

Surfacing material for gravel road should satisfy the criteria that standard sets for the usage of each types of material. Surfacing materials can be classified depending on their physical and chemical behaviors. In the world to day, there are many classification systems such AASHTO soil classification and USCS classification systems.

In the AASHTO classification system, road materials are classified in to

- Boulders:-retained on 3 in. square sieve
- Gravel: - material passing sieve with 3 in. square opening and retained on the No. 10 sieve.
- Coarse sand:- are material passing No.10 sieve and retained on the No.200 sieve
- Fine sand:- are material passing the No.40 and retained on No.200 sieve
- Combined silt and clay:- materials passing the No.200 sieve

The term clay and silt are also categorized by the use of plasticity index .if the material is silt it has plasticity index of 10 or less and if it is clayey it has plasticity index of 11 or greater. They can also be classified by the use of gradation. If the material has size between (2-75 $\mu$ m) it is silt and if it has a size less than 2 $\mu$ m it is clay.

According to Dr, K.R. Arora [43], plasticity of a soil is the ability to undergo deformation without cracking or fracturing. A plastic soil can be molded in to various shapes when it is wet. Plasticity is an important index property of fine grained soil, especially clayey soil. Plasticity in soil is due to the presence of clay material. The clay materials carry a negative charge on their surface

The clay particles are separated by layers of adsorbed water which allow them to slip over one another. When the soil is subjected to deformation, the particles do not return to original position, with the result that deformations are plastic (irreversible). As the water content of the soil reduces, the plasticity of the soil reduces. Soil becomes dry when the particles are cemented together as a solid mass. The presence of adsorbed water is necessary to impart plasticity characteristics of soil. The soil becomes plastic only when it has clay mineral. If the soil contains only non-clay mineral, such as quartz, it would not become plastic whatever maybe the fineness of the soil. When such soils are ground to very fine size, these cannot be rolled in to the threads.

Material selection is one of the most crucial for design and maintenance considerations. Often, alternative surfacing options are considered for poor performing unsealed roads, whilst the problem can be resolved by using quality materials. Gravel loss is the single most important reason why gravel roads are expensive in whole life cost terms and often unsustainable, especially when traffic levels increase. Reducing gravel loss by selecting better quality gravels or modifying the properties of poorer quality materials is one way of reducing long term costs.

Gravel losses (gravel loss in mm/year) are determined in relation to the quality of the gravel wearing course [14].

#### 2.4.4. Geometric design of gravel roads /Absolute Gradient

Geometric design is the process whereby the layout of the road through the terrain is designed to meet the needs of all the road users. It covers road width, cross-fall, horizontal and vertical alignments, sight distance and transverse profile or cross-section [44]. The geometric features influencing gravel loss are horizontal and vertical curvature, the cross section elements and longitudinal grades. Geometric cross-sectional characteristics particularly crown, camber, side-drains and run-off points have pronounced effects on drainage and gravel road deterioration during high rainfall.

Longitudinal-section, in particular the grade above 6%, interacts with rain water to cause gravel loss. Horizontal curvature not in harmony with vehicle speed will create gravel materials whip off, and vertical curvature with steep grades will interact with rain water to erode the gravel materials [16]. Loss of surface material depends on material quality, traffic, rainfall, gradient and maintenance regime [14]. In Ethiopia topography is classified in to four.

Table 2.8: classification of Topography

Source: ERA [44]

<b>Flat</b>	0 to 10 five-metre contours per km. The natural ground slopes perpendicular to the ground contours are generally below 3%.
<b>Rolling</b>	11 to 25 five-metre contours per km. The natural ground slopes perpendicular to the ground contours are generally between 3 and 25%.
<b>Mountainous</b>	26 to 50 five-metre contours per km. The natural ground slopes perpendicular to the ground contours are generally above 25%.
<b>Escarpment</b>	Escarpments are geological features that require special geometric standards because of the engineering risks involved. Typical gradients are greater than those encountered in mountainous terrain.

Roads that are constructed in mountainous and escarpment topography have greater gradient compared to the other classes of topography. In low volume road design, the maximum gradient that can be fixed to the roads ranges 6% to 12%. The higher gradient values corresponds for the roads that have less traffic flow and the roads that are found in mountainous and escarpment parts of the country[44]. According to [29], the slope length and gradient of the road plays a significant role in erosion of the road surface. The longer the slope length and the higher the gradient, the impact of the rainfall becomes devastating.

According to [37], the study indicates that erosion increases significantly between 4% and 6% road gradient. It has been commonly acknowledged that gradients above 6-8% are not usually suitable for gravel surfacing. The table 2.9 shows the magnitude of each range of gradient and the associated erosion.

Table 2.9: gradient and surface erosion relation  
 Source: Vietnam rural road assessment program [37]

	Road Gradient at Survey Point				
	Flat	>0-2%	>2-4%	>4-6%	>6%
% Slight or no erosion	91	67	47	47	26
% Significant erosion	9	23	53	53	74

### 2.5. Gravel loss models

Gravel road deterioration prediction models are important components of a pavement management system. The following approaches are normally used to predict pavement performance:

- **Probabilistic**, or trend, approach that inherently recognizes the stochastic nature of pavement performance by predicting the variability of the dependent variable
- **Deterministic** approach that predicts a single value of the dependent variable from pavement performance prediction models based on statistical relationships between the dependent and independent pavement performance indicators [35].

Regravelling is the major maintenance operation on unpaved roads, and it is analogous with overlaying of asphaltic concrete. It is therefore important that the agency responsible for regravelling know when it should be programmed. Modeling of gravel loss to predict the amount of surface gravel needed for regravelling and the respective economy of maintenance is significant in maintenance management system. According to Peterson [44], gravel loss is one of the modes of gravel roads deterioration of primary relevance to the management of gravel roads. Understanding the factors that influence gravel loss is important in two ways; to assist asset management processes, i.e. to plan re-gravelling at the appropriate time and to reduce gravel loss through improved construction and maintenance practices [8].

Gravel loss models are developed in different countries taking in to consideration of different factors that depend on their local gravel road behavior.

The model developed by U.S. Forest Service which is presented by [46], model the gravel loss as follow:

$$GL= D (-1.58+0.366G +0.083SV-0.210 PI +0.0132NC +0.0081NT+420.45/R).....2.1$$

where:

GL= gravel thickness loss in mm

D=time period considered, in hundreds days, i.e., days /100

G=absolute gradient value in percent

SV=percent of surfacing material passing the 0.074mm sieve;

PL= plasticity index  
 NC= average car and pick up traffic both direction  
 NT= average daily truck, both direction  
 R= radius of horizontal curvature, in m.

The R-square of this model is 0.60, the sample size 604, and the standard error of the model was 11.43. Assuming normality of the residuals, the approximate 95 percent estimate is GL + or - 22.8 mm

Gravel loss model prepared by Transport and Road Research Laboratory (TRRL) and by T.E.Jones [12] which was adopted by ERA [13], was given as follow:

$$GL_A = f \frac{T_A^2}{T_A^2 + 50} (4.2 + 0.092 T_A + 3.50 R^2 + 1.88V) \dots\dots\dots 2.2$$

Where

- GL = the annual gravel loss measured in mm
- T<sub>A</sub> = the total traffic volume in the first year in both directions, measured in thousands of vehicles
- R = the average annual rainfall measured in m
- V = the total (rise + fall) as a percentage of the length of the road
- f = 0.94 to 1.29 for lateritic gravels
  - = 1.1 to 1.51 for quartzitic gravels
  - = 0.7 to 0.96 for volcanic gravels (weathered lava or tuff)
  - = 1.5 for coral gravels
  - = 1.38 for sandstone gravels

According to Visser (1981) and Paterson (1987) referred by Land Transport New Zealand [8], their model was given as follow:-

$$GL = D (1.58 + 0.366 \times G + 0.083 \times SV - 0.210 \times PI + 0.0132 \times NC + 0.0081 \times NT + 420.45R) \dots\dots\dots 2.3$$

Where

- GL = is the gravel loss in mm
- D = number of days since last bladding in hundreds (days/100)
- NC = average daily light vehicles in both directions
- NT = average heavy vehicle traffic in both directions
- G = absolute grade in percentage
- SV = percent of surface material passing the 0.074 mm sieve
- PI = plasticity index of surfacing material (%)
- R = radius of horizontal curve.

The model was developed by considering gravel roads in Brazil, consisted of 48 Sections; the model was developed for 11 to 288 passenger car and 1 to 435 two axle trucks per day. Rainfall range of the model was 1200 to 2000 mm/year. Climate was classified between moist sub-

humid to humid. The material considered was Lateritic and Quartzite. Some earth roads (without wearing course) were also monitored.

Paige-Green [47 a] developed gravel loss prediction model considering axle loads of the vehicle. The model was given as follow:-

$$GL = K_g \times \left\{ -0.671 \times D \times \left( \frac{axles}{1.4 \times (0.059 + 0.0027 \times N - 0.0006 \times P26)} - 0.367 \times N - 0.0014 \times PF + 0.0474 \times P26 \right) \right\}$$

.....2.4

Where

GL=depth of gravel loss after time D, Where d is hundreds of days (days/100) after routine Maintenance

Kg=Calibration factors gravel loss to suit local conditions (default=1.0).

D= hundreds of days between routine maintenance (Days /100).

axles =numbers of axles light and heavy vehicles (both ways )

$$=ADT \times (PctHeavy/100 \times 5 + (1-PctHeavy/100) \times 2)$$

ADT=Average daily traffic (both ways)

PctHeavy=proportion of heavy vehicle (%)

N=Weinert value

$$=12 \times EJ/Pa \text{ (N=1 wet; N=10+ dry)}$$

EJ= Evaporation in the warmest month (mm)

Pa=annual precipitation (mm)

P26= percentage of particle passing 26.5 mm sieve

PF=Plastic Index (PI)\*P75

P75=percentage of particle passing 0.075 mm sieve (%)

Gravel loss model that was developed based on road sections established in South Africa and Namibia by Paige-Green (47b] in the research entitled influence of geotechnical properties on the performance of gravel wearing course material, was given as follow:-

$$GL = D \times ADT \times \left\{ 0.059 + 0.0027 \times N - 0.006 \times P26 - 0.367 \times N - 0.0014 \times PF + 0.0474 \times P26 \right\}$$

.....2.5

Where N = Weinert N-value (climatic region)

ADT=annual daily traffic

PF =plastic factor

P26=percentage passing a 26.5 mm sieve

A total of 110 sections were observed. The range of total traffic was between 18 to 608 per day and rainfall of 300–1100 mm/yr. Dry arid to moist humid. The material was acid and basic crystalline, high silica, arenaceous, argillaceous and pedocretes.

According to Giummarra G.J. et.al [48 a], in establishing deterioration model for local roads in Australia, they tried to develop a model which was stated as follow:

$$GL= D \times (ADT \times (g_1+g_2 \times I-g_3 \times P26)-g_4 \times I-g_5 \times PF).....2.6$$

Where:

- GL= gravel thickness loss (mm)
- ADT=average daily traffic (vehicle/day) all lanes
- I=Thorntwaite index
- P26= percentage passing 26.5mm sieve
- PF= Plasticity Index Percentage passing 0.075mm sieve

$g_1, g_2, g_3, g_4$  and  $g_5$ =regression coefficient

The formula was developed using 21 samples. The progression of gravel loss on the roads was depicted as below

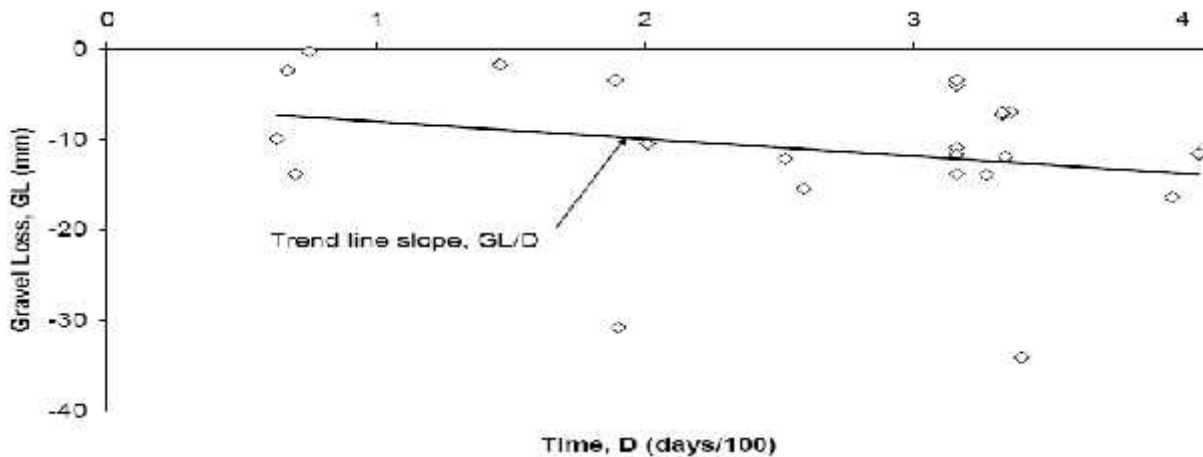


Figure 2.17: gravel loss (mm) over time (days /100)

Source: 6<sup>TH</sup> International Conference on managing gravel roads, 2004

In Australia -Tasmania based on long-term pavement performance studies (LTPP), Giummarra et al. [48 b], has developed gravel loss model. The model contains coefficients that can be obtained from regression formula after adequate number of data was collected. The model was given as follow:-

$$GL = D \times (F1 \times ADT + F2 \times MMP + F3 \times PF).....2.7$$

Where:

- GL=the average gravel thickness loss (mm)
- D=time period in hundreds of days (days/100)
- ADT =average daily vehicular traffic in both directions, in vehicle/day
- MMP =mean monthly precipitation, in mm/month
- PF=plasticity factor (PI  $\times$  P075)
- P075 =amount of material passing the 0.075 mm sieve, in percentage by mass
- PI=plasticity index

F1 to F3 are model coefficients.

This model considers a single road of 2.7 km and it was divided into 300m test sections in order to try different treatment options. In contrast with other models the model considered only single traffic volume which was ADT of 83.

T. F. P. Henning, et.al. [8], proposed a model that tried to predict gravel loss in New Zealand. A model was given as follow:-

$$\Delta GL = 2 \times [25.6 - F1 \times \text{Width} - F2 \times Pi + F3 \times P265 - F4 \times \text{TLB} + F5 \times \text{ADT}] \dots\dots\dots 2.8$$

Where

- Delta GL =annual change in surface thickness
- WIDTH =surface width
- Pi =plasticity index
- P265 = percentage aggregate passing the 26.5 mm sieve
- TLB = number of days since last bladding
- Fi = model coefficients

The model was conducted on the range of traffic between 50 and 100 average daily traffic. The material considered was greywacke/quartz sandy gravels sourced from lower flood plain areas , generally clean with little silt, ‘Muruhiku Rocks, hard–moderately and hard siltstone/sandstones with minor tuff (volcanic ashfall deposits)

World Bank HDM-III gravel loss models [45], relates gravel loss with the surface material behavior, traffic, climate and geometry. The model was given as follow:

$$MLA = 3.65 \times (3.46 + 0.246 \times MM \times PRF + \text{MAX}[0.022 + \frac{0.969 \times C}{57300} + 0.00342 \times P075 - 0.0092 \times MMP \times PI - 0.101 \times MMP]) \dots\dots\dots 2.9$$

Where

- MLA = the annual material loss in mm
- PI = the plasticity index
- MMP =the mean monthly precipitation
- C = the average horizontal curvature of the road (deg/km).
- P075 =percentage passing a 0.075 mm sieve.

Adewole S. Oladele et.al [5], predicts gravel loss using different approach than the other model discussed above. The model considers the types of deterioration on the road in addition to the factor that causes gravel loss .The model is stated as follow:

$$GVL = -1.46899 + 0.00246264(\text{ADT}) + 1.83355(\text{GVQ}) + 0.327(\text{GVT}) + 27.0301001(\text{POT}) - 0.21302(\text{LMT}) - 0.325393(\text{STN}) \dots\dots\dots 2.10$$

Where:

ADT =Annual Daily Traffic  
 GVQ = Gravel material Quality  
 GVT =Gravel Thickness  
 POT =Pothole  
 LMT = Loss Material  
 STN =Stoniness

The result of the regression analysis was R-squared = 74.4%, R-squared (adjusted) =73.5%, Standard Error of Est. = 0.41 and Mean absolute error of 0.28.

In some circumstances, the model developed may over estimate gravel loss compared to the actual gravel loss. The figure 2.18 shows that for the different model, the predicted gravel loss was higher than the observed gravel loss.

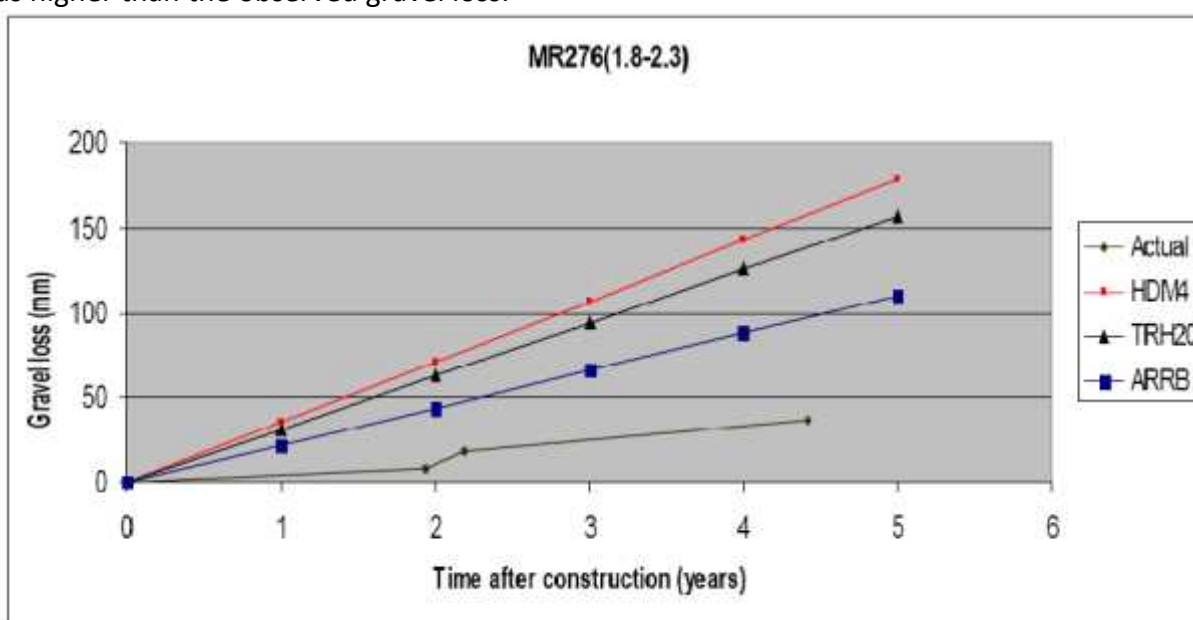


Figure 2.18: Comparison of actual versus predicted gravel loss

Source: Van Zyl *et al*, 2007, referred by P Paige-Green [47 a]

### 2.5.1. USES OF GRAVEL LOSS PREDICTING MODEL

Gravel loss models have many benefits for road agencies. According to R. R. Mwaipungu, et.al [16], based on life cycle of gravel roads, the uses of gravel loss predictions models are;

#### 2.5.1.1. Gravel road management system

GLPMs are imperative for a complete gravel road management system. In the gravel road management system, GL prediction models are the driving force behind effective preventive maintenance.

#### 2.5.1.2. Determining maintenance and rehabilitation requirement

Prediction models are used at both the network and project levels to analyze the condition and determine maintenance and rehabilitation (M&R) requirements. At the network level,

prediction models uses for condition forecasting, budget planning, inspection scheduling, and work planning. One of the most important network uses of prediction models is to conduct “what if” analysis- to study the effects of various budget levels on future pavements conditions. At the project level, prediction models are used to select specific rehabilitation alternatives to meet expected traffic and climatic conditions. The models provide the major input performing life-cycle cost analysis to compare the economics of various M&R alternatives.

#### **2.5.1.3. Predicting the effects of proposed policies**

It is important to be able to predict the effects that proposed policies are likely to have in the future. Such predictive capabilities enable the decision-maker to test alternative course of action to determine which policies and strategies will be the most effective in accomplishing the desired goals with the resources available.

#### **2.5.1.4. Predicting the residual life of gravel roads**

GLPMs are used to predict the remaining residual life of gravel road surface layer, by using data of distress survey, climatic, road alignment, traffic, and materials characteristics. Knowing the rate of GL, and the initial thickness of gravel wearing course, one will be able to accurately foretell the residual life of gravel road surfacing layer.

#### **2.5.1.5. Evaluating the trade-offs between different maintenance and construction policies.**

The predicting model of GL is suitable for use in evaluating the trade-offs between different maintenance and construction policies. However, to employ this method requires good knowledge about the gravel materials being used and the rates at which they will deteriorate under different traffic levels and climatic situations. As the gravel road deteriorates, its GL increases and at different level of residual gravel layer, different treatment become appropriate (Robinson et al, 1998). Also knowing the rate of GL of particular gravel materials, can assist in designing measures to control it during design, construction, and maintenance periods.

#### **2.5.1.6. Establishing an economically defensible grading cycle**

The GLPMs form the basis for the establishment of an economically defensible grading cycle based on cost-optimized arguments.

#### **2.5.1.7. Inhibiting gravel loss**

The knowledge of factors behind the annual rate of GL for the particular gravel materials can be used to inhibit GL at the design stage. GL control measures have to be built at the design stage by selecting materials which when properly constructed and maintained can be able to withstand the combined actions of traffic and climate. Unsealed roads should be designed to withstand the effect of local climatic influence on GL. It is clear that through appropriate material selection and construction procedures, the performance of the unsealed roads can be improved and the consequent negative environment effects reduced.

### 2.5.1.8. Determining regravelling frequency

For a maintenance and rehabilitation management model, the life-cycle of deterioration and maintenance of gravel roads can be depicted by the downward trends in surfacing material thickness over time

Knowing the rate of annual GL and the life-cycle of the gravel road in question, will indicate the gravel material that will be lost over the design life of the road. Once the threshold level of a gravel layer residual thickness has been established, one will be in a position to calculate the regravelling frequency.

### 2.5.1.9. Gravel materials characteristics and specification

The characteristics of gravel materials to lose or retain water for a considerable length of time and its cohesive nature of granular particles can be specified by using performance study. The derivation of appropriate specification for the selection of surfacing materials for unsealed roads can be derived locally from monitoring among other parameters the GL on a range of existing gravel roads, and correlating it with the materials physical characteristics.

## 2.6. Review of Methodology and procedure to obtain gravel loss data

The method and procedure for modeling gravel loss, in deferent countries, was different. The work done in Australia by Giummarra et.al [48 b], the lay out of survey grid shown below, depicts all the matter concerning the sample survey grid. Each site was 60 m long and was surveyed in a grid pattern. The surveys, therefore, resulted in measuring a total of seven cross sections, with each cross section consisting of a height measurement interval of 0.5 m. The gravel loss surveys were undertaken at six-monthly periods and a total of seven surveys were conducted to model the gravel loss. The rate of gravel loss was recorded as a vertical loss in the millimeters of material from the road surface.

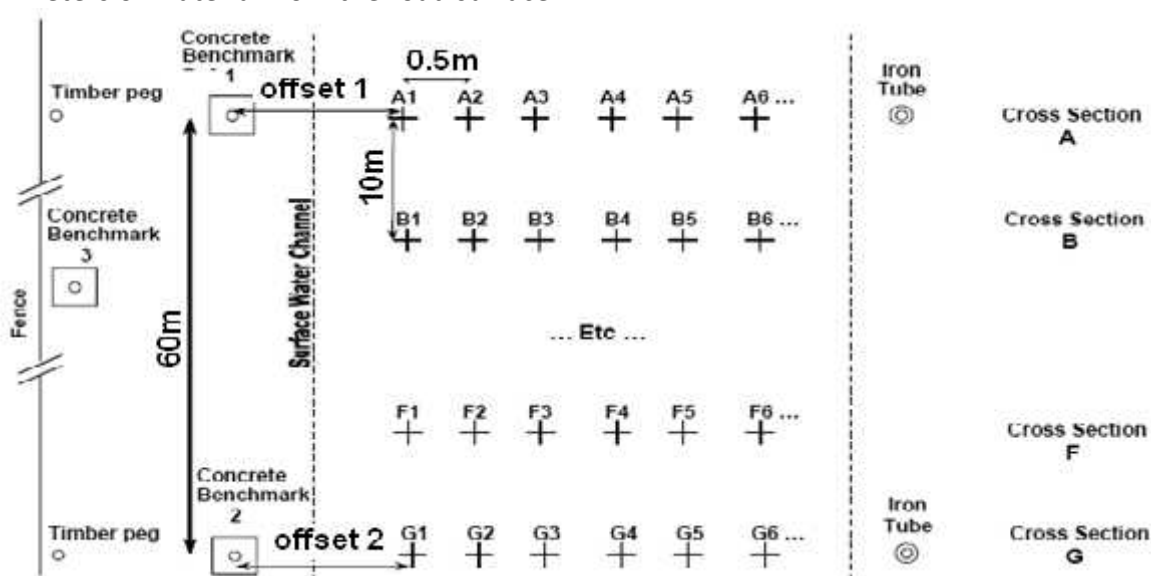


Figure 2.19: layout grid survey

Source: Giummarra et.al (2007) [48 b]

Research by T.E. Jones [12], states the procedure of gravel loss data gathering as follow. In each experiment section, representative grids were selected for the survey. Readings were taken at 25cm increment across the width of the roads in to the drainage channel, at 5m interval along a 60m meter length profile. At the sides of each test section, concrete monuments were installed parallel to the center of the grid and approximately 15 m from the center line of the road, an additional bench mark, consisting of a 300mm plate 10mm thick, was placed in the road beyond the survey grids at the sub grade level to monitor any differential movement between the road structure and the concrete bench marks.



Figure 2.20: Measuring gravel loss on the field

Source: Giummarra et.al [48b]

In general, gravel roads can be deteriorated by many factors. In this chapter only the effects of ADT, MMP, PI, G and D were reviewed. Deteriorations on gravel roads that may lead to gravel loss were also discussed. Model developed in different country and methods to conduct the research were reviewed.

## Chapter 3: Methodology, Material and Procedure

### 3.1. Rationale for methodological approach

A longitudinal observational study was conducted to collect the data regarding gravel loss by the help of optical survey equipment (total station). The reduction in thickness of the gravel road was recorded as the gravel lost from the roads. The duration between the first and the second observation for this research was three month.

To model gravel loss, the factors that cause gravel loss should be considered. The approach to collect the data regarding traffic volume in each road was found to be different. For the roads D/Birhan – Kasima and Chcha –Tsgerada –Ginager, Direct traffic count was conduct to obtain ADT. But for the roads D/Birhan-Ankober the forecasted traffic was used in model.

Climate is the major factor for gravel road deterioration. Precipitation, specifically rainfall data was needed to model the gravel loss of the gravel roads. Rainfall data of the area that the sample road passes was collected from National Metrological Agency of Ethiopia. Secondary data was used to calculate and model the gravel loss from the sample gravel roads.

Surfacing material of the road was also used to model the gravel loss. From each specific road section quarry site, the sample surfacing material was taken to be tested in the laboratory. Only the fine material that pass 0.425 mm sieve was taken to conduct Atterberg limit test. The behavior of the surfacing material that can be lost by wind or traffic as a dust is the fine material and this is mainly characterized by plasticity index of the material.

Geometrical design parameters of the sample roads are also the factors for gravel loss. Since geometry of the roads contain cross-sectional element, horizontal and vertical alignment of the road, trying to include the entire element make development of the model impossible. Therefore, only gradient of the road was included in the model. The data regarding gradient of the road was obtained from the observational survey aligned with gravel loss data by the use of total station.

The interval of observation matters because of deteriorations on gravel roads are time dependant. In this research the intervals of observation in days per 100 was directly included in the model for each sample roads since no bladding of sample roads was executed in the interval of observation.

### 3.2. Details of the study population

The study population includes three gravel roads that are located around D/Birhan town and Chacha town. The selected roads were about 110km in their length. These roads are D/Birhan – Kasima (21km), Chacha –Tsgerada –Ginager (48km) and D/Birhan-Ankober (41km). The first two roads are authorized by Amhara Rural Roads Authority and the other one is by ERA. All roads selected are found in northern Shewa Zone of Amhara region.

The sample road segment were 1.2 km, which was taken from D/Birhan – Kasima (0.3km), Chacha –Tsgerada –Ginager (0.5 km) and D/Birhan-Ankober (0.4km). The selection of the length of the segments from sample road follows no scientific method and it was determined by the

difficulty of data collection of the specific road and the weather conditions of the area when the initial observation was conducted.

The surfacing material of the first two gravel roads was selected material but the surfacing material of third road was crushed aggregate. The width of the roads was variable. According to the observation, the width of the roads ranges from 5.5m to 7.5m.

### 3.3. Descriptions of methods and procedures for obtaining data

Different kinds of methods and procedures were used to obtain the data regarding dependent and independent variable. Although there was no unique method developed in this research, the method and procedure followed in similar research works in the past was adapted. Except gravel loss data collection method and procedure, all other data collection was followed standardized procedure and method. In this regard, traffic count, material test for plasticity index, mean monthly precipitation and gradient of the road was done with respect to the standard method.

#### 3.3.1. Methods and procedures for obtaining gravel loss data

Gravel loss data was obtained by the uses of prepared survey grids. In each experimental section, representative grids were selected at 5m interval along a 15m length. The height of each point (A0, A1, A2...) was recorded at 1m interval across the width of road and in to the edge of the drainage channel. At the start of each reading, approximately 1cm diameter wooden peg was installed. At the point of the station, the wooden peg was also installed to make the second time observation easier. The whole design of the grid survey was shown in the figure 3.1.

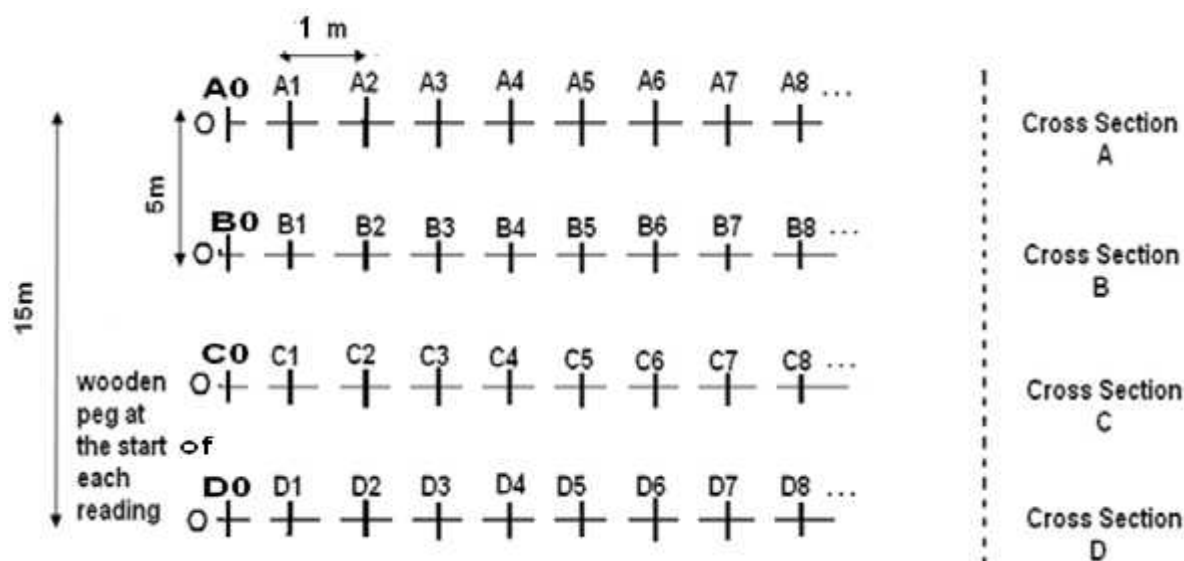


Figure 3.1: Survey Grids on the Sample Roads



Figure 3.2. Gathering of Gravel Loss Data

### 3.3.2. Methods and procedures for obtaining traffic data

One of the basic measures of the traffic demand for a highway is average daily traffic (ADT). The ADT is defined as the total volume during a given time period (in whole period), greater than one day and less than one year, divided by the number of days in the time period [50].

The type of traffic in each day was recorded using standard table for traffic count. Since the observation was in summer season, i.e. it starts and ends in summer (July, August and September), traffic volume was collected for about one week for each road section. For the road which is managed by Amhara Rural Roads Authority, two directional volumes were collected for about one week and for 16 hour in each day. The traffic at the night level was recorded for two days and found to be insignificant and only the day traffic was included in the analysis for the two road section (D/Birhan-Kasima and Chacha-Tsgereda-Ginager). The table used for data collection was found in appendix B. For the road in federal roads authority (D/Birhan-Ankober), ADT for 2011 was obtained from ERA and forecasted for 2014 using growth factor of 6 % (D/Birhan –Ankober upgrading project).

### 3.3.3. Methods and procedures for obtaining mean monthly precipitation of the roads

The rainfall data of the two towns were collected from Ethiopian Metrological Agency. For D/Birhan rainfall history of 1984-2013 and for Chacha town rainfall history of 1987-2012 was used, since this was the only available historical data obtained from the agency. In case of this research, the three month precipitation (July, August and September), was averages to had single values. This was done to reduce the difficulties that would be encountered in using each month precipitation data in the model.

Average of three month rainfall dada

$$= \frac{\text{Sum of Mean Monthly Precipitation (July+August+ September)}}{3}$$

### 3.3.4. Methods and procedures for obtaining plasticity index

The data concerning the surfacing material of the gravel road was obtained by the laboratory test of the sample material. Sample material was obtained from the quarry site of each road. The needed out put of the test was plasticity index. Standard procedure, ASTM D4318-10 [51], was used to obtain the liquid limit and plastic limit of the sample material of each road. After the plasticity index was obtained, the type of the surfacing material was determined by figur3.3.

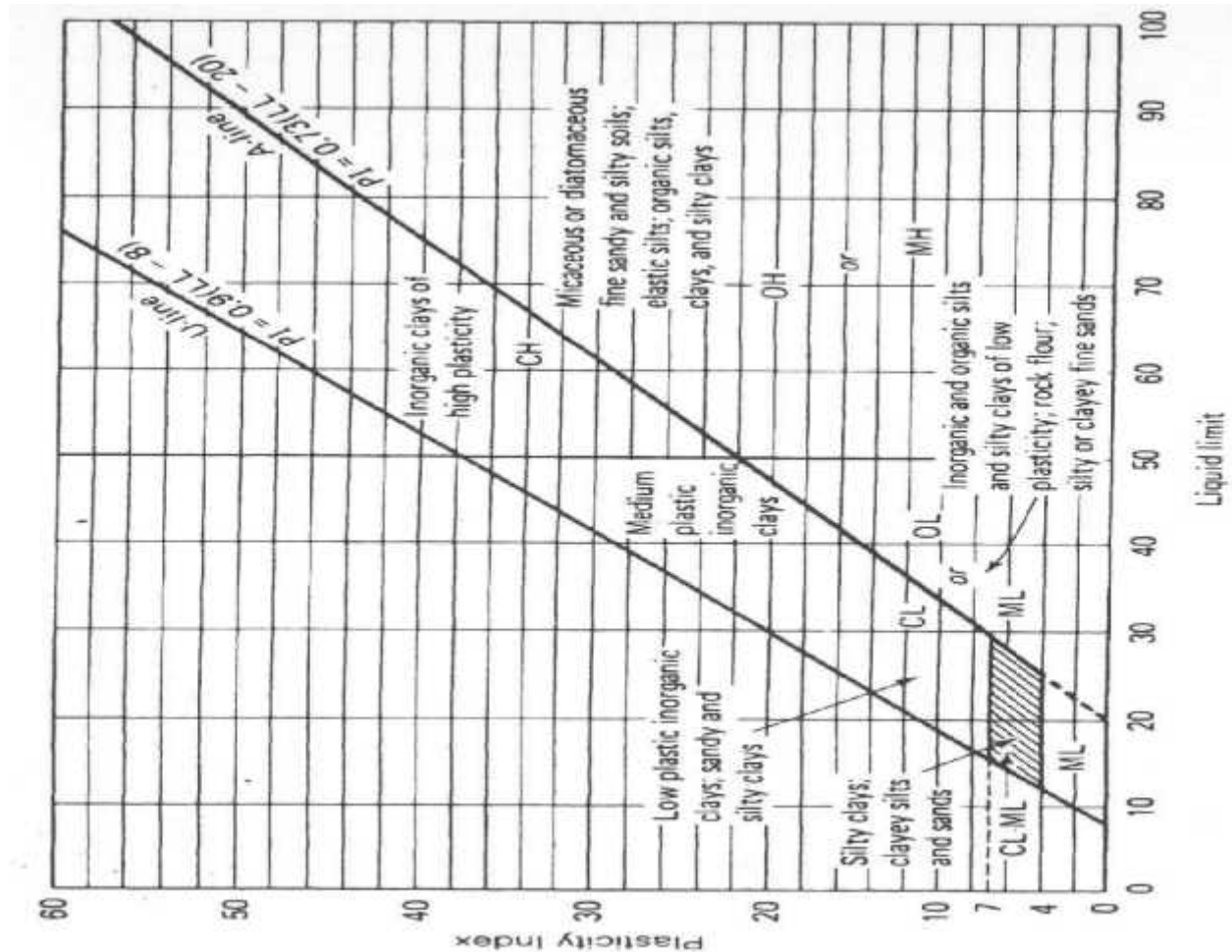


Figure 3.3: Soil behavior determination chart for USCS method of soil classification

### 3.3.5. Methods and procedures for obtaining gradient of the roads

The data regarding the absolute gradient of the road was obtained by the help of total station. The elevation difference between 5m (for example between A2 and B2 of figure 3.3) was recorded as the height difference (a). The length of the road which was recorded as horizontal difference between the two points was calculated by Pythagorean formula.

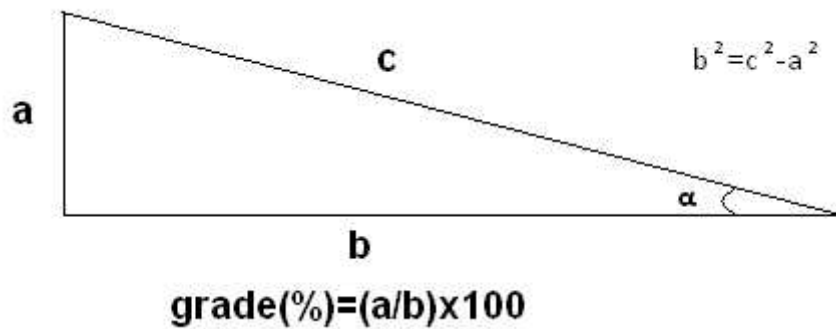


Figure3.4: Calculation of gradient of the road

The absolute value of the observed gradient was used to eliminate the problem that will be encountered in using the model for different signs.

### 3.3.6. Methods and procedures for obtaining time interval between observation

The time interval between the two observations was easily obtained by counting the number of days between the two observations. Number of days between the two observations was the same for three sample roads. To eliminate the larger values of coefficient in the developed model, days between the two observations was divided by one hundred.

### 3.3.7. Software to compute MLR and GLM

To simplify the task of working with regression, there are plenty software's in the market nowadays. SPSS is one of the famous in computing regression. According to Segonds-Picho [52], SPSS stands for Statistical Package for the Social Sciences as it was first designed by a psychologist. Regression procedures are used to obtain statistically established causal relationships between variables. Regression analysis is a multi-step technique. Several options must be carefully selected while running a regression, because the all-important process of interpretation and diagnostics depends on the output (tables and charts produced from the regression procedure) of the regression and this output depends upon the chosen option [53].

Assumptions in working with linear regression in SPSS are:-

1. The dependent variable must be normally distributed.
2. The data must not exhibit heteroskedasticity; that is, variance of the dependent variable must not depend on the independent variables.
3. There should be no multi-collinearity among the independent variables. That is, the correlations among the independent variables should not be too high [54].

Modeling is the simplification of the complex phenomena. In this research, the complex interaction between dependent and independent variables were investigated. Multiple linear regression and general linear modeling were used to model the relationships between dependent and independent variables by the uses of software known as SPSS 15.0.

In statistics linear regression is an approach for modeling the relation between a scalar dependent variable  $y$  and one or more explanatory (independent) variable  $x$ . Multiple linear regression attempts to model the relationship between two or more explanatory (independent) variables and a response (dependent) variable by fitting a linear equation to observed data. Every value of the independent variable  $x$  is associated with a value of the dependent variable  $y$ . The best-fitting line for observed data is calculated by minimizing the sum of the squares of the vertical deviation from each data point to the line. If a point lies on the fitted line exactly, then its vertical deviation is zero. Because the deviations are first squared, then summed, there are no cancellations between positive and negative values.

In the SPSS 15.0, the result of the analysis by multiple linear regressions was expressed by the statistical terminologies. Descriptive statistics for each variable, Regression Correlations, Regression Variables Entered/Removed, Regression Model Summary, Regression ANOVA, Regression Coefficients, Regression Casewise Diagnostics, Regression Residual Statistics, Regression Coefficient Correlations, Regression Collinearity Diagnostics, and Regression Excluded Variables are the terminologies to evaluate the model developed. Only the relevant tables were extracted from the analysis to be discussed and the other terminologies and tables found at the appendix F.

The general linear model goes a step beyond the multivariate regression model allowing for the linear transformation or linear combination of multiple dependent variables. This extension gives the general linear model important advantage over multiple linear regressions. The second usefulness of general linear model is it can operate the dependent variable and it can include the redundant variable in the model which is not possible in multiple linear regressions. Although the same analysis method used the general linear model become superior in many aspects.

The same to that of multiple linear regression, the result to general linear model was given by many terminologies such as GLM univariate descriptive statistics, GLM Univariate Between-Subjects Factors, GLM Univariate Levene's Test of Equality of Error Variances, GLM Univariate Tests of Between-Subjects Effects, GLM Univariate Tests of Between-Subjects Effects, GLM Univariate Expected Mean Squares, GLM Univariate Parameter Estimates, GLM Univariate Lack of Fit Tests and so on. But for the purpose of discussion some of the table was extracted and the rest of the table was attached on appendix F.

## Chapter 4: Results and Discussion

### 4.1. Results

After the data was collected as specified in the methodology section, it was analyzed using different mechanism and methods. The results of the analysis were explained in the consecutive sub sections.

#### 4.1.1. Gravel loss observation results

Using the prepared experimental 15m sample, as shown in figure 3.1, the surfacing material lost from the gravel roads were obtained. Observation result was tabulated in table 4.1.

Table 4.1: Gravel loss (GL) observation result

No.	D/Birhan- Kasima	No.	D/Birhan - Ankober	No.	Chacha- Tsgerada- Ginager	No.	Chacha- Tsgerada- Ginager
	GL(mm)		GL(mm)		GL(mm)	26	20.56
1	27.90	1	37.60	1	20.40	27	22.12
2	21.80	2	35.27	2	27.93	28	18.50
3	24.40	3	37.40	3	29.25	29	16.64
4	24.20	4	38.70	4	25.36		
5	22.00	5	34.00	5	26.48		
6	23.00	6	34.72	6	26.68		
7	26.00	7	30.00	7	25.11		
8	24.40	8	31.70	8	24.04		
9	26.45	9	30.50	9	21.93		
10	26.96	10	29.50	10	20.79		
11	27.60	11	28.30	11	17.81		
12	24.82	12	29.50	12	14.39		
13	32.10	13	28.20	13	14.26		
14	26.63	14	29.20	14	15.04		
15	25.23	15	29.50	15	14.64		
16	24.85	16	28.61	16	16.46		
17	27.53	17	29.60	17	16.63		
18	31.18	18	28.31	18	19.9		
19	31.57	19	29.64	19	19.14		
20	29.37	20	27.85	20	17.33		
		21	23.40	21	17.00		
		22	27.63	22	17.88		
		23	29.41	23	19.21		
		24	26.32	24	22.83		
		25	27.24	25	21.83		

74 samples

Maximum	38.7 mm
Minimum	14.26 mm
Average	25.40mm
St.dev	5.76

#### 4.1.2. Traffic count results

Traffic count was done to obtain average daily traffic of the selected roads. The highest traffic volume was encountered in D/Birhan –Ankober and lowest traffic was observed on Chacha – Tsgerada –Ginager –Roads. The average value of the traffic observed on the roads was 89 veh/day.

Table 4.2: Traffic Volume of the Selected Roads

No.	Road name	Total km	ADT
1	Debre Birhan –Kasima	21	55
2	Debre Birhan-Ankober	41	190
3	Chacha –Tsgereda –Ginager	48	22

#### 4.1.3. Climatic Data Results

The gathered data was analyzed to obtain the mean monthly precipitation of the two towns. Mean monthly precipitation of D/Birhan town was 220.8mm/month and for Chacha town it was 234.4mm/month. Since the two towns are neighbors, the historical precipitation data was not highly varied.

#### 4.1.4. Material Test Results

The sample material of the wearing surface of the particular roads was taken from the respective quarry sites. The samples were appropriately stored and prepared for the laboratory test. The aim of the laboratory test was to have the plasticity index of each sample roads wearing surface material. Laboratory test result was summarized in table 4.3.

Table 4.3: Material test result of the selected roads

Name of the road	Liquid Limit(LL) %	Plastic Limit(PL) %	Plasticity Index (PI)%	Soil Type
				USCS Classification
Debre Birhan - Kasima	52.5	39.01	13.49	MH or OH
Debre Birhan-Ankober	26.71	23.33	3.38	ML,SM,GM
Chacha –Tsgereda Ginager Road	42.4	23.73	18.67	CL or OL



Debre Birhan-Ankober



Debre Birhan - Kasima



Chacha –Tsgereada Ginager Road

Figure 4.1 Sample materials from the Roads

#### 4.1.5. Gradient of the Road Section

Gradient of each sample road was calculated using the optical survey equipment (total station). Table 4.4 summarizes the gradient of each sample.

Table 4.4: Absolute gradient of the selected roads

sample no.	d/bir-kasima Gradient	sample no.	d/bir -ankober Gradient	sample no.	chacha-tsgereda Gradient
1	1.32	1	4.07	1	4.10
2	1.62	2	4.15	2	4.56
3	2.30	3	4.08	3	4.81
4	2.67	4	3.65	4	5.60
5	2.67	5	2.97	5	5.86
6	2.85	6	3.55	6	5.45
7	2.04	7	2.85	7	4.95
8	2.92	8	2.83	8	4.61
9	2.15	9	2.56	9	4.23
10	1.91	10	2.30	10	4.10
11	2.20	11	1.12	11	3.05

74 sample

Maximum 5.86  
 Minimum 0.19  
 Average 2.5  
 St.dev 1.43

sample no.	d/bir-kasima Gradient	sample no.	d/bir -ankober Gradient	sample no.	chacha-tsgereda Gradient
12	2.35	12	1.03	12	0.57
13	4.01	13	0.85	13	0.48
14	2.72	14	0.59	14	0.69
15	2.83	15	0.73	15	0.82
16	2.97	16	0.80	16	1.19
17	3.07	17	0.76	17	0.61
18	3.27	18	0.68	18	2.65
19	3.19	19	0.62	19	2.86
20	2.94	20	0.69	20	2.26
		21	0.61	21	2.44
		22	0.19	22	2.74
		23	0.66	23	3.02
		24	0.29	24	3.44
		25	0.61	25	3.36
				26	3.19
				27	3.27
				28	2.98
				29	1.82

**4.1.6. Observation days result**

Observation days were used to calculate the relative gravel loss from the roads. The second observation was conducted, for all roads, after three month of the first observation. Therefore, for all roads, 90 days were used. In order to be included in the model, the time interval in days between the two observations was divided by hundreds. Therefore, 0.9 (90 days /100) were used in the model. This was only to reduce the larger coefficient values in the model.

**4.2. Modeling of Gravel Loss result**

Using the above collected data, it was tried to model gravel loss from the unpaved roads. SPSS 15.0 was used to develop the models. The desired model looks like this:-

$$GL=D(C+C_1ADT+C_2MMP+C_3PI+C_4G).....4.1$$

Where

- GL =Gravel Loss from the road in mm
- ADT =Average Daily Traffic of the specific road in veh/day
- MMP =Mean monthly precipitation in mm
- PI = Plasticity Index in %
- G =Absolute Gradient in %
- D = duration to which the gravel loss will be predicted days/100

C=Model Constant

C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>, C<sub>4</sub> = model coefficients

Having much option to model gravel loss, only multiple linear regressions (MLR) and general linear modeling (GLM) was used. The two models by MLR and GLM had the same out put description. This made the selection of the best model easy. Using MLR to model gravel loss, since it is not allowable to use the constant term D (Duration) in the model, prior to the analysis, each independent variable data was multiplied by D (0.9). The result of the analysis was tabulated as follow:

Table 4.5: Descriptive Statistics for dependent and independent variable

	Mean	Std. Deviation	N
Gravel Loss	25.4084	5.75522	74
Average Daily Traffic	78.9081	67.30008	74
Mean Monthly Pricipitation	203.5168	6.01602	74
Plasticity index	10.8811	5.96906	74
Absolute Gradient	2.4705	1.45356	74

The measure of the prediction power of the model i.e. R square was given as follow:

Table 4.6: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.937 <sup>a</sup>	.878	.873	2.05307

The final out put of the analysis which determine the coefficients of each independent variable was given as follows:-

Table 4.7: Coefficient of the Model Parameters

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	108.203	11.832		9.145	.000
	Average Daily Traffic	.050	.005	.587	9.611	.000
	Mean Monthly Pricipitation	-.455	.057	-.475	-8.005	.000
	Absolute Gradient	2.337	.179	.590	13.042	.000

In this result the coefficient for the plasticity index become zero and the variable become excluded.

Table 4.8: Excluded Variables from the Model

Model	Beta In	t	Sig.	Partial Correlation
1 Plasticity Index	.a	.	.	.

The figure below shows the scatter plot of observed , predicted and residuals of gravel loss values.

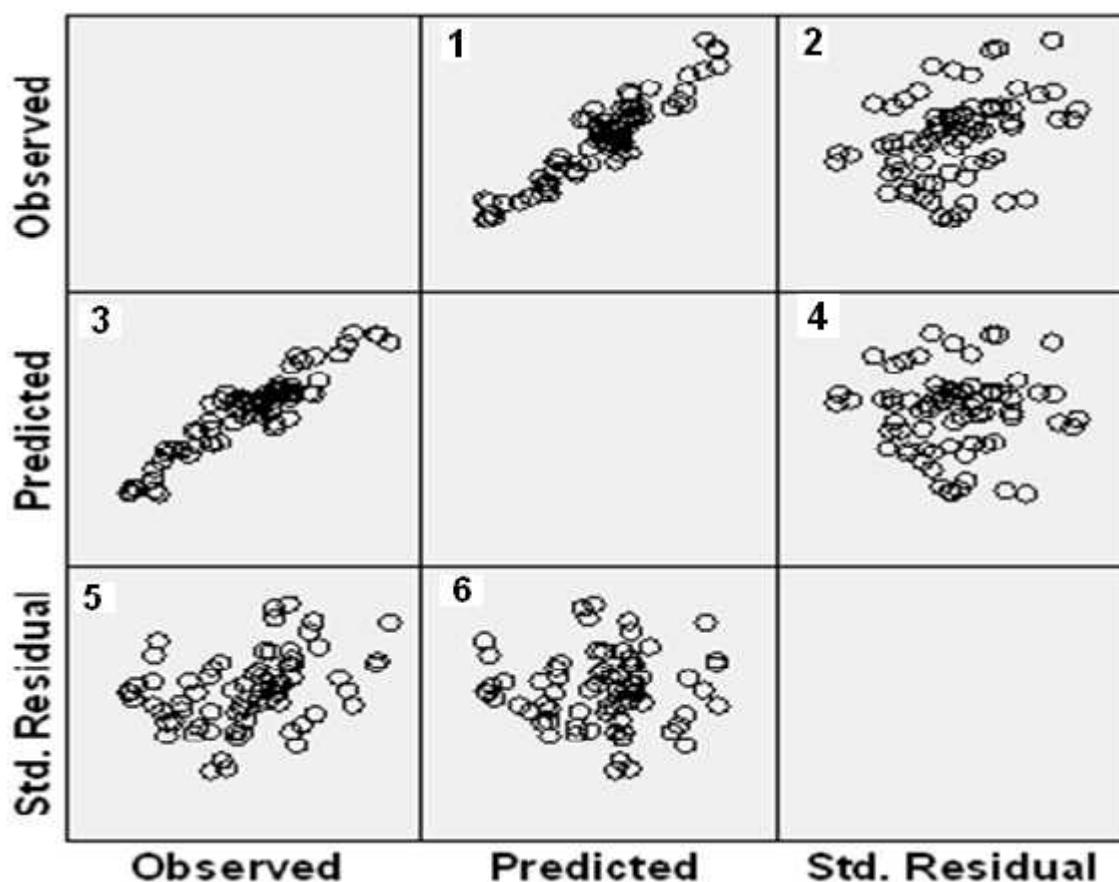


Figure 4.2: Scatter plot: 1. Predicated Vs Observed Gravel Loss; 2. Standard residual Vs observed gravel loss; 3. Observed Vs predicted gravel loss; 4. Standard residual Vs predicted gravel loss; 5.Observed Gravel Loss Vs Standard residual; 6. Predicted gravel loss Vs Standard residual.

The model was given as follow:

$$GL=108.203+D*(0.05ADT-0.455MMP+2.337G).....4.2$$

Where: GL= Gravel Loss, D= Observation days (days/100), ADT= Average Daily Traffic, MMP= Mean Monthly Precipitation, PI=Plasticity Index and G= Absolute Gradient.

Referring to equation 4.1, the coefficients of this model are:-

$$C=108.203 \quad C_1=0.05 \quad C_2=-0.455 \quad C_3= 0 \quad C_4=2.337$$

In the above model, plasticity index of the surfacing material was excluded. Since it was the major determinant of the gravel loss, as shown in the observation, it must be included. Therefore, there is a need to use another kind of modeling mechanism, which was GLM. The result of general linear modeling was given as follow

Table 4.9: Parameter Estimates for GLM

Parameter	B	Std. Error	t	Sig.
ADT	-.299	.042	-7.118	.000
MMP	.461	.044	10.590	.000
PI	-4.643	.508	-9.145	.000
G	2.337	.179	13.042	.000

- a. Computed using alpha = .05
- b. R Squared = .904 (Adjusted R Squared = .904)

The model developed by GLM having an intercept had the same parameter estimate to that of model by MLR. Therefore the second model proposed did not include the intercept (constant term in the model by MLR) of the line in the model. The equation of the model was given as follow:

$$G=D (-0.299*ADT+0.461*MMP-4.643*PI+2.337*G).....4.3$$

$$C=0 \quad C_1=-0.299 \quad C_2=0.461 \quad C_3=-4.643 \quad C_4=2.337$$

### 4.3. Discussion

Gravel roads benefit the public by giving access to different infrastructures and it facilitates the country's development. Although such types of road are very important, its maintenance cost becomes the problem in many road agencies. Since the surface of the roads is not sealed, it can be affected by different natural and man made environmental factors. It is difficult to name exhaustively the factors that cause gravel roads deterioration, in this research, the major factors was included.

Traffic in terms of average daily traffic had a strong relation with gravel loss. From observation result, it was clearly indicated that a road that had higher traffic volume i.e. D/Birhan – Ankober (180veh/day), also had higher observed gravel loss and the less trafficked road i.e. Chacha – Tsegereda- Ginager (22 veh/day), had minimum gravel loss of the surfacing material. The traffic volume shown for each road was two directional. For the road D/Birhan –Kasima, the significant traffic was the passenger cars, Pick –Ups, small and large buses. ADT of 55 veh/day was the amount of traffic that passes the roads. Considering ADT of D/Birhan –Ankober road, it includes all kinds of vehicle starting from pick ups to truck –trailer. From the data obtained in 2011 and forecast it for 2014, ADT of 190 veh/day becomes the traffic of the roads. In the case of Chacha –Tsegereda- Ginager road, the significant traffic on the road were mini-bus and larger buses. These roads had 22 veh/day of traffic.

Dust from the gravel roads is inevitable and it is caused by different agents. Traffic is one of the factors. Traffic volume, traveled speed and the type of vehicle that travelled on gravel roads determine the amount of dust created. From observation of sample roads, the road that has highest traffic volume had highest dust on the road. D/Birhan –Ankober road had highest traffic dust and highest gravel loss. Since this road is federal road, heavy vehicle and higher traveled speed was observed. In addition to dust creation, traffic is also the causes of raveling of surfacing material. Since the bond between the surfacing materials of the gravel roads is weak, traffic can detaches the gravel from the roads and transport it to the side of the roads. This condition makes the thickness of the roads to be reduced. Observation was conducted to determine the level of dust created after the vehicle passes on the sample roads. The road that had higher traffic volume had also higher dust and raveled easily by traffic and vice versa. Although rutting, potholes and corrugation can be caused by traffic characteristic, in the three month observation of the three roads, the significant types of defects found were dusting and raveling of the gravel roads.

In this research, two models were developed using MLR and GLM. Traffic was considered in these models. In the first model by MLR, the coefficient in the model for traffic was positive. This means there were positive relationships between traffic and gravel loss. Considering equation 4.2, the coefficient of traffic is 0.05. In review of similar works, the coefficient of traffic was 0.013 and 0.008, 0.092, 0.013 and 0.008, 0.002 in equation 2.1, 2.2, 2.3 and 2.10 respectively and all are positive. Regarding the importance of traffic in the model, as a guide, look for t values well below -2 or above +2. From table 4.7, it was shown that the t statistic was

9.61 and it was well above 2. This indicates that traffic was one of the major independent variable which causes gravel loss.

Considering the model developed by GLM, ADT had a coefficient of -0.299. Comparing the coefficient of the model developed with the first model, it was higher in magnitude and negative. This difference was encountered because of in this model there were no intercepts and the line was allowed to pass through the origin. Table 4.10 indicates that the traffic data was significant.

Figure 4.6 puts some important ideas that are discussed before. Since three roads were observed, only three traffic count data were entered in the model. The figure shows that for higher traffic volume, observed gravel loss was relatively higher.

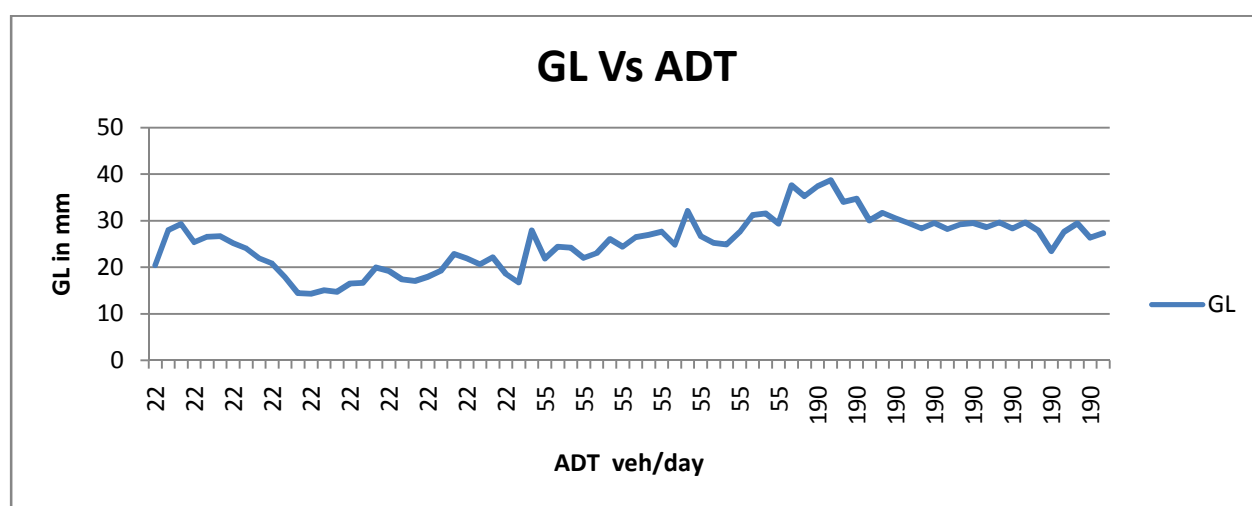


Figure 4.6: Relationship between observed gravel loss and traffic volume

One of the most important factors considered was climate of the road surrounding which was represented by its MMP. The three gravel road selected originate from the two towns i.e., D/Birhan and Chacha. The observation of three roads starts and ends at these towns. Therefore, it was appropriate to take only the MMP of the two towns. For the roads that originate from D/Birhan, the MMP was 220.8mm and for that of Chacha town, it was 234.4mm.

The models developed used only the two town data for 74 samples. 45 samples have MMP of 220mm and 29 samples have 234.4mm of MMP. This may be reduced the significance of precipitation in the model. The historical precipitation data gathered shows smaller difference in their magnitude. This was due to the two towns are neighbors and have almost similar climatic conditions.

Considering the observed gravel loss and the MMP of the three roads selected, it was expected that the road which had higher mean monthly precipitation could had higher observed gravel loss. This was not true in this research due to other factors that caused the observed gravel loss. Chacha–Tsgereda–Ginager road has higher mean monthly precipitation (234.4mm/month) and it had ADT of 22veh/day. D/Birhan –Ankober had 220.8mm/month of MMP and ADT of 180

veh/day. Considering the observed gravel loss of the two samples, the road that had higher traffic volume had higher observed gravel loss.

MMP of the selected roads was entered in the two proposed model. For the model developed by MLR, the coefficient of MMP was -0.455. Comparing these results to other research worked in the past, it was +3.50, +0.246 in equations 2.2 and 2.9 respectively. In this research, it was related with dependent variable negatively. The higher the precipitation, the lower would be the magnitude of the predicted value of gravel loss. The t value in table 4.7 becomes -8.0, which was well below -2, i.e. it was an important variable that should be considered in the model. Compared to other independent variable, it had lowest absolute value of t i.e. it had lowest importance in the mode.

MMP in the second model, which was developed by GLM, had positive coefficient of 0.461. This difference was encountered because of in this model there were no intercepts and the line was allowed to pass through the origin. Table 4.9 shows that the mean monthly precipitation was significant to 0.05.

Figure 4.7 indicates that the observed gravel loss was in line with the model developed by multiple linear regressions. Observed gravel loss and MMP related in negative manner i.e. the higher MMP the lower GL and vice versa.

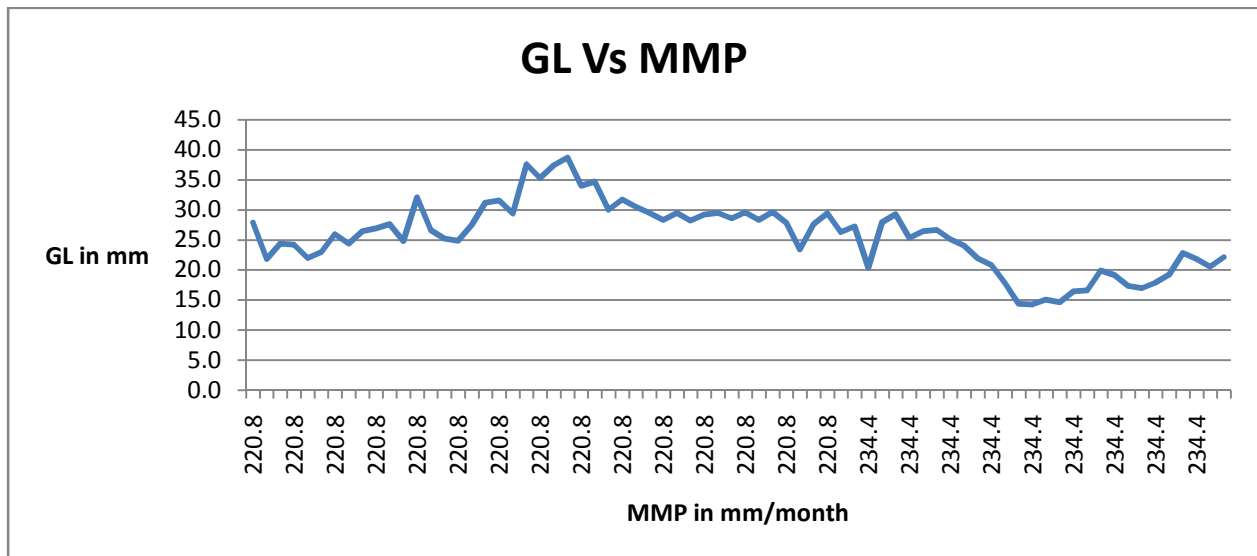


Figure 4.7: Relationship between observed gravel losses and mean monthly precipitation

Material quality, to which the surfacing of gravel road constructed, maintained and rehabilitated, affects the observed gravel loss result. In this research, plasticity index of the material was used to determine whether the fine material in the surfacing of the roads was significantly sand, clay and silt. Using the standard procedure to obtain liquid limit and plasticity limit, plasticity index was obtained. The plasticity index of D/birhan –Kasima road was found to be 13.49%. The sample surfacing material was classified as MH (Silt with High Plasticity) or OH



The maximum gradient observed was on Chacha-Tsgereda –Ginager road section and it was 5.86 %. The minimum gradient was observed on D/Birhan –Ankober and it was 0.19%.The gradient of the road was entered in the two model proposed. In the model developed by MLR, the coefficient of gradient was 2.337. Considering the significance of gradient in the model, from the table 4.7, it has a t value of 13.04 which was greater than any variable entered in the model. This was caused due to for each value entered as an observed gravel loss; there was single value of gradient unlike to other independent variable in the model. In the model developed by GLM, it has a coefficient of 2.337. It has positive value in both models and also has the same coefficient. Considering the research done in other countries, gradient had a coefficient of +0.366 and +1.88 in equation 2.1 and 2.2.

Considering the observed gravel loss and the absolute gradient of selected gravel roads, the increase in absolute gradient of the sample roads will increase the gravel loss. Figure 4.10 clearly shows this condition.

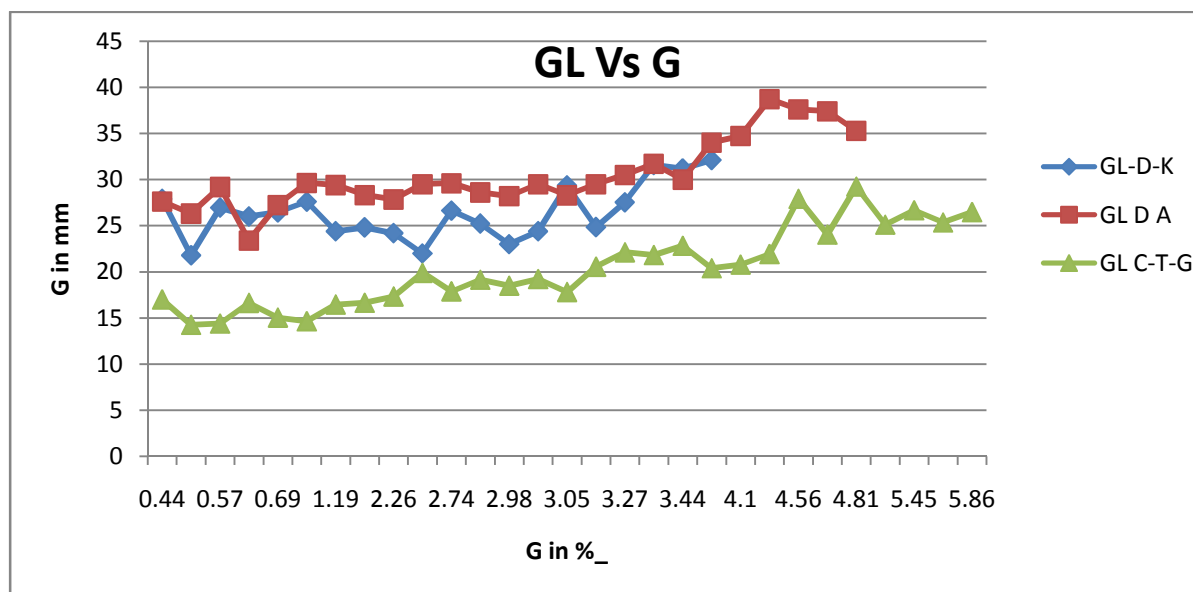


Figure 4.10: Relationship between observed gravel loss and gradient

Duration of observation was calculated by counting days between the first and the second observation. The observation was done between July the 5<sup>th</sup> and October 5<sup>th</sup> of 2014. The difference of these two observations was three month. To be entered in the two models, days of observation was divided by 100. This was to minimize large amount of significant figures in the model. This was apparent in equation 2.1 up to 2.10.

Gravel loss depends on the duration between observations. The gravel loss from the surface of the specific road is not the same for different observation time. Since gravel loss is the reduction of the thickness of the road by many factors, the total gravel loss will be higher for higher observation interval. For example in this research, the duration of observation was three

months and there would be higher observed gravel loss if the duration was higher than three months.

All independent variable was multiplied by 0.9 and entered in the software to be analyzed. In the first model by MLR, the duration of observation (D) was a multiplicative constant for all independent variable except the intercept of the model which was C in equation 4.1. In the second model by GLM, there was no intercept and the duration of observation become the multiplicative constant for all independent variables and this was as equation 4.3.

The result of modeling by MLR was shown on consecutive tables. Table 4.5 displays descriptive statistics for each variable. The mean is the average value for each variable entered in the model. The standard deviation measures the variability (or spread) of the values. N is the number of cases with non-missing values. In this research the value of N was 74. Table 4.6 displays R, R squared, adjusted R squared, and the standard error. Larger values of R indicate stronger relationships. In this research the values of R become 0.937. The sample R squared tends to optimistically estimate how well the models fit the population. Adjusted R squared attempts to correct R squared to more closely reflect the goodness of fit of the model in the population. In this research, the model by MLR has 0.878 and 0.873 of R square and adjusted R square respectively.

Table 4.7 displays the coefficient of the model parameter. The unstandardized coefficients are the coefficients of the estimated regression model. The estimated coefficients of the model were found from this table. Equation 4.2 of the model used this table for its coefficient. Form column B of this table, the coefficients were 108.2, 0.05, -0.455 and 2.337 for the intercept C, ADT, MMP and G respectively. The coefficient for the plasticity index was zero in the table and zero in the equation.

Table 4.9 summarizes the parameter estimates of a model by GLM. This table displays the parameter estimates in the column labeled B. This data was included in equation 4.3. The coefficients are -0.299, 0.461, -4.643 and 2.337 for ADT, MMP, PI and G respectively. Confidence intervals for the parameter estimates are also displayed. Considering this criterion, all independent variable had significant value of 0.00. ( $<<0.05$ ). This mean all variables was significant. This model had 0.994 of R square and adjusted R squares.

As shown in the table 4.9, GLM did include all the important parameter. It includes ADT, MMP, PI, G and D. Duration of observation was not included in the table exclusively. This was because prior to the model analysis, all independent parameter was multiplied by duration of observation. This was also true for model developed by MLR. Considering the coefficient of the model by GLM, it was not identical to that of the model resulted from MLR. The difference between the two was due the use of intercept.

Although it was difficult to obtain the details of studies in other countries concerning modeling of gravel loss, it was tried to compare the result of this research with the obtained data from the reference, especially their R square. The model developed by Lund [46], had R square of 0.6 and Adewole S. Oladele et.al [5], modeled gravel loss and the result had R square of 0.74. The

model developed in this research, compared with the other model developed in different countries, would give the best estimates of gravel loss.

Using the model obtained by the MLR and compared to the observed gravel loss value in each case (observed value-predicted value), depending on table 4.10, the maximum difference was 5.92 mm and the minimum difference was -4.21mm.

Comparing the predicted value by GLM and observed value of gravel loss, the maximum difference was 5.83mm and the minimum difference was -4.21mm.

Although the two models developed had approximately similar maximum and minimum residuals, the number of independent variable included, the coefficient of the these variables and their R squares were not the same. To select the best model from the two alternatives, according to SPSS 15.0 for window, the model that had higher value of R Square should be selected. The model by MLR had R square value of 0.878 and the model developed by GLM had R square value of 0.994. The model developed by GLM had higher R square value. Therefore, the second model was selected to be used in prediction of gravel loss on the sample roads observed.

Table 4.10 Model Result for General Linear Model and Multiple Linear Regressions

NO.	GL	ADT	MMP	PI	g	D	GLM	RESU	MLR	RESU
1	27.90	55	220.8	13.5	1.32	0.9	23.17	4.726	23.04	4.86
2	21.80	55	220.8	13.5	1.62	0.9	23.81	-2.007	23.67	-1.87
3	24.40	55	220.8	13.5	2.30	0.9	25.23	-0.829	25.09	-0.69
4	24.20	55	220.8	13.5	2.67	0.9	26.02	-1.819	25.88	-1.68
5	22.00	55	220.8	13.5	2.67	0.9	26.01	-4.013	25.88	-3.88
6	23.00	55	220.8	13.5	2.85	0.9	26.39	-3.394	26.26	-3.26
7	26.00	55	220.8	13.5	2.04	0.9	24.69	1.308	24.56	1.44
8	24.40	55	220.8	13.5	2.92	0.9	26.54	-2.140	26.41	-2.00
9	26.45	55	220.8	13.5	2.15	0.9	24.92	1.530	24.78	1.67
10	26.96	55	220.8	13.5	1.91	0.9	24.42	2.534	24.29	2.67
11	27.60	55	220.8	13.5	2.20	0.9	25.03	2.567	24.90	2.70
12	24.82	55	220.8	13.5	2.35	0.9	25.34	-0.520	25.20	-0.38
13	32.10	55	220.8	13.5	4.01	0.9	28.84	3.263	28.70	3.40
14	26.63	55	220.8	13.5	2.72	0.9	26.12	0.510	25.99	0.65
15	25.23	55	220.8	13.5	2.83	0.9	26.35	-1.115	26.21	-0.98
16	24.85	55	220.8	13.5	2.97	0.9	26.65	-1.796	26.51	-1.66
17	27.53	55	220.8	13.5	3.07	0.9	26.86	0.670	26.73	0.81
18	31.18	55	220.8	13.5	3.27	0.9	27.27	3.903	27.14	4.04
19	31.57	55	220.8	13.5	3.19	0.9	27.10	4.469	26.96	4.61
20	29.37	55	220.8	13.5	2.94	0.9	26.58	2.784	26.45	2.92
21	37.60	190	220.8	3.39	4.07	0.9	34.89	2.708	34.89	2.71

NO.	GL	ADT	MMP	PI	g	D	GLM	RESU	MLR	RESU
22	35.27	190	220.8	3.39	4.15	0.9	35.06	0.214	35.06	0.21
23	37.40	190	220.8	3.39	4.08	0.9	34.92	2.483	34.92	2.48
24	38.70	190	220.8	3.39	3.65	0.9	34.01	4.689	34.01	4.69
25	34.00	190	220.8	3.39	2.97	0.9	32.58	1.425	32.57	1.43
26	34.72	190	220.8	3.39	3.55	0.9	33.81	0.913	33.81	0.91
27	30.00	190	220.8	3.39	2.85	0.9	32.32	-2.323	32.32	-2.32
28	31.70	190	220.8	3.39	2.83	0.9	32.30	-0.595	32.29	-0.59
29	30.50	190	220.8	3.39	2.56	0.9	31.73	-1.229	31.73	-1.23
30	29.50	190	220.8	3.39	2.30	0.9	31.17	-1.669	31.17	-1.67
31	28.30	190	220.8	3.39	1.12	0.9	28.68	-0.381	28.68	-0.38
32	29.50	190	220.8	3.39	1.03	0.9	28.50	0.996	28.50	1.00
33	28.20	190	220.8	3.39	0.85	0.9	28.12	0.082	28.12	0.08
34	29.20	190	220.8	3.39	0.59	0.9	27.57	1.632	27.57	1.63
35	29.50	190	220.8	3.39	0.73	0.9	27.88	1.623	27.88	1.62
36	28.61	190	220.8	3.39	0.80	0.9	28.02	0.591	28.02	0.59
37	29.60	190	220.8	3.39	0.76	0.9	27.93	1.665	27.93	1.67
38	28.31	190	220.8	3.39	0.68	0.9	27.77	0.537	27.77	0.54
39	29.64	190	220.8	3.39	0.62	0.9	27.64	1.996	27.64	2.00
40	27.85	190	220.8	3.39	0.69	0.9	27.78	0.065	27.78	0.07
41	23.40	190	220.8	3.39	0.61	0.9	27.61	-4.209	27.61	-4.21
42	27.63	190	220.8	3.39	0.19	0.9	26.74	0.894	26.74	0.89
43	29.41	190	220.8	3.39	0.66	0.9	27.72	1.689	27.72	1.69
44	26.32	190	220.8	3.39	0.29	0.9	26.94	-0.616	26.94	-0.62
45	27.24	190	220.8	3.39	0.61	0.9	27.62	-0.378	27.62	-0.38
46	20.40	22	234.4	18.67	4.10	0.9	21.94	-1.531	21.84	-1.43
47	27.93	22	234.4	18.67	4.56	0.9	22.90	5.030	22.80	5.13
48	29.25	22	234.4	18.67	4.81	0.9	23.43	5.825	23.33	5.92
49	25.36	22	234.4	18.67	5.60	0.9	25.09	0.267	24.99	0.36
50	26.48	22	234.4	18.67	5.86	0.9	25.63	0.845	25.53	0.94
51	26.68	22	234.4	18.67	5.45	0.9	24.76	1.921	24.66	2.02
52	25.11	22	234.4	18.67	4.95	0.9	23.71	1.398	23.61	1.50
53	24.04	22	234.4	18.67	4.61	0.9	23.00	1.033	22.91	1.13
54	21.93	22	234.4	18.67	4.23	0.9	22.20	-0.267	22.10	-0.17
55	20.79	22	234.4	18.67	4.10	0.9	21.93	-1.136	21.83	-1.04
56	17.81	22	234.4	18.67	3.05	0.9	19.72	-1.907	19.62	-1.81
57	14.39	22	234.4	18.67	0.57	0.9	14.51	-0.113	14.41	-0.02
58	14.26	22	234.4	18.67	0.48	0.9	14.32	-0.059	14.22	0.04
59	15.04	22	234.4	18.67	0.69	0.9	14.76	0.279	14.66	0.38

NO.	GL	ADT	MMP	PI	g	D	GLM	RESU	MLR	RESU
60	14.64	22	234.4	18.67	0.82	0.9	15.02	-0.377	14.92	-0.28
61	16.46	22	234.4	18.67	1.19	0.9	15.80	0.665	15.70	0.76
62	16.63	22	234.4	18.67	0.61	0.9	14.59	2.042	14.49	2.14
63	19.90	22	234.4	18.67	2.65	0.9	18.88	1.018	18.78	1.12
64	19.14	22	234.4	18.67	2.86	0.9	19.31	-0.174	19.21	-0.08
65	17.33	22	234.4	18.67	2.26	0.9	18.06	-0.726	17.96	-0.63
66	17.00	22	234.4	18.67	0.44	0.9	14.22	2.778	14.12	2.88
67	17.88	22	234.4	18.67	2.74	0.9	19.07	-1.194	18.97	-1.10
68	19.21	22	234.4	18.67	3.02	0.9	19.66	-0.451	19.56	-0.35
69	22.83	22	234.4	18.67	3.44	0.9	20.54	2.290	20.45	2.39
70	21.83	22	234.4	18.67	3.36	0.9	20.38	1.456	20.28	1.55
71	20.56	22	234.4	18.67	3.19	0.9	20.02	0.536	19.93	0.63
72	22.12	22	234.4	18.67	3.27	0.9	20.19	1.935	20.09	2.03
73	18.50	22	234.4	18.67	2.98	0.9	19.58	-1.078	19.48	-0.98
74	16.64	22	234.4	18.67	1.82	0.9	17.14	-0.502	17.04	-0.40
max	38.70				5.86		35.06	5.825	35.06	5.92
min	14.26				0.19		14.22	-4.209	14.12	-4.21

Note- RESU=Residual=difference =Observed Value –Predicted Value of each model in each case. Table 4.12 is similar to casewise diagnostic, which is included in appendix F. Max=maximum value of each roads and for each independent and dependent variable. Min= minimum value of each roads and for each independent and dependent variables.

## Chapter 5: Conclusion and Recommendation

### 5.1. Conclusion

To develop gravel loss model for unsealed roads, the major factors that affect gravel roads were selected. The selected factors were average daily traffic (ADT), mean monthly precipitation (MMP), plasticity index (PI), absolute gradient (G) and the duration of observation in terms of days/100(D).

From observation result, the relationship between GL and ADT was positive. The relation between GL and MMP was surprisingly negative. The relationship between GL and PI was also negative. The relationship between GL and G was positive. The relationship between GL and D was positive.

Two models were developed using MLR and GLM. Model developed by MLR had an intercept in the equation and did not include plasticity index. The model developed by GLM did not include the intercept and had all the selected independent variable in the model. A model developed by MLR had R square of 0.878 and model developed by GLM had R square of 0.994.

The major defects on the gravel roads that lead to gravel loss were identified. From observation of the sample roads, the major significant defects on the observed roads were dust and raveling of the surfacing material. Although other factors such as potholes, ruts and corrugation could affect the gravel loss result, on the selected roads they were not observed.

Methods and procedures were proposed in developing the gravel loss model. The method that was used to obtain the gravel loss data can be used for future researches. The method used to obtain all independent variables followed standard procedures.

## 5.2. Recommendation

To easily use the model, all road agencies need to have, ADT, MMP, PI, G and duration to which the prediction would be made ahead. Some of the data regarding the independent variables can be found in their data base and some other information can be gathered from other agencies.

The first model by MLR includes intercept (C) in the model equation and eliminates PI. The second model by GLM had all the parameter required and had higher R squares. Although the first model was simple, the impacts of gravel road surfacing material should not be underestimated and omitted in the model. Therefore, it was preferred to use the second model which includes all the independent variable proposed and had high R square.

The limitation of the developed model was they lack variety of each independent variable. For further studies, gravel roads located in different region of the country should be assessed to develop a comprehensive model. By doing this, ADT, MMP, PI, G will be different for each case entered in the model.

The model developed did not include all the factors that can cause gravel loss. For further studies the characteristics of the traffic such as axle loads, vehicle speed, and the impacts of heavy vehicle should be studied. The effect climatic conditions of the road such as seasonal variation of rainfall, temperature, and so on should be investigated. The behaviors of the surfacing and the sub- grade material should also be studied to know the exact contributor of gravel loss. In this regard, gradation, durability of the surfacing material, the behaviors of sub-grade material, and thickness of the surfacing material and so on should be studied. The geometric design parameters should be looked carefully to develop a comprehensive model. Cross -sectional element, such as cross fall, lane width and so on; horizontal alignment such as horizontal curve and tangents, should be studied. Duration of observation should be higher to include all the variation that would be encountered by traffic and climatic condition. It was recommended to stretch the duration of observation up to at least one year.

It was found difficult to do the research alone. To conduct such kinds of research, there needs a group of experienced personnel. Transportation to the sites, survey equipment manipulation and material testing were the most challenging operation to conduct this research. To develop this very useful model, it is recommended that the concerned organization need to prepare, organize the group and allocate appropriate budgets.

### 5.2.1. Further Study Topics

- Quantifying dust created on gravel roads by the effects of traffic characteristics (speed, axle loads, traffic composition etc.)
- The study of the effects of climatic conditions on gravel loss (temperature, rainfall)
- The study of the effects of cross-section element of gravel roads on gravel loss (lane width, cross-fall)
- The study of the effects of horizontal alignment of gravel roads on gravel loss

- The study of the effects of lane width, traffic speed and absolute gradient on gravel loss.
- The study of the effects of vertical alignment of the gravel roads on gravel loss
- The study of the relationship between raveling and surface material gradation
- The study of relationship between durability of the surfacing material and dust on gravel roads
- The study of the influence of sub-grade material on gravel loss result.
- The Study of the residual life of gravel roads
- Gravel roads surfacing material specification to inhibit grave loss
- Determination of future demand of resurfacing of the specific road using gravel loss models
- Determination of grading cycle using gravel loss models

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# APENDICES

**APPENDIX A**  
**Sample Gravel loss observation Result**

Modeling of Gravel loss for Unsealed roads										
Road section name :-		D/Birhan -Kasima			Segment Name :-			Observation date:-		
Road Segment No.	1	Start km		End km.		St. Pt. Lordinate -	N=0, E=0, Z=0			
discrption of the Sample										
length of the road at 5 m interval	Z values along the Width of the road at 1m interval									
		0	1	2	3	4	5	average	section	gradient
	0	0.124	0.165	0.182	0.196	0.195	0.195			
	0	0.112	0.141	0.159	0.160	0.163	0.154			
	change	0.012	0.023	0.022	0.036	0.033	0.041	0.0285		
	5	0.162	0.215	0.238	0.244	0.249	0.245			
	5	0.146	0.182	0.206	0.212	0.203	0.164			
	change	0.016	0.033	0.032	0.033	0.045	0.081	0.0359		
	10	0.192	0.255	0.282	0.290	0.287	0.265			
	10	0.175	0.225	0.250	0.261	0.264	0.244			
	change	0.017	0.030	0.031	0.030	0.023	0.020	0.0233		
	15	0.205	0.268	0.310	0.322	0.325	0.304			
	15	0.201	0.249	0.287	0.297	0.297	0.261			
	change	0.004	0.019	0.023	0.025	0.029	0.044	0.0239	0.0279	1.32
	20	0.203	0.272	0.305	0.313	0.304	0.277			
	20	0.194	0.250	0.281	0.291	0.285	0.250			
	change	0.009	0.022	0.024	0.022	0.019	0.027	0.0220		
	25	0.263	0.329	0.355	0.369	0.363	0.328			
	25	0.268	0.315	0.336	0.348	0.335	0.289			
	change	-0.005	0.014	0.019	0.021	0.033	0.039	0.0217		
30	0.347	0.396	0.420	0.426	0.411	0.356				
30	0.336	0.379	0.404	0.405	0.392	0.343				
change	0.011	0.016	0.022	0.020	0.019	0.013	0.0195	0.0218	1.62	
35	0.447	0.527	0.542	0.549	0.543	0.488				
35	0.442	0.498	0.524	0.524	0.513	0.472				
change	0.005	0.029	0.018	0.024	0.025	0.015	0.0240			
40	0.534	0.597	0.627	0.618	0.595	0.524				
40	0.554	0.589	0.591	0.588	0.565	0.472				
change	-0.020	0.008	0.035	0.030	0.031	0.052	0.0260			
45	0.615	0.572	0.675	0.680	0.653	0.576				
45	0.606	0.543	0.653	0.651	0.624	0.549				
change	0.009	0.029	0.026	0.029	0.029	0.027	0.0284	0.0244	2.30	
50	0.643	0.595	0.708	0.723	0.697	0.660				
50	0.613	0.569	0.688	0.696	0.680	0.640				
change	0.030	0.026	0.021	0.027	0.017	0.019	0.0227			
55	0.708	0.762	0.776	0.798	0.780	0.732				
55	0.680	0.738	0.753	0.767	0.757	0.720				
change	0.029	0.024	0.023	0.031	0.024	0.012	0.0251			
60	0.786	0.840	0.852	0.864	0.843	0.791				
60	0.760	0.815	0.835	0.839	0.823	0.772				
change	0.025	0.025	0.017	0.025	0.015	0.019	0.0208	0.0242	2.67	
NOTE:	The second observation was shown a number at the point and a mark The observations was recorded in meter and converted to mm in the model development.									

Modeling of Gravel loss for Unsealed roads											
Road section name :-			D/Birhan-Ainkober			Segment Name :-			Observation date		
Road Segment No.		1 Start km		End km.				N=0, E=0, Z=0			
disciption of the Sample											
length of the road at: 5 m interval	Z values along the Width of the road at 1m interval										
		0	1	2	3	4	5	5	average	section	Gracient
	0	0.055	0.077	0.067	0.048	-0.067	-0.053	-0.128			
	0'	0.016	0.044	0.029	0.009	-0.116	-0.090	-0.174			
	change=	0.039	0.033	0.037	0.039	0.049	0.037	0.047	0.040		
	5	-0.383	-0.211	-0.205	-0.231	-0.261	-0.330	-0.375			
	5'	-0.476	-0.270	-0.247	-0.267	-0.307	-0.362	-0.410			
	change	0.043	0.059	0.035	0.036	0.047	0.032	0.040	0.030		
	10	-0.551	-0.503	-0.503	-0.520	-0.517	-0.581	-0.645			
	10'	-0.505	-0.537	-0.544	-0.555	-0.555	-0.581	-0.652			
	change	0.033	0.035	0.035	0.035	0.037	0.100	0.005	0.035		
	15	0.817	0.763	0.765	0.794	0.783	0.874	0.932			
	15'	-0.851	-0.801	-0.802	-0.833	-0.821	-0.908	-0.970			4.07
	change	0.035	0.037	0.035	0.035	0.037	0.035	0.037	0.036	0.0376	
	20	-1.117	-1.081	-1.048	-1.092	-1.106	-1.133	-1.192			
	20'	-1.134	-1.110	-1.084	-1.123	-1.135	-1.162	-1.212			
	change=	0.017	0.029	0.036	0.031	0.029	0.029	0.019	0.027		
	25	-1.371	-1.354	-1.333	-1.381	-1.348	-1.416	-1.469			
	25'	-1.390	-1.372	-1.379	-1.425	-1.388	-1.454	-1.502			
	change	0.039	0.038	0.040	0.043	0.040	0.038	0.033	0.030		
30	-1.604	-1.575	-1.577	-1.612	-1.580	-1.547	-1.680				
30'	1.643	1.515	1.612	1.652	1.623	1.586	1.719			4.15	
change	0.039	0.040	0.035	0.040	0.040	0.039	0.038	0.035	0.0353		
35	2.050	2.003	2.022	2.043	2.028	2.087	2.165				
35'	-2.105	-2.049	-2.062	-2.091	-2.071	-2.132	-2.205				
change	0.045	0.047	0.040	0.048	0.044	0.045	0.033	0.044			
40	-2.415	-2.303	-2.315	-2.331	-2.357	-2.398	-2.510				
40'	-2.448	-2.340	-2.350	-2.364	-2.393	-2.434	-2.520				
change=	0.033	0.037	0.034	0.033	0.036	0.036	0.010	0.030			
45	-3.030	-2.956	-2.999	-2.907	-2.875	-2.944	-3.052				
45'	-3.104	-2.967	-2.930	-2.930	-2.908	-2.978	-3.084			4.08	
change	0.023	0.031	0.031	0.031	0.033	0.034	0.031	0.032	0.0374		
50	-3.751	-3.655	-3.605	-3.557	-3.571	-3.541	-3.751				
50'	3.798	3.702	3.655	3.608	3.620	3.587	3.772				
change	0.017	0.047	0.049	0.051	0.049	0.045	0.021	0.018			
55	-4.092	-3.977	-4.003	-3.882	-3.863	-4.166	-4.022				
55'	-4.129	-4.013	-4.043	-3.916	-3.895	-4.505	-4.055				
change	0.037	0.037	0.040	0.033	0.031	0.038	0.033	0.036			
60	-4.346	-4.241	-4.242	-4.213	-4.213	-4.293	-4.425				
60'	-4.336	-4.281	-4.285	-4.248	-4.249	-4.337	-4.463			3.05	
change	0.040	0.040	0.044	0.035	0.037	0.038	0.037	0.030	0.0306		
NOTE:	The second observaton was shown a number at the point and a mark The observations was recorded in meter and converted to mm in the model development										

Road section name :-		hacha -Tsgerada-Ginager				Observation date				
Road Segment No	1	Start km		End km		t.Pt. Cordinate	N:-0,E=0,Z=0			
disciption of the Sample										
length of the road at 5 m interval	Z values along the Width of the road at 1m interval									
		0	1	2	3	4	5	6	Average	Section
	0	0.172	0.286	0.372	0.41	0.404	0.37	0.323		
	0'	0.151	0.263	0.351	0.389	0.379	0.34	0.302		
	loss	0.021	0.023	0.021	0.021	0.025	0.03	0.021	0.0226	
	5	-0.037	0.081	0.167	0.214	0.194	0.16	0.009		
	5'	-0.051	0.062	0.142	0.19	0.17	0.13	-0.01		
	loss	0.014	0.019	0.025	0.024	0.024	0.02	0.015	0.0203	
	10	-0.227	-0.113	-0.038	-0.01	-0.03	-0.08	-0.01		
	10'	-0.239	-0.131	-0.056	-0.03	-0.05	-0.1	-0.03		
loss	0.012	0.018	0.018	0.019	0.024	0.02	0.02	0.0180		
15	-0.438	-0.325	-0.254	-0.23	-0.05	-0.31	-0.37			
15'	-0.459	-0.349	-0.275	-0.26	-0.06	-0.33	-0.39			
loss	0.021	0.024	0.021	0.022	0.018	0.02	0.019	0.0207	0.0204	
20	-0.602	-0.514	-0.462	-0.44	-0.46	-0.51	-0.56			
20'	-0.621	-0.537	-0.483	-0.46	-0.48	-0.53	-0.59			
loss	0.019	0.023	0.021	0.02	0.025	0.02	0.023	0.0217		
25	-0.82	-0.725	-0.671	-0.66	-0.68	-0.72	-0.78			
25'	-0.842	-0.746	-0.693	-0.68	-0.7	-0.74	-0.8			
loss	0.022	0.021	0.022	0.023	0.024	0.02	0.018	0.0216		
30	-1.056	-0.958	-0.912	-0.91	-0.92	-0.97	-1.04			
30'	-1.068	-0.986	-0.933	-0.93	-0.94	-1.18	-1.06			
loss	0.012	0.028	0.021	0.021	0.022	0.21	0.02	0.0477	0.0279	
35	-1.285	-1.201	-1.155	-1.16	-1.16	-1.22	-1.27			
35'	-1.309	-1.224	-1.179	-1.18	-1.19	-1.24	-1.29			
loss	0.024	0.023	0.024	0.024	0.025	0.03	0.021	0.024		
40	-1.538	-1.455	-1.408	-1.39	-1.41	-1.44	-1.49			
40'	-1.561	-1.476	-1.432	-1.42	-1.43	-1.46	-1.51			
loss	0.023	0.021	0.024	0.023	0.022	0.02	0.021	0.022		
45	-1.791	-1.699	-1.655	-1.64	-1.64	-1.67	-1.72			
45'	-1.816	-1.72	-1.68	-1.66	-1.66	-1.7	-1.75			
loss	0.025	0.021	0.025	0.024	0.023	0.02	0.024	0.023	0.0293	
50	-2.048	-1.968	-1.925	-1.9	-1.9	-1.94	-1.98			
50'	-2.069	-1.995	-1.951	-1.93	-1.93	-1.96	-2.01			
loss	0.021	0.027	0.026	0.028	0.024	0.02	0.024	0.0244		
55	-2.338	-2.257	-2.208	-2.18	-2.17	-2.21	-2.25			
55'	-2.359	-2.284	-2.234	-2.2	-2.2	-2.23	-2.28			
loss	0.021	0.027	0.026	0.023	0.027	0.03	0.03	0.026		
60	-2.613	0	-2.507	-2.49	-2.49	-2.51	-2.56			
60'	-2.613	0	-2.507	-2.49	-2.49	-2.51	-2.56			
loss	0.029	0.027	0.028	0.031	0.027	0.03	0.027	0.028	0.0254	
65	-2.925	-2.852	-2.812	-2.79	-2.79	-2.82	-2.86			
65'	-2.946	-2.879	-2.839	-2.82	-2.82	-2.85	-2.88			
loss	0.021	0.027	0.027	0.029	0.03	0.03	0.019	0.026		

**APPENDIX B**  
**Traffic Count Result**

Date 4-10/8/2014

**Traffic count worksheet for D/Birhan –Kasima road**

Class	Type	Days of the week						
		Mon	Tue	Wed	Thr	Fri	Sat	Sun
1	Car	 	 		 			 
2	Pick-up/4WD							
3	Small bus	 	 		 		 	 
4	Bus/Coach					 	 	 
5	Small truck							
6	Medium truck							
7	Large two axle truck							
8	3-axled truck							
9	4-axled truck							
10	5-axled truck							
11	6-axled truck							
12	3-axled trailer							
13	4-axled trailer							
Two directional traffic veh/dfay		53	55	40	54	53	66	70
Average		55.85 veh/day approximately 55veh/day						

Date 11-17/8/2014

**Traffic count worksheet for the road Chacha-Tsgerada-Ginager road**

Class	Type	Days of the week						
		Mon	Tue	Wed	Thr	Fri	Sat	Sun
1	Car						<del>   </del>	<del>   </del>
2	Pick-up/4WD	<del>   </del>	<del>   </del>	<del>   </del> <del>   </del>	<del>   </del>	<del>   </del>		
3	Small bus	<del>   </del> <del>   </del>	<del>   </del> <del>   </del>	<del>   </del>	<del>   </del> <del>   </del>	<del>   </del>	<del>   </del> <del>   </del>	<del>   </del> <del>   </del>
4	Bus/Coach						<del>   </del>	<del>   </del>
5	Small truck							
6	Medium truck							
7	Large two axle truck							
8	3-axled truck							
9	4-axled truck							
10	5-axled truck							
11	6-axled truck							
12	3-axled trailer							
13	4-axled trailer							
Two directional traffic veh/day		22	26	17	23	14	29	25
Average		22.28 veh/day approximately 22 veh/day						

## **APPENDIX C**

### **Rain Fall History of the two towns**

**Debre Birhan Town Rainfall History**

PRECIP	1984	236.5	108.4	93.1	146
PRECIP	1985	314.6	376.6	88.4	259.9
PRECIP	1986	271.3	274.7	115.7	220.6
PRECIP	1987	32.3	309.5	47.5	129.8
PRECIP	1988	286.2	290	153.1	243.1
PRECIP	1989	211.4	177.4	67.7	152.2
PRECIP	1990	321	217.2	168.7	235.6
PRECIP	1991	215.6	387.5	86.6	229.9
PRECIP	1992	307.6	267.6	92.9	222.7
PRECIP	1993	294.7	168.4	97.3	186.8
PRECIP	1994	281.7	222.9	101.7	202.1
PRECIP	1995	305.1	233.8	60.4	199.8
PRECIP	1996	328.4	252.5	24.3	201.7
PRECIP	1997	272.1	200.6	34.8	169.2
PRECIP	1998	337.3	289	70.6	232.3
PRECIP	1999	362.4	365.1	52.4	260
PRECIP	2000	352.4	317.5	105.2	258.4
PRECIP	2001	406.7	260.4	32.2	233.1
PRECIP	2002	214.4	294.8	109.1	206.1
PRECIP	2003	334.1	288.7	74.2	232.3
PRECIP	2004	334.7	301.3	78.9	238.3
PRECIP	2005	310.7	228.3	106.8	215.3
PRECIP	2006	432.6	224.2	59.8	238.9
PRECIP	2007	309.9	414.6	128.5	284.3
PRECIP	2008	397.7	234.8	76.6	236.4
PRECIP	2009	423.4	273.1	31.4	242.6
PRECIP	2010	242.3	312.2	53.8	202.8
PRECIP	2011	357.4	312.3	79	249.6
PRECIP	2012	351.6	394.5	92.4	279.5
PRECIP	2013	358.5	204.4	79.6	214.2
				avg	220.7833

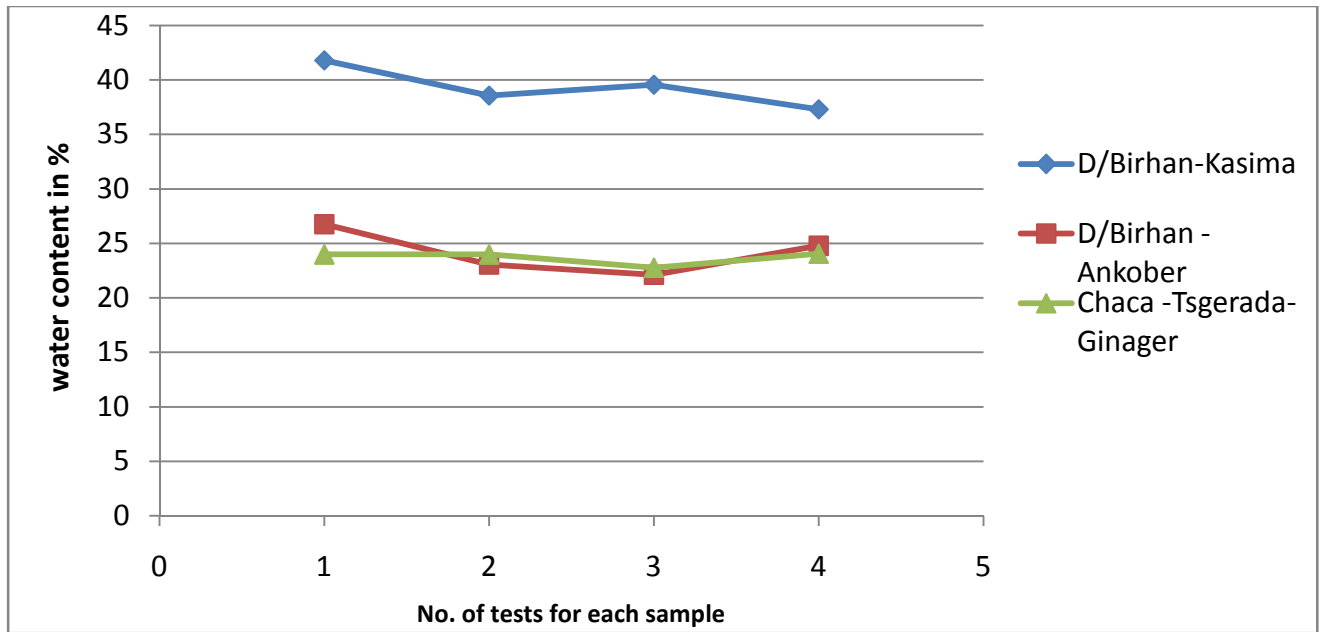
**Chacha Town Rainfall History**

Eg abbreviation	Year	Jul	Aug	Sep	avg
PRECIP	1987	63	256.8	44.1	121.3
PRECIP	1988	291.6	294.1	206.9	264.2
PRECIP	1989	245.8	309.8	131.8	229.1
PRECIP	1990	355.3	440.7	245.7	347.2
PRECIP	1991	341.1	391.6	190.7	307.8
PRECIP	1992	246.4	302.3	82.6	210.4
PRECIP	1993	427.6	337.9	136.2	300.6
PRECIP	1994	165.2	152.3	73.3	130.3
PRECIP	1995	202.8	210.2	45.7	152.9
PRECIP	1996	327.2	310	11.1	216.1
PRECIP	1997	152.5	159.9	0	104.1
PRECIP	1998	398.4	347.4	242.2	329.3
PRECIP	1999	284.9	264.9	66	205.3
PRECIP	2000	160.7	277.8	25.3	154.6
PRECIP	2001	339.5	381.8	36.6	252.6
PRECIP	2002	245.2	289.6	71.6	202.1
PRECIP	2003	423	356.6	102.7	294.1
PRECIP	2004	429.1	263.7	124.6	272.5
PRECIP	2005	249.7	310	121.7	227.1
PRECIP	2006	410.9	302.3	107.1	273.4
PRECIP	2007	278	454.5	122.3	284.9
PRECIP	2008	343.5	442.4	98.2	294.7
PRECIP	2009	292.3	430.3	74.1	265.6
PRECIP	2010	311.4	378.3	71.8	253.8
PRECIP	2011	53.4	339.8	102.9	165.4
PRECIP	2012		354.2		
PRECIP	2013				
PRECIP	2014				
				avg	234.4

**APPENDIX D**  
**MATERAIL TEST RESULT**



**Plasticity Limit Test Result Summary for each sample road**



**APPENDIX E**  
**MODELLING RESULT**

REGRESSION

```

/DESCRIPTIVES MEAN STDDEV CORR SIG N
/MISSING LISTWISE
/STATISTICS COEFF OUTS CI BCOV R ANOVA COLLIN TOL CHANGE ZPP
/CRITERIA=PIN(.05) POUT(.10) CIN(95)
/NOORIGIN
/DEPENDENT GL
/METHOD=ENTER ADT MMP PI G
/PARTIALPLOT ALL
/SCATTERPLOT=(GL ,*ZPRED ) (GL ,*ZRESID ) (GL ,*SRESID ) (GL ,*SDRESID )
(*ZPRED ,*ZRESID ) (*ZPRED ,*DRESID ) (*ZPRED ,*ADJPRED )
/RESIDUALS DURBIN HIST(ZRESID) NORM(ZRESID)
/CASEWISE PLOT(ZRESID) ALL
/SAVE PRED ZPRED ADJPRED SEPREP MAHAL COOK LEVER MCIN RESID ZRESID SRESID
DRESID SDRESID DFBETA SDBETA DFFIT SDFIT COVRATIO .

```

## Regression

[DataSet0]

### Descriptive Statistics

	Mean	Std. Deviation	N
Gravel Loss	25.4084	5.75522	74
Average Daily Traffic	78.9081	67.30008	74
Mean Monthly Pricipitation	203.5168	6.01602	74
Plasticity index	10.8811	5.96906	74
Absolute Gradient	2.4705	1.45356	74

### Correlations

		Gravel Loss	Average Daily Traffic	Mean Monthly Pricipitation
Pearson Correlation	Gravel Loss	1.000	.699	-.710
	Average Daily Traffic	.699	1.000	-.710
	Mean Monthly Pricipitation	-.710	-.710	1.000
	Plasticity index	-.735	-.990	.801
	Absolute Gradient	.219	-.382	.308
Sig. (1-tailed)	Gravel Loss	.	.000	.000
	Average Daily Traffic	.000	.	.000
	Mean Monthly Pricipitation	.000	.000	.
	Plasticity index	.000	.000	.000
	Absolute Gradient	.030	.000	.004
N	Gravel Loss	74	74	74
	Average Daily Traffic	74	74	74
	Mean Monthly Pricipitation	74	74	74
	Plasticity index	74	74	74
	Absolute Gradient	74	74	74

**Correlations**

		Plasticity index	Absolute Gradient
Pearson Correlation	Gravel Loss	-.735	.219
	Average Daily Traffic	-.990	-.382
	Mean Monthly Pricipitation	.801	.308
	Plasticity index	1.000	.386
	Absolute Gradient	.386	1.000
Sig. (1-tailed)	Gravel Loss	.000	.030
	Average Daily Traffic	.000	.000
	Mean Monthly Pricipitation	.000	.004
	Plasticity index	.	.000
	Absolute Gradient	.000	.
N	Gravel Loss	74	74
	Average Daily Traffic	74	74
	Mean Monthly Pricipitation	74	74
	Plasticity index	74	74
	Absolute Gradient	74	74

**Variables Entered/Removed<sup>b</sup>**

Model	Variables Entered	Variables Removed	Method
1	Absolute Gradient, Mean Monthly Pricipitation, Average Daily Traffic <sup>a</sup>	.	Enter

a. Tolerance = .000 limits reached.

b. Dependent Variable: Gravel Loss

**Model Summary<sup>b</sup>**

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.937 <sup>a</sup>	.878	.873	2.05307

**Model Summary<sup>b</sup>**

Model	Change Statistics					Durbin-Watson
	R Square Change	F Change	df1	df2	Sig. F Change	
1	.878	167.879	3	70	.000	1.427

a. Predictors: (Constant), Absolute Gradient, Mean Monthly Pricipitation, Average Daily Traffic

b. Dependent Variable: Gravel Loss

**ANOVA<sup>b</sup>**

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2122.885	3	707.628	167.879	.000 <sup>a</sup>
	Residual	295.057	70	4.215		
	Total	2417.943	73			

a. Predictors: (Constant), Absolute Gradient, Mean Monthly Pricipitation, Average Daily Traffic

b. Dependent Variable: Gravel Loss

**Coefficients<sup>a</sup>**

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	108.203	11.832		9.145	.000
	Average Daily Traffic	.050	.005	.587	9.611	.000
	Mean Monthly Pricipitation	-.455	.057	-.475	-8.005	.000
	Absolute Gradient	2.337	.179	.590	13.042	.000

**Coefficients<sup>a</sup>**

Model		95% Confidence Interval for B		Correlations		
		Lower Bound	Upper Bound	Zero-order	Partial	Part
1	(Constant)	84.606	131.800			
	Average Daily Traffic	.040	.061	.699	.754	.401
	Mean Monthly Pricipitation	-.568	-.341	-.710	-.691	-.334
	Absolute Gradient	1.979	2.694	.219	.842	.545

**Coefficients<sup>a</sup>**

Model		Collinearity Statistics	
		Tolerance	VIF
1	(Constant)		
	Average Daily Traffic	.467	2.143
	Mean Monthly Pricipitation	.494	2.022
	Absolute Gradient	.851	1.175

a. Dependent Variable: Gravel Loss

**Excluded Variables<sup>b</sup>**

Model		Beta In	t	Sig.	Partial Correlation
1	Plasticity index	. <sup>a</sup>	.	.	.

**Excluded Variables<sup>b</sup>**

Model		Collinearity Statistics		
		Tolerance	VIF	Minimum Tolerance
1	Plasticity index	.000	.	.000

- a. Predictors in the Model: (Constant), Absolute Gradient, Mean Monthly Pricipitation, Average Daily Traffic  
 b. Dependent Variable: Gravel Loss

**Coefficient Correlations<sup>a</sup>**

Model			Absolute Gradient	Mean Monthly Pricipitation	Average Daily Traffic
1	Correlations	Absolute Gradient	1.000	-.057	.244
		Mean Monthly Pricipitation	-.057	1.000	.674
		Average Daily Traffic	.244	.674	1.000
1	Covariances	Absolute Gradient	.032	-.001	.000
		Mean Monthly Pricipitation	-.001	.003	.000
		Average Daily Traffic	.000	.000	2.73E-005

- a. Dependent Variable: Gravel Loss

**Collinearity Diagnostics<sup>a</sup>**

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions			
				(Constant)	Average Daily Traffic	Mean Monthly Pricipitation	Absolute Gradient
1	1	3.407	1.000	.00	.01	.00	.01
	2	.478	2.669	.00	.27	.00	.15
	3	.114	5.466	.00	.25	.00	.84
	4	.000	127.945	1.00	.47	1.00	.00

- a. Dependent Variable: Gravel Loss

**Casewise Diagnostics<sup>a</sup>**

Case Number	Std. Residual	Gravel Loss	Predicted Value	Residual
1	2.328	27.90	23.1198	4.78018
2	-1.132	21.80	24.1246	-2.32461
3	-.640	24.40	25.7136	-1.31357
4	-1.158	24.20	26.5782	-2.37816
5	-2.230	22.00	26.5782	-4.57816
6	-1.948	23.00	26.9988	-3.99877
7	.435	26.00	25.1060	.89397
8	-1.344	24.40	27.1623	-2.75934
9	.529	26.45	25.3631	1.08693
10	1.051	26.96	24.8023	2.15775
11	1.033	27.60	25.4799	2.12010
12	-.494	24.82	25.8304	-1.01341
13	1.164	32.10	29.7094	2.39064
14	-.030	26.63	26.6950	-.06199
15	-.837	25.23	26.9520	-1.71903
16	-1.183	24.85	27.2792	-2.42917

**Casewise Diagnostics<sup>a</sup>**

Case Number	Std. Residual	Gravel Loss	Predicted Value	Residual
17	.010	27.53	27.5128	.02015
18	1.556	31.18	27.9802	3.19481
19	1.838	31.57	27.7933	3.77375
20	1.051	29.37	27.2091	2.15793
21	.802	37.60	35.9529	1.64707
22	-.424	35.27	36.1399	-.86987
23	.693	37.40	35.9763	1.42370
24	1.816	38.70	34.9715	3.72849
25	.301	34.00	33.3825	.61746
26	-.009	34.72	34.7378	-.01884
27	-1.511	30.00	33.1021	-3.10214
28	-.660	31.70	33.0554	-1.35540
29	-.937	30.50	32.4245	-1.92449
30	-1.127	29.50	31.8169	-2.31394
31	-.370	28.30	29.0596	-.75962
32	.317	29.50	28.8493	.65069
33	-.111	28.20	28.4287	-.22870
34	.672	29.20	27.8212	1.37884
35	.658	29.50	28.1483	1.35170
36	.145	28.61	28.3119	.29813
37	.673	29.60	28.2184	1.38160
38	.136	28.31	28.0315	.27854
39	.852	29.64	27.8913	1.74874
40	-.100	27.85	28.0548	-.20483
41	-2.176	23.40	27.8679	-4.46789
42	.362	27.63	26.8865	.74353
43	.694	29.41	27.9847	1.42527
44	-.390	26.32	27.1201	-.80014
45	-.306	27.24	27.8679	-.62789
46	-1.198	20.40	22.8627	-2.45866
47	1.944	27.93	23.9376	3.99145
48	2.303	29.25	24.5217	4.72827
49	-.492	25.36	26.3677	-1.01074
50	-.243	26.48	26.9753	-.49928
51	.322	26.68	26.0172	.66177
52	.126	25.11	24.8489	.25813
53	-.009	24.04	24.0544	-.01839
54	-.603	21.93	23.1664	-1.23743
55	-1.008	20.79	22.8627	-2.06966
56	-1.265	17.81	20.4091	-2.59811
57	-.108	14.39	14.6141	-.22105
58	-.070	14.26	14.4037	-.14275
59	.069	15.04	14.8945	.14154
60	-.270	14.64	15.1982	-.55523
61	.195	16.46	16.0628	.40118
62	.936	16.63	14.7075	1.92148
63	.207	19.90	19.4744	.42558
64	-.403	19.14	19.9651	-.82713
65	-.599	17.33	18.5631	-1.23010
66	1.310	17.00	14.3103	2.68972
67	-.881	17.88	19.6847	-1.80973

**Casewise Diagnostics<sup>a</sup>**

Case Number	Std. Residual	Gravel Loss	Predicted Value	Residual
68	-.551	19.21	20.3390	-1.13101
69	.737	22.83	21.3204	1.51257
70	.341	21.83	21.1335	.69951
71	-.087	20.56	20.7362	-.17825
72	.583	22.12	20.9232	1.19781
73	-.850	18.50	20.2455	-1.74554
74	-.436	16.64	17.5349	-.89595

a. Dependent Variable: Gravel Loss

**Residuals Statistics<sup>a</sup>**

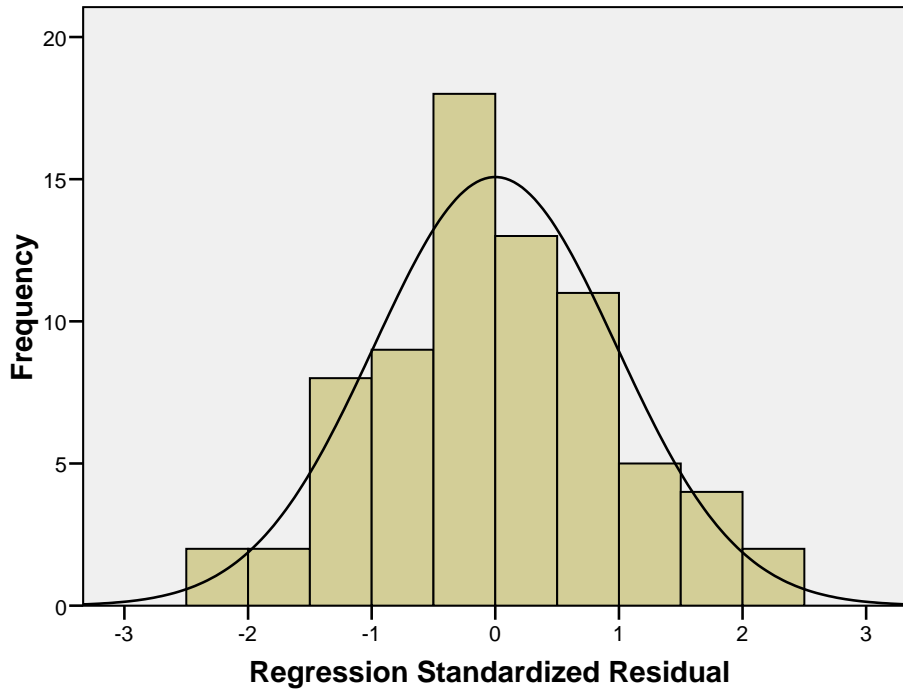
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	14.3103	36.1399	25.4084	5.39265	74
Std. Predicted Value	-2.058	1.990	.000	1.000	74
Standard Error of Predicted Value	.381	.635	.473	.063	74
Adjusted Predicted Value	14.0593	36.2203	25.4000	5.39573	74
Residual	-4.57816	4.78018	.00000	2.01044	74
Std. Residual	-2.230	2.328	.000	.979	74
Stud. Residual	-2.288	2.408	.002	1.007	74
Deleted Residual	-4.81934	5.11250	.00840	2.12589	74
Stud. Deleted Residual	-2.361	2.496	.003	1.022	74
Mahal. Distance	1.531	6.001	2.959	1.074	74
Cook's Distance	.000	.101	.014	.022	74
Centered Leverage Value	.021	.082	.041	.015	74

a. Dependent Variable: Gravel Loss

**Charts**

# Histogram

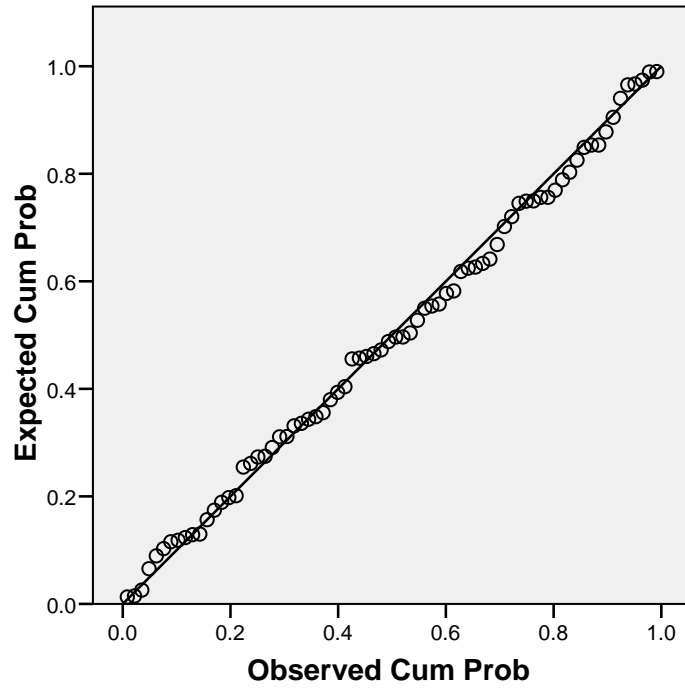
Dependent Variable: Gravel Loss



Mean =7.06E-14  
Std. Dev. =0.979  
N =74

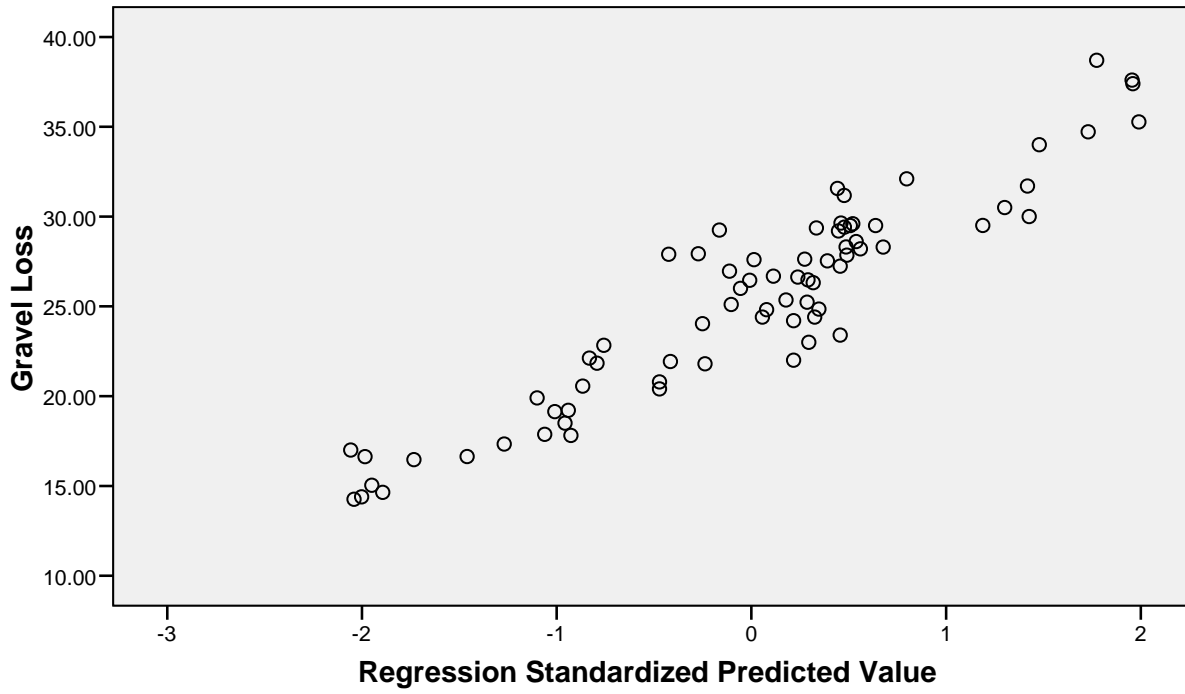
# Normal P-P Plot of Regression Standardized Residual

Dependent Variable: Gravel Loss



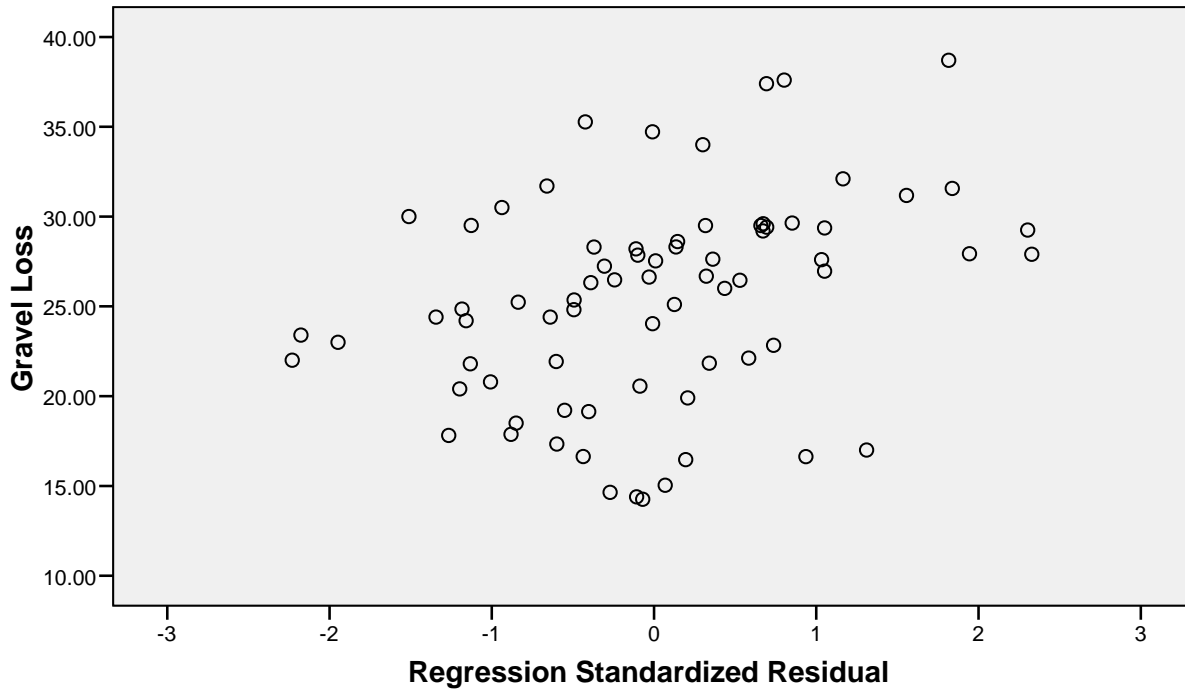
# Scatterplot

Dependent Variable: Gravel Loss



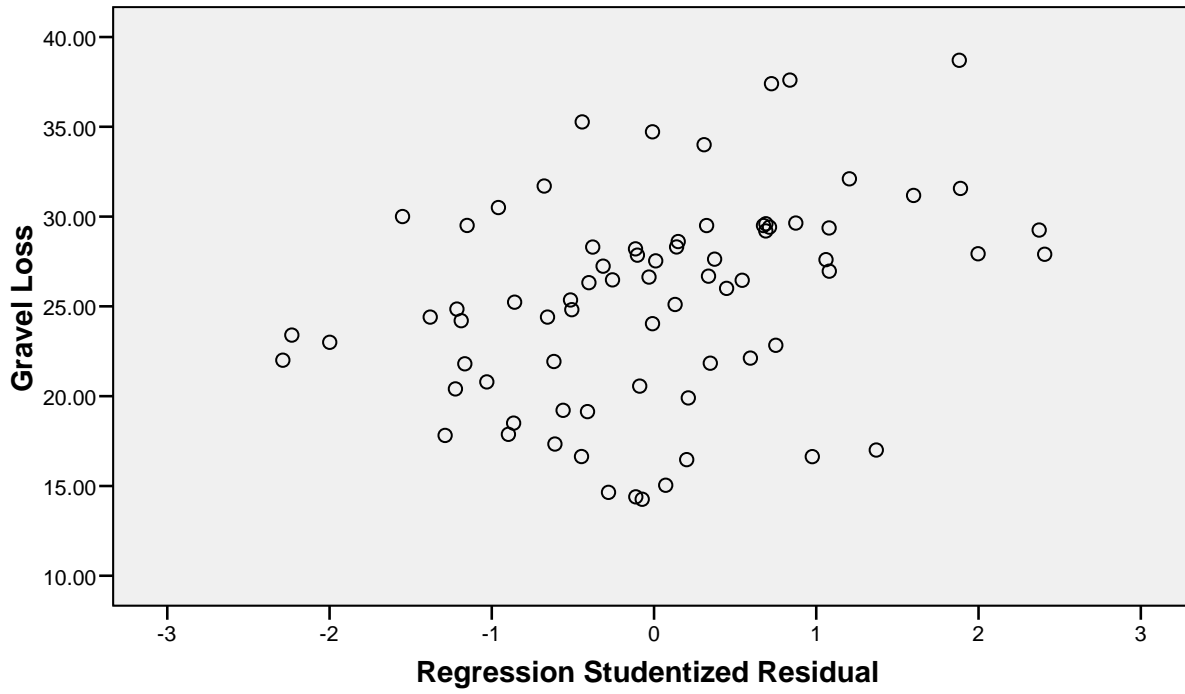
# Scatterplot

Dependent Variable: Gravel Loss



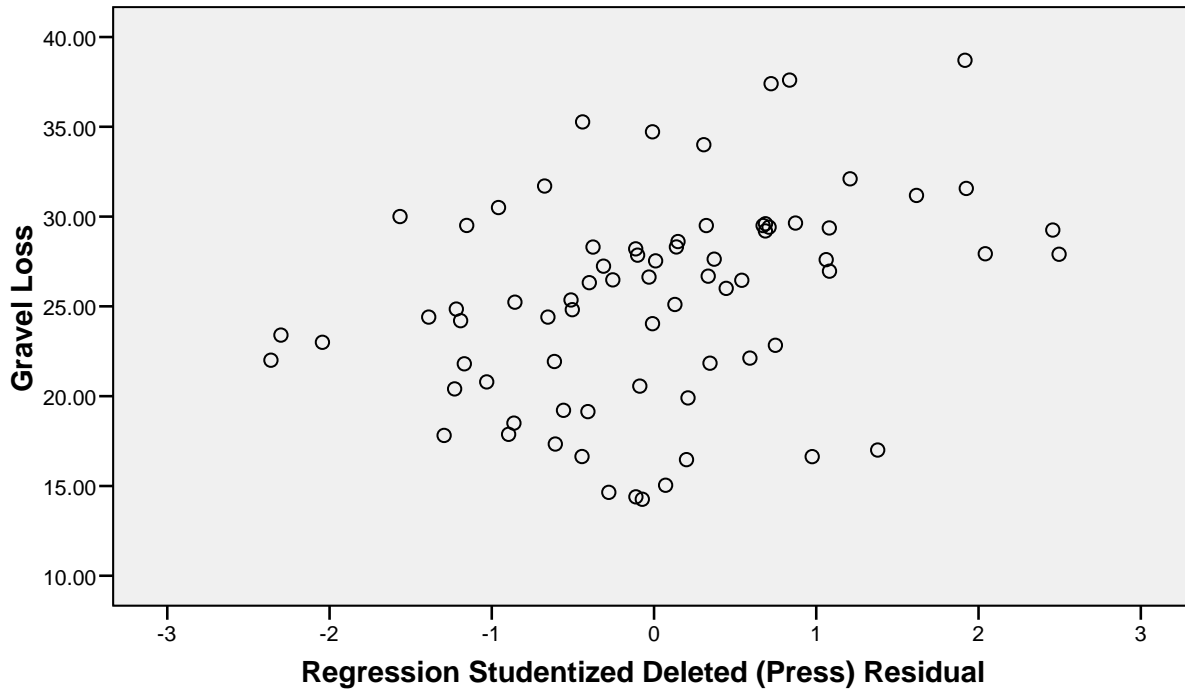
# Scatterplot

Dependent Variable: Gravel Loss



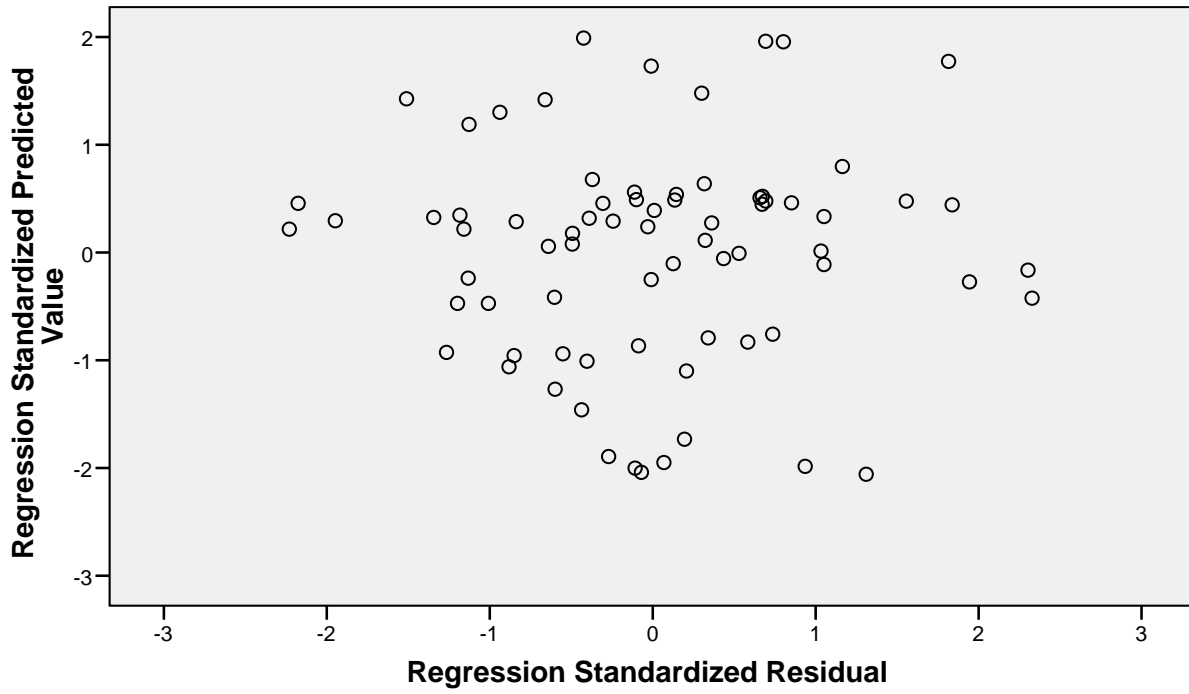
# Scatterplot

Dependent Variable: Gravel Loss



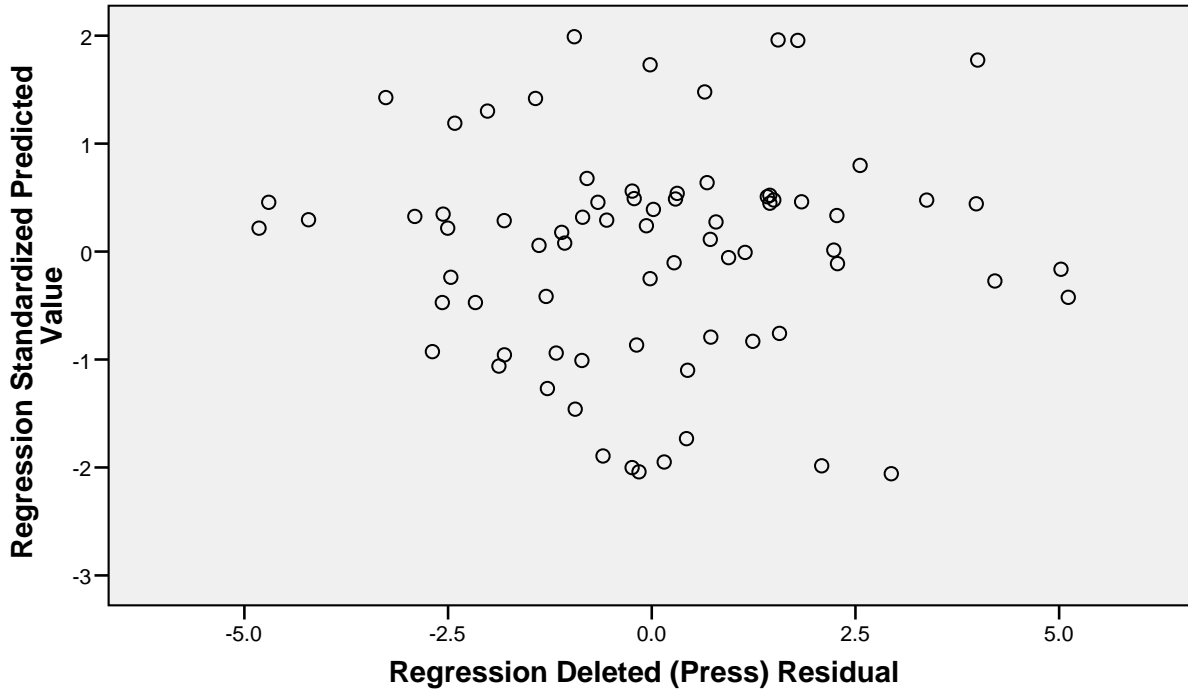
# Scatterplot

Dependent Variable: Gravel Loss



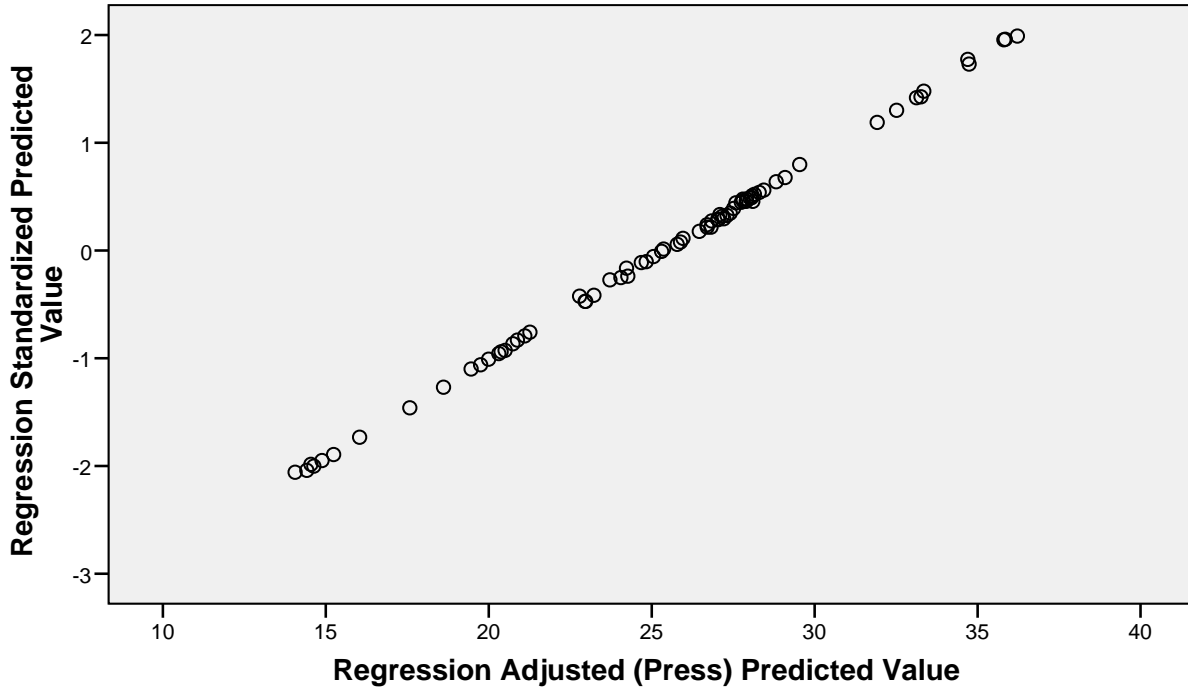
# Scatterplot

Dependent Variable: Gravel Loss



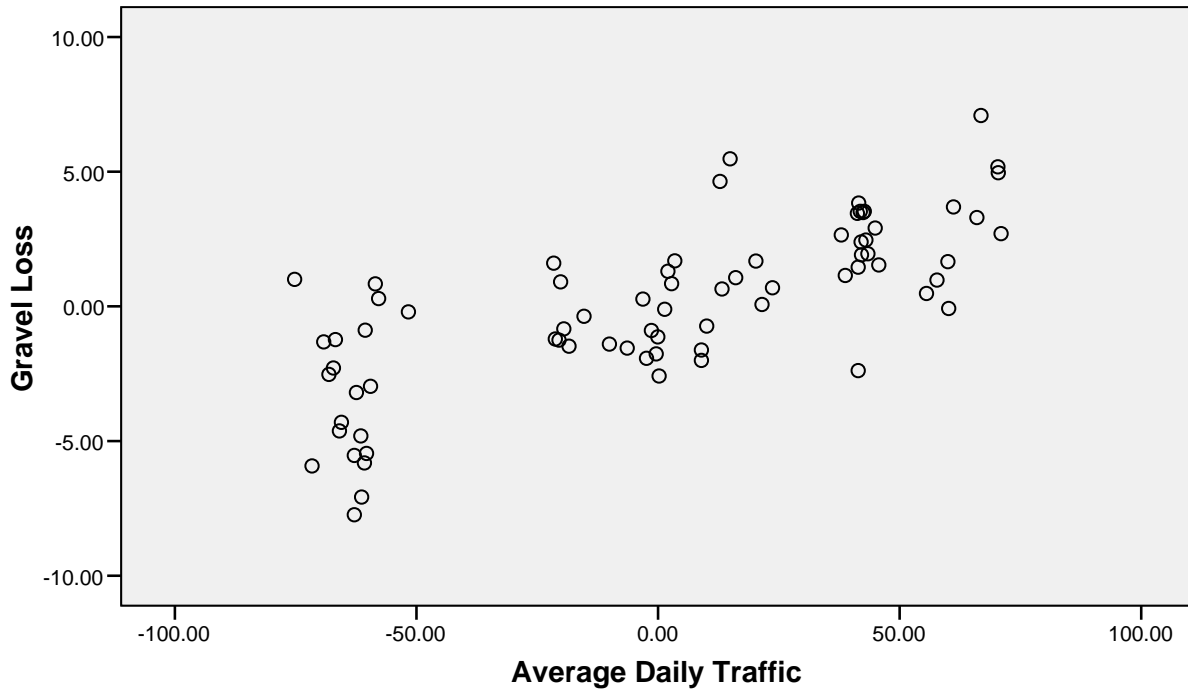
# Scatterplot

Dependent Variable: Gravel Loss



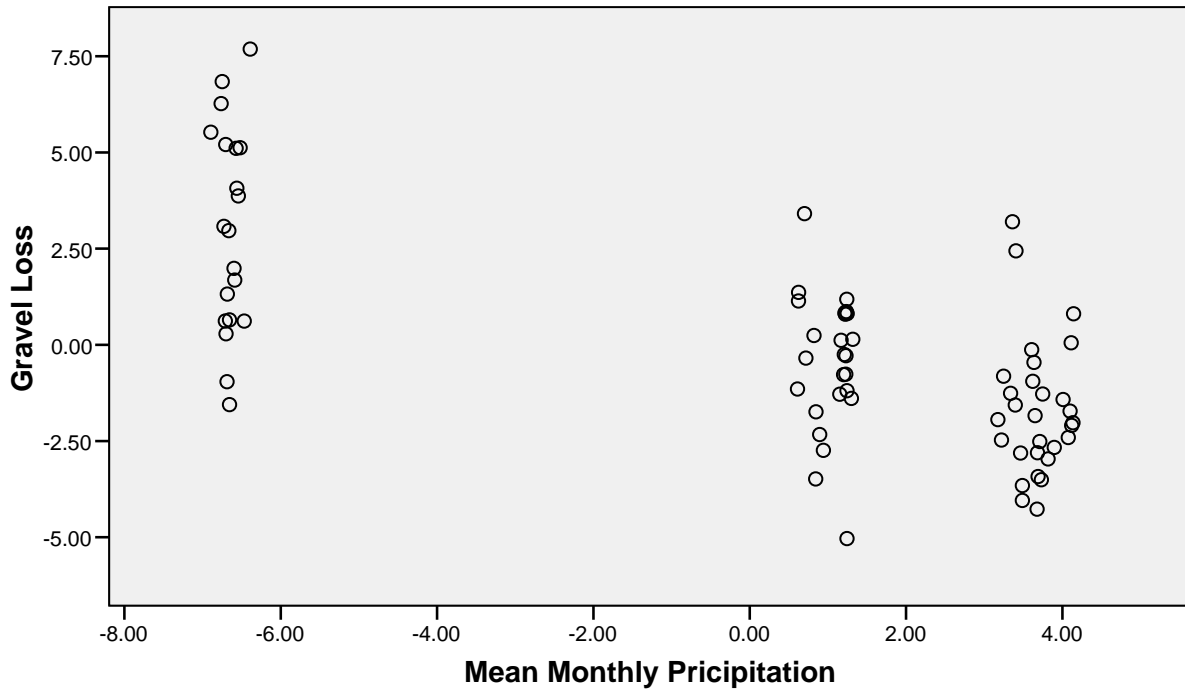
# Partial Regression Plot

Dependent Variable: Gravel Loss



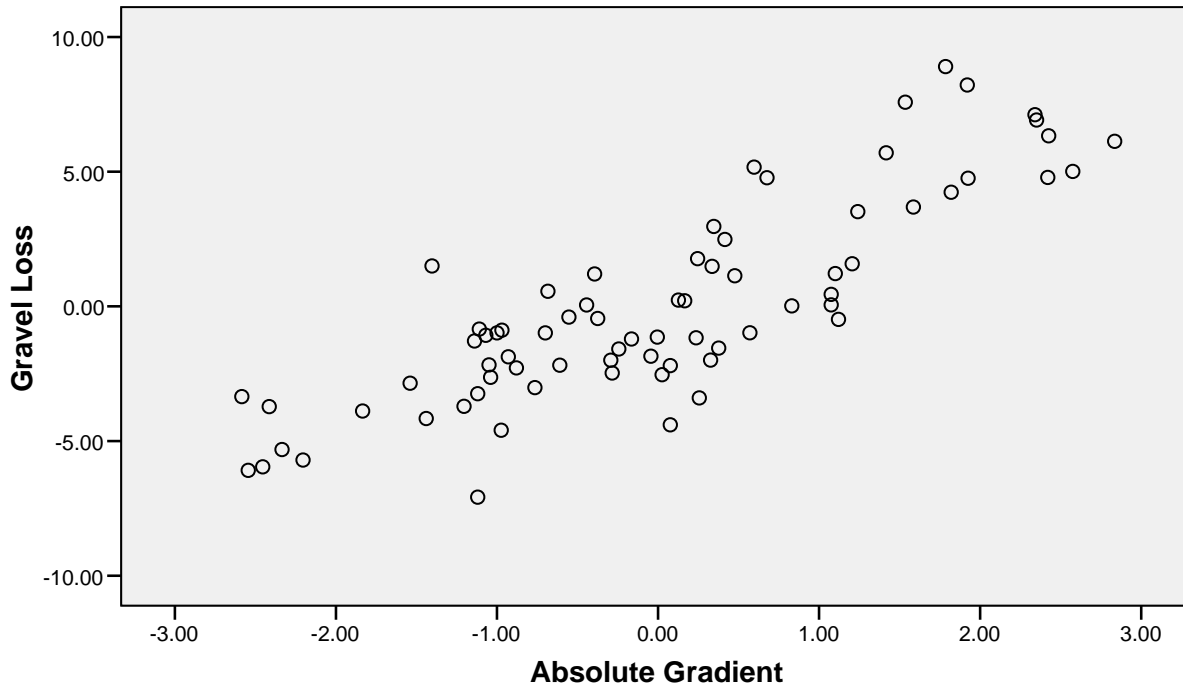
# Partial Regression Plot

Dependent Variable: Gravel Loss



## Partial Regression Plot

Dependent Variable: Gravel Loss



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```
GL WITH ADT MMP PI G
/METHOD = SSTYPE(3)
/INTERCEPT = INCLUDE
/SAVE = PRED SEPRD RESID ZRESID SRESID DRESID COOK LEVER
/PRINT = DESCRIPTIVE ETASQ OPOWER PARAMETER TEST(LMATRIX) LOF GEF
/PLOT = RESIDUALS
/CRITERIA = ALPHA(.05)
/DESIGN = ADT MMP PI G .
```

## Univariate Analysis of Variance

[DataSet0]

### Descriptive Statistics

Dependent Variable: Gravel Loss

Mean	Std. Deviation	N
25.4084	5.75522	74

**Tests of Between-Subjects Effects**

Dependent Variable: Gravel Loss

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2122.885 <sup>b</sup>	3	707.628	167.879	.000	.878
Intercept	.000	0	.	.	.	.000
ADT	.000	0	.	.	.	.000
MMP	.000	0	.	.	.	.000
PI	.000	0	.	.	.	.000
G	716.994	1	716.994	170.101	.000	.708
Error	295.057	70	4.215			
Total	50191.538	74				
Corrected Total	2417.943	73				

**Tests of Between-Subjects Effects**

Dependent Variable: Gravel Loss

Source	Noncent. Parameter	Observed Power <sup>a</sup>
Corrected Model	503.638	1.000
Intercept	.000	.
ADT	.000	.
MMP	.000	.
PI	.000	.
G	170.101	1.000
Error		
Total		
Corrected Total		

a. Computed using alpha = .05

b. R Squared = .878 (Adjusted R Squared = .873)

**Parameter Estimates**

Dependent Variable: Gravel Loss

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval		Partial Eta Squared
					Lower Bound	Upper Bound	
Intercept	108.203	11.832	9.145	.000	84.606	131.800	.544
ADT	.050	.005	9.611	.000	.040	.061	.569
MMP	-.455	.057	-8.005	.000	-.568	-.341	.478
PI	0 <sup>b</sup>	.	.	.	.	.	.
G	2.337	.179	13.042	.000	1.979	2.694	.708

## Parameter Estimates

Dependent Variable: Gravel Loss

Parameter	Noncent. Parameter	Observed Power <sup>a</sup>
Intercept	9.145	1.000
ADT	9.611	1.000
MMP	8.005	1.000
PI	.	.
G	13.042	1.000

- a. Computed using alpha = .05
- b. This parameter is set to zero because it is redundant.

### General Estimable Function<sup>a</sup>

Parameter	Contrast			
	L1	L2	L3	L5
Intercept	1	0	0	0
ADT	0	1	0	0
MMP	0	0	1	0
PI	-23.303	-.075	.197	0
G	0	0	0	1

- a. Design: Intercept+ADT+MMP+PI+G

## Contrast Coefficients (L' Matrix)

### Intercept<sup>a</sup>

- 
- a. This matrix cannot be constructed because there are zero degrees of freedom. Hypothesis tests cannot be performed.

### ADT<sup>a</sup>

- 
- a. This matrix cannot be constructed because there are zero degrees of freedom. Hypothesis tests cannot be performed.

### MMP<sup>a</sup>

- 
- a. This matrix cannot be constructed because there are zero degrees of freedom. Hypothesis tests cannot be performed.

### PI<sup>a</sup>

- 
- a. This matrix cannot be constructed because there are zero degrees of freedom. Hypothesis tests cannot be performed.

**G**

Parameter	Contrast
	L5
Intercept	0
ADT	0
MMP	0
PI	0
G	1

The default display of this matrix is the transpose of the corresponding L matrix.  
Based on Type III Sums of Squares.

**Lack of Fit Tests**

Dependent Variable: Gravel Loss

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Lack of Fit	285.189	67	4.257	1.294	.487	.967
Pure Error	9.868	3	3.289			

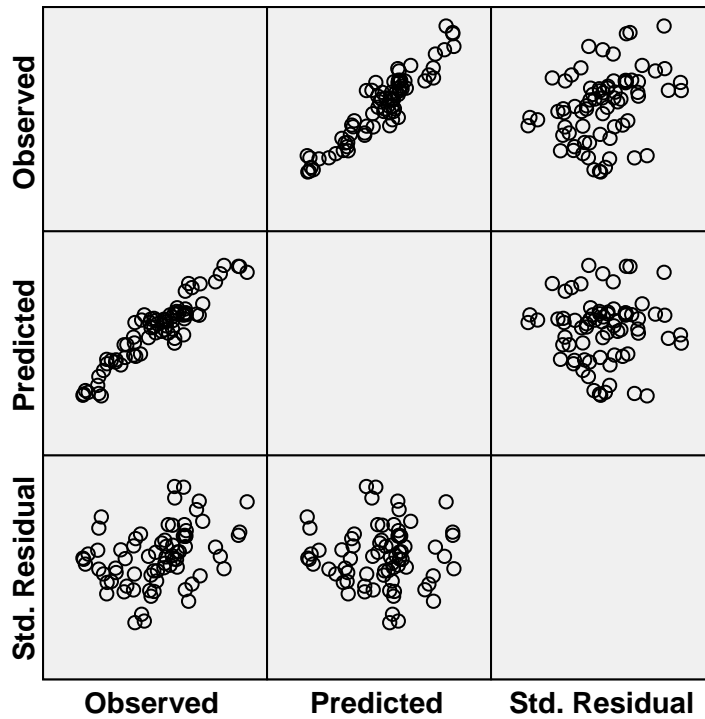
**Lack of Fit Tests**

Dependent Variable: Gravel Loss

Source	Noncent. Parameter	Observed Power <sup>a</sup>
Lack of Fit	86.697	.152
Pure Error		

a. Computed using alpha = .05

## Dependent Variable: Gravel Loss



Model: Intercept + ADT + MMP + PI + G

UNIANOVA

```
GL WITH ADT MMP PI G
/METHOD = SSTYPE(3)
/INTERCEPT = EXCLUDE
/SAVE = PRED SEPRED RESID ZRESID SRESID DRESID COOK LEVER
/PRINT = DESCRIPTIVE ETASQ OPOWER PARAMETER TEST(LMATRIX) LOF GEF
/PLOT = RESIDUALS
/CRITERIA = ALPHA(.05)
/DESIGN = ADT MMP PI G .
```

## Univariate Analysis of Variance

[DataSet0]

### Descriptive Statistics

Dependent Variable: Gravel Loss

Mean	Std. Deviation	N
25.4084	5.75522	74

### Tests of Between-Subjects Effects

Dependent Variable: Gravel Loss

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Model	49896.481 <sup>b</sup>	4	12474.120	2959.386	.000	.994
ADT	213.542	1	213.542	50.661	.000	.420
MMP	472.737	1	472.737	112.153	.000	.616
PI	352.536	1	352.536	83.636	.000	.544
G	716.994	1	716.994	170.101	.000	.708
Error	295.057	70	4.215			
Total	50191.538	74				

### Tests of Between-Subjects Effects

Dependent Variable: Gravel Loss

Source	Noncent. Parameter	Observed Power <sup>a</sup>
Model	11837.543	1.000
ADT	50.661	1.000
MMP	112.153	1.000
PI	83.636	1.000
G	170.101	1.000
Error		
Total		

a. Computed using alpha = .05

b. R Squared = .994 (Adjusted R Squared = .994)

### Parameter Estimates

Dependent Variable: Gravel Loss

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval		Partial Eta Squared
					Lower Bound	Upper Bound	
ADT	-.299	.042	-7.118	.000	-.383	-.216	.420
MMP	.461	.044	10.590	.000	.374	.548	.616
PI	-4.643	.508	-9.145	.000	-5.656	-3.631	.544
G	2.337	.179	13.042	.000	1.979	2.694	.708

### Parameter Estimates

Dependent Variable: Gravel Loss

Parameter	Noncent. Parameter	Observed Power <sup>a</sup>
ADT	7.118	1.000
MMP	10.590	1.000
PI	9.145	1.000
G	13.042	1.000

a. Computed using alpha = .05

**General Estimable Function<sup>a</sup>**

Parameter	Contrast			
	L1	L2	L3	L4
ADT	1	0	0	0
MMP	0	1	0	0
PI	0	0	1	0
G	0	0	0	1

a. Design: ADT+MMP+PI+G

**Contrast Coefficients (L' Matrix)**

**ADT**

Parameter	Contrast
	L1
ADT	1
MMP	0
PI	0
G	0

The default display of this matrix is the transpose of the corresponding L matrix. Based on Type III Sums of Squares.

**MMP**

Parameter	Contrast
	L2
ADT	0
MMP	1
PI	0
G	0

The default display of this matrix is the transpose of the corresponding L matrix. Based on Type III Sums of Squares.

**PI**

Parameter	Contrast
	L3
ADT	0
MMP	0
PI	1
G	0

The default display of this matrix is the transpose of the corresponding L matrix. Based on Type III Sums of Squares.

**G**

Parameter	Contrast
	L4
ADT	0
MMP	0
PI	0
G	1

The default display of this matrix is the transpose of the corresponding L matrix.  
Based on Type III Sums of Squares.

**Lack of Fit Tests**

Dependent Variable: Gravel Loss

Source	Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Lack of Fit	285.189	67	4.257	1.294	.487	.967
Pure Error	9.868	3	3.289			

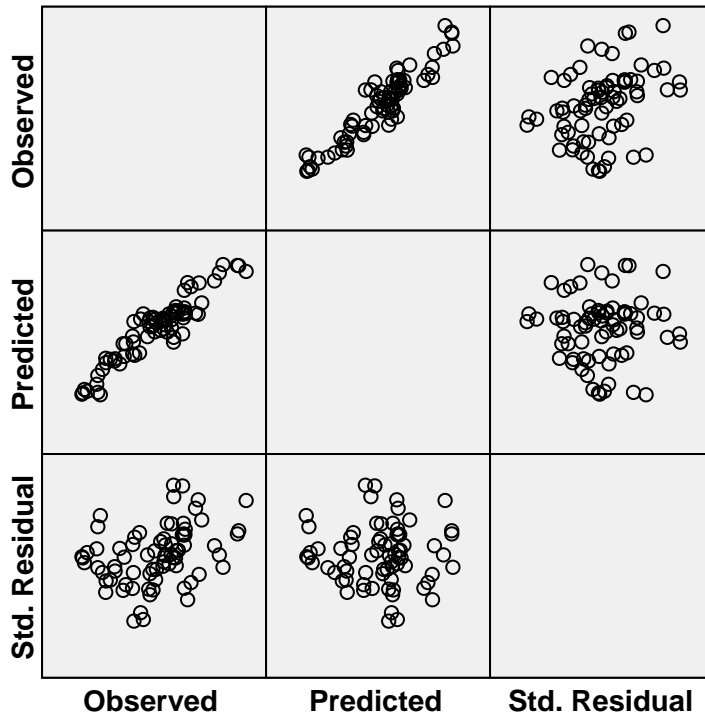
**Lack of Fit Tests**

Dependent Variable: Gravel Loss

Source	Noncent. Parameter	Observed Power <sup>a</sup>
Lack of Fit	86.697	.152
Pure Error		

a. Computed using alpha = .05

**Dependent Variable: Gravel Loss**



Model: ADT + MMP + PI + G

**Appendix F**  
**Definition of terms for MLR and GLM**

## Definition of terms for MLR

### 1. Descriptive statistics

- The mean is the average value.
- The standard deviation measures the variability (or spread) of the values
- N is the number of cases with non-missing values

### 2. Regression correlation

- The correlations table displays Pearson correlation coefficients, significance values, and the number of cases with non-missing values.
- Pearson correlation coefficients assume the data are normally distributed.
- The Pearson correlation coefficient is a measure of linear association between two variables
- The values of the correlation coefficient range from -1 to 1.
- The sign of the correlation coefficient indicates the direction of the relationship (positive or negative).
- The absolute value of the correlation coefficient indicates the strength, with larger absolute values indicating stronger relationships
- The correlation coefficients on the main diagonal are always 1.0, because each variable has a perfect positive linear relationship with itself
- Correlations above the main diagonal are a mirror image of those below.
- The significance of each correlation coefficient is also displayed in the correlation table
- The significance level (or p-value) is the probability of obtaining results as extreme as the one observed.
- If the significance level is very small (less than 0.05) then the correlation is significant and the two variables are linearly related
- If the significance level is relatively large (for example, 0.50) then the correlation is not significant and the two variables are not linearly related
- N is the number of cases with non-missing values

### 3. Regression Variables Entered /Removed

- This table displays the variables entered and/or removed at each step
- The variables entered into model at each step are listed in the Variables Entered column.
- The variables removed from the model at each step are listed in the Variables Removed column.
- The Method column displays the selection method that was used to remove or enter the variable

### 4. Regression Model summary

- This table displays R, R squared, adjusted R squared, and the standard error.
- R, the multiple correlation coefficients, is the correlation between the observed and predicted values of the dependent variable.
- The values of R for models produced by the regression procedure range from 0 to 1.
- Larger values of R indicate stronger relationships.

- R squared is the proportion of variation in the dependent variable explained by the regression model.
- The values of R squared range from 0 to 1.
- Small values indicate that the model does not fit the data well.
- The sample R squared tends to optimistically estimate how well the model fits the population.
- Adjusted R squared attempts to correct R squared to more closely reflect the goodness of fit of the model in the population
- Use R Squared to help you determine which model is best.
- Choose a model with a high value of R squared that does not contain too many variables.
- Models with too many variables are often over fit and hard to interpret.

#### 5. Regression ANOVA

- This table summarizes the results of an analysis of variance.
- The sum of squares, degrees of freedom, and mean square are displayed for two sources of variation, regression and residual
- The output for Regression displays information about the variation accounted for by your model.
- The output for Residual displays information about the variation that is not accounted for by your model
- And the output for Total is the sum of the information for Regression and Residual
- A model with a large regression sum of squares in comparison to the residual sum of squares indicates that the model accounts for most of variation in the dependent variable
- Very high residual sum of squares indicate that the model fails to explain a lot of the variation in the dependent variable, and you may want to look for additional factors that help account for a higher proportion of the variation in the dependent variable.
- The mean square is the sum of squares divided by the degrees of freedom.
- The F statistic is the regression mean square (MSR) divided by the residual mean square (MSE).
- The regression degrees of freedom is the numerator df and the residual degrees of freedom is the denominator df for the F statistic.
- The total number of degrees of freedom is the number of cases minus 1.
- If the significance value of the F statistic is small (smaller than say 0.05) then the independent variables do a good job explaining the variation in the dependent variable.
- If the significance value of F is larger than say 0.05 then the independent variables do not explain the variation in the dependent variable.

#### 6. Regression Coefficients

- The unstandardized coefficients are the coefficients of the estimated regression model

- Often the independent variables are measures in different units. The standardized coefficients or betas are an attempt to make the regression coefficients more comparable.
- If you transformed the data to z scores prior to your regression analysis, you would get the beta coefficients as your unstandardized coefficients
- The t statistics can help you determine the relative importance of each variable in the model
- As a guide regarding useful predictors, look for t values well below -2 or above +2.

#### **7. Regression Casewise Diagnostics**

- This table displays statistics for individual cases which are identified by their case number.
- Statistics are displayed for cases with standardized residuals more than a specified number of standard deviations away from the mean
- Standardized residuals are ordinary residuals divided by the sample standard deviation of the residuals
- Standardized residuals have a mean of 0 and a standard deviation of 1.
- The observed values of the dependent variable are displayed.
- You may also see the predicted value and residual value for each case.
- The predicted value is the value for the case predicted by the model.
- The residual is the difference between the observed value of the dependent variable and the predicted value.
- Regression Residual Statistics

#### **8. Regression residual statistics**

- This table displays statistics about the residuals and predicted values.
- For each case, the predicted value is the value predicted by the regression model.
- And for each case, the residual is the difference between the observed value of the dependent variable and the value predicted by the model.
- Residuals are estimates of the true errors in the model.
- If the model is appropriate for the data, the residuals should follow a normal distribution.
- Standardized predicted values are predicted values standardized to have mean 0 and standard deviation 1.
- Similarly, standardized residuals are ordinary residuals divided by the sample standard deviation of the residuals and have mean 0 and standard deviation 1.
- The minimum, maximum, mean, standard deviation and sample size are displayed for predicted value, residual, standardized predicted value, and standardized residual.

#### **9. Regression Coefficients Correlation**

- This table displays correlation and covariance matrices of the independent variables included in the model at each step.
- This table displays correlation and covariance matrices of the independent variables included in the model at each step.

- In the correlation matrices, the values of the correlation coefficients range from -1 to 1.
- The sign of the correlation coefficient indicates the direction of the relationship (positive or negative).
- The absolute value of the correlation coefficient indicates the strength, with larger absolute values indicating stronger relationships
- The correlation coefficients on the main diagonal are always 1.0, because each variable has a perfect positive linear relationship with itself.
- Correlations above the main diagonal are a mirror image of those below
- In the covariance matrices, the variances are displayed on the main diagonal.
- And covariances are displayed above and below the main diagonal.
- Covariances above the main diagonal are a mirror image of those below.

#### **10. Regression Collinearity Diagnostics**

- This table displays statistics that help you determine if there are any problems with collinearity.
- Collinearity (or multicollinearity) is the undesirable situation where the correlations among the independent variables are strong.
- Eigenvalues provide an indication of how many distinct dimensions there are among the independent variables.
- When several eigenvalues are close to zero, the variables are highly intercorrelated and small changes in the data values may lead to large changes in the estimates of the coefficients.
- Condition indices are the square roots of the ratios of the largest eigenvalue to each successive eigenvalue
- A condition index greater than 15 indicates a possible problem and an index greater than 30 suggests a serious problem with collinearity.
- The variance proportions are the proportions of the variance of the estimate accounted for by each principal component associated with each of the eigenvalues.
- Collinearity is a problem when a component associated with a high condition index contributes substantially to the variance of two or more variables.

#### **11. Regression Excluded Variable**

- This table displays information about the variables not in the model at each step.
- Beta in is the standardized regression coefficient that would result if the variable were entered into the equation at the next step.
- The t statistic and its significance value are used to test the null hypothesis that the regression coefficient is zero (or that there is no linear relationship between the dependent and independent variable
- If the significance value is small (less than say 0.05) then the coefficient is considered significant
- The partial correlation is the correlation of each independent variable with the dependent variable after removing the linear effect of variables already in the model.
- Collinearity (or multicollinearity) is the undesirable situation where the correlations among the independent variables are strong.

- Tolerance is a statistic used to determine how much the independent variables are linearly related to one another (multicollinear).
- Tolerance is the proportion of a variable's variance not accounted for by other independent variables in the model.
- A variable with very low tolerance contributes little information to a model, and can cause computational problems.
- VIF or the variance inflation factor is the reciprocal of the tolerance.
- As the variance inflation factor increases, so does the variance of the regression coefficient, making it an unstable estimate.
- Large VIF values are an indicator of multicollinearity
- Minimum tolerance is the minimum tolerance of all independent variables already in the model if an independent variable not in the equation is included.

## Definition of terms for GLM

### 1. GLM Univariate Descriptive Statistics

- This table displays descriptive statistics for all combination of factors in the model.
- The mean is the average value of the observations in that cell.
- The standard deviation measures the variability (or spread) of the values.
- N is the number of cases in each category

### 2. GLM Univariate Between –Subject Factors

- This table displays the number of cases for each level of each factor.
- This table allows you to see if any of the factor levels do not contain any observations.
- GLM Univariate Levene's Test of Equality of Error Variances

### 3. GLM Univariate Leven's Test Of Equality Of Errors Variances

- One of the assumptions for an analysis of variance is that the data in each cell come from populations with the same variance
- This table tests the null hypothesis that the error variance of the dependent variable is equal across groups.
- The F statistic and the numerator (df1) and denominator (df2) degrees of freedom are used to calculate the significance value
- If the significance value is small (<0.05) then the null hypothesis of equal error variances across groups is rejected.
- If the null hypothesis is rejected then the assumption of equal cell variances is not met and you may want to consider transforming your data

### 4. GLM Univariate test of Between –Subject Effect

- This is an analysis of variance table.
- The column labeled Source lists the effects in the model.
- The second column displays the sum of squares for each effect.
- The degrees of freedom for each sum of squares is displayed in the column labeled df.

- The mean square of each effect is calculated by dividing the sum of squares by its degrees of freedom.
- The F statistic and its significance value are displayed in the next columns
- The F statistic is calculated by dividing the mean square by the mean square error
- Effects with a small significance value (smaller than 0.05) are significant

#### 5. GLM Univariate Expected Mean Squares

- This table displays the expected mean square components of each effect in the model
- The expected mean square of an effect is usually a linear combination of variance components of the random effects and quadratic terms of the fixed effects in the model.
- Each row in this table represents the linear combination of variance components involved in the expected mean square of the effect in the mode

#### 6. GLM Univariate Parameter Estimates

- This table displays the parameter estimates in the column labeled B.
- The t statistics can help you determine the relative importance of each variable in the model.
- The t statistic is B divided by the standard error.
- As a guide regarding useful predictors, look for t values well below -2 or above +2.
- Confidence intervals for the parameter estimates are also displayed

#### 7. GLM Univariate Lack of Fit Test

- The lack of fit ANOVA table helps you determine if the current model adequately fits the data.
- The source column displays the two components of the error sum of squares (SSE): lack of fit (SSLF) and pure error (SSPE).
- The error sum of squares is the lack of fit sum of squares plus the pure error sum of squares ( $SSE = SSLF + SSPE$ ).
- Pure error represents variation of the observed values around the group mean
- Lack of fit represents variation of the predicted values around the group mean.
- The mean square values are calculated by dividing the sum of squares by the degrees of freedom.
- The F statistic is the mean square for lack of fit divided by the mean square for pure error.
- Sig indicates the significance level of the F statistic
- Small significance values (<0.05) imply that the current model cannot adequately account for the relationship between the dependent variable and the predictors.

**Appendix G**  
**Photos of Observation, Traffic on the Road and Material Test**

Observation of Gravel Loss



Observation of Gravel Loss

**Material test**



D/Birhan –Ankober road



D/Birhan –Kasima road



Chacha-Tsgerada-Ginager road



preparation of sample for test



Liquid limit test



Plasticity limit test

**Traffic**



Traffic on D/Birhan –Kasima road



Traffic on Chacha -Tsgerada -Ginager road