Exploration of Gravel Roads Erosion Data in Uganda

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Exploration of Gravel Roads Erosion Data in Uganda

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Abstract— **The main objective for this study was to explore the erosion data from across Uganda gravel roads. Gravel/dirt/rural roads constitute a larger part of the total road networks in developing countries and are top-listed for accumulation of wealth for such countries like Uganda. Generally, quantitative methods through experimental designs were used. Data was generated from various experiments and STATA output and used in the analysis and exploration. They include among others sieve analysis, measurement of road rill/dune sizes, Atterberg tests, and dry-density tests. These were conducted to reflect the characteristics of road subgrades and sediments from these roads. A brief comparison of one of the original erosion models, USLE/RUSLE was done with the erosion model developed for the maintenance of gravel roads, EMMOGR and conclusions reached.**

Findings showed that the dry densities were average but not standard and comparable to those in other specific areas of the world. It was unique to engage these tests on sediments (eroded soils from road surfaces) and make conclusions therefrom. For example a small percentage difference between the two samples (sediment and borrow pit) was realized. It signified the fact that most soils used in the construction and maintenance are eroded. The data maps well to the erosion characteristics on these roads and data models could be used for future estimations. Finally, it was observed that the EMMOGR reflected the erosion/deposition characteristics better than the USLE/RUSLE.

The study suggested that there was need to improve on the soils used in the construction/maintenance of gravel roads. There is also need to follow the actual design standards. Knowledge from this paper shall also help in road construction and maintenance designs.

Keywords— Atterberg, Erosion data, Model, Maintenance, Road.

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1. INTRODUCTION

Roads comprise to one of the most risky parts of human transport in the world. This is because one of the most important and affected landscape is the unpaved surface of a road. These roads support the biggest income percentages for most economies in the developing countries [1]. Modeling erosion on gravel roads is a unique recent study of managing erosion through mathematical modeling. In fact erosion on roads is managed through the various road designs which are fixed as earlier analyzed in [2].

Roads also collect and channelize large volumes of water which eventually cause severe gulling [3]. Current road designs in most developing countries are standard and to some extent realistic. They are however not implemented when it comes to construction and maintenance of such roads. This tends to give erosion practices along roads a gap to create such serious impacts which are dangerous to road users. Poorly constructed roads may lose as much as 100mg/ha of soil by erosion of the road surface as noted in [3]. In the event of all this, various experiments data collected in earlier studies [1], [4], [5] & [6] is further analyzed and conclusions made. Thus the main objective of this paper was to explore the gravel roads erosion data in Uganda.

2. METHODOLOGY

2.1 Experimental Layout and Design.

This study used the quantitative methods with regard to experimental designs and standards [7] & [8]. The paper involved exploring the application of the erosion data for non-paved roads. It also focused on accelerated erosion type that occurs when such roads are constructed. The total number of roads that were experimented was eight and was selected from the Eastern, Central, Western, and Northern Uganda. Various spots were identified on these roads for possible experimentations as seen in [1].

2.2 Data Collection, Analysis and Interpretation Methods

The experimental data were collected depending on the rains in the given regions and on the experiment days selected by both the researcher and field assistants. This was because most field experiments like measuring rill/dune formation or size change, depended on the effects due to rain. Measurements were taken and raw-recorded for further handling. Measurements for five cross-sections for each drainage spot were taken for each 100m block (20m apart). The time interval was taken as a rain-day. Rain day experiments were taken in the respective regions for a total of sixty times. An average time of 5400s for a rain-day was taken for this study. The slopes measured for all experiment

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spots ranged between 2^0 and 42^0 or 3.5% and 90%. These were notably steep gradients for some of these roads which are already exposed to erosion. On the other hand, the collected data were analyzed through evaluation of each sub-models using the various experiment-spots data, and finally by simple comparisons from some renowned and developed model parameters [1] & [5].

3. FINDINGS

3.1 Compaction values/graphs:

TABLE 1: Compaction Values for the Borrow Pit and Sediment Samples for Uganda's Gravel Roads

	Test Number	*1*	*2*	*3*	*4*	*5*
Borrow pit Sample	(MC) (%) (m)	6.55	8.21	11.24	14.03	17.47
	(DD) (kg/m^3) (d)	1597	1772	1952	1709	1553
Sediment Sample	(MC) (%) (m)	5.71	8.79	11.84	12.47	16.83
	(DD) (kg/m^3) (d)	1615	1639	1679	1684	1575

Hydrometer analysis values were similarly handled regionally to give a country's general view of this analysis in figures 3 and 4.

It should be noted that the soil strength is lowest at the liquid state and highest at the solid state [9]. Alternatively, a soil becomes weaker if its water content increases. Therefore rain water should be an important factor when it comes to road construction and repair. Liquid limit tests were done for both sediments and borrow pit samples. The liquid limits for these samples fit the typical Atterberg limits for soils as shown in table II below. It should be noted that these limits were not however used for soil classification.

TABLE 2: Typical Atterberg Limits for Soils [7].

Soil Type	*LL (%)*	*PL (%)*	*PI (%)*
Sand		Non Plastic	
Silt	30-40	20-25	10-15
Clay	40-150	25-50	15-100

These produced the following linear models for the samples from borrow pits and sediments on these roads.

$$c = 0.83m - 15.75 \quad (3)$$

$$c = 0.19m - 11.56 \quad (4)$$

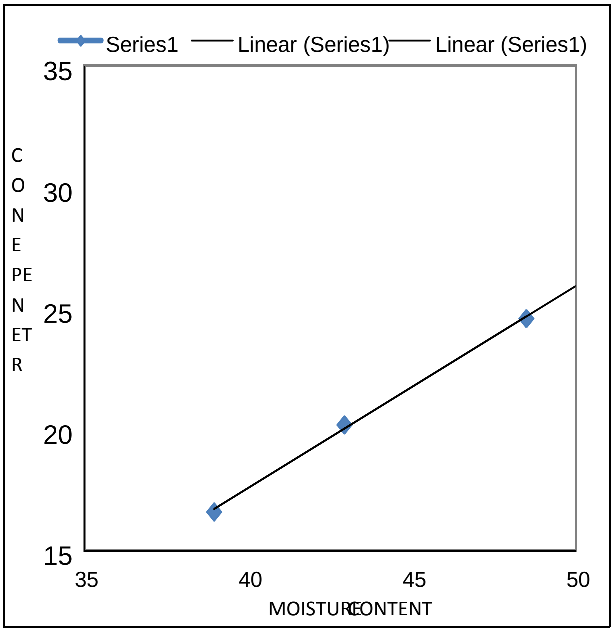

Figure 1. Liquid Limit analysis, Uganda's Murram Roads borrow pits

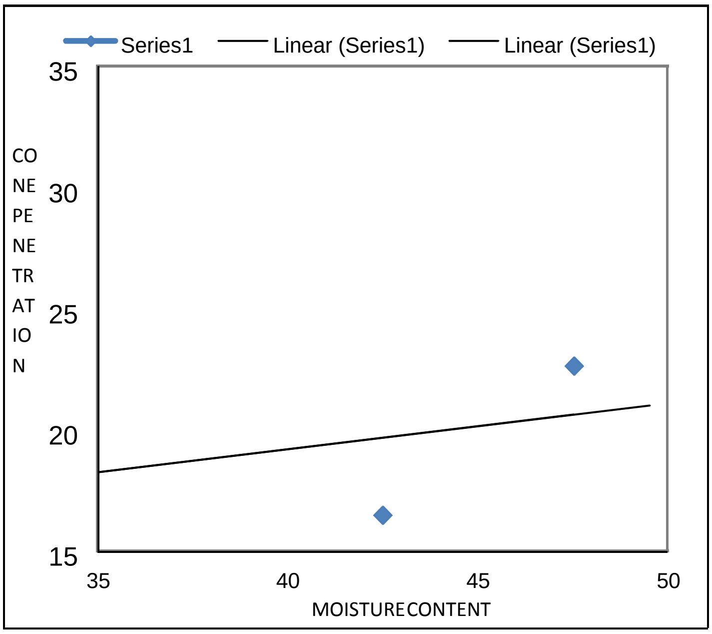

Figure 2. Liquid Limit analysis, Uganda's Murram Roads sediments

3.3 Sieve Analysis Data

Sieve analysis experiments were done in [1], [4], [6] & [10] as identified in the figures 3, 4, 5 and 6 below. Limits for Arua and Kabale sediments were not considered in this

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study. It was noted that a lot of blending is necessary for the soil materials used to make these roads.

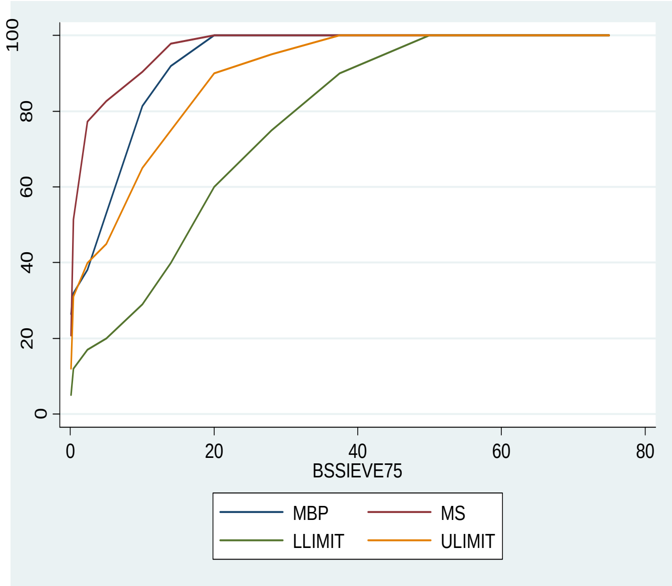

Figure 3. Line graphs for MBP, MS, BSSIEVE & Standard gravel specifications.

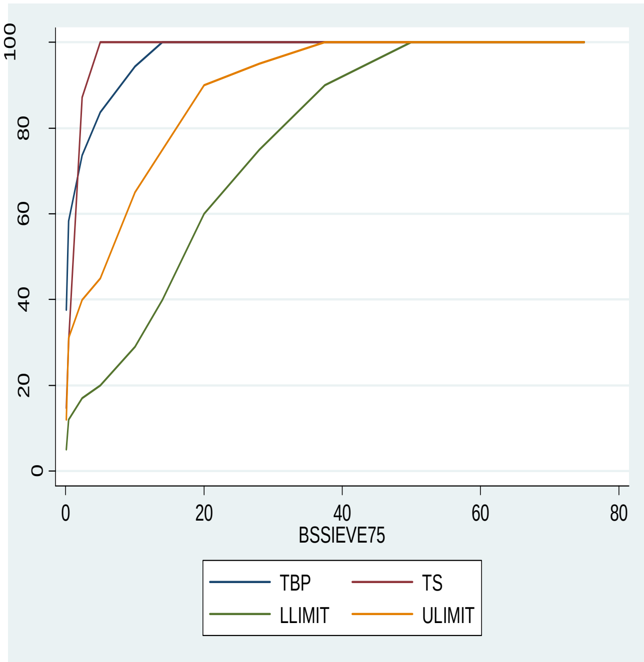

Figure 4. Line graphs for TBP, TS, BSSIEVE & Standard gravel specifications.

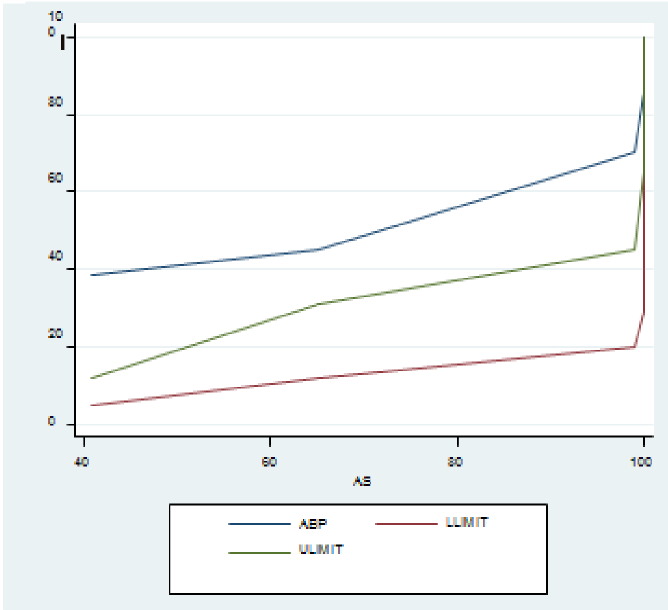

Figure 5. Arua Borrow Pit Samples Tested for Gravel Specifications.

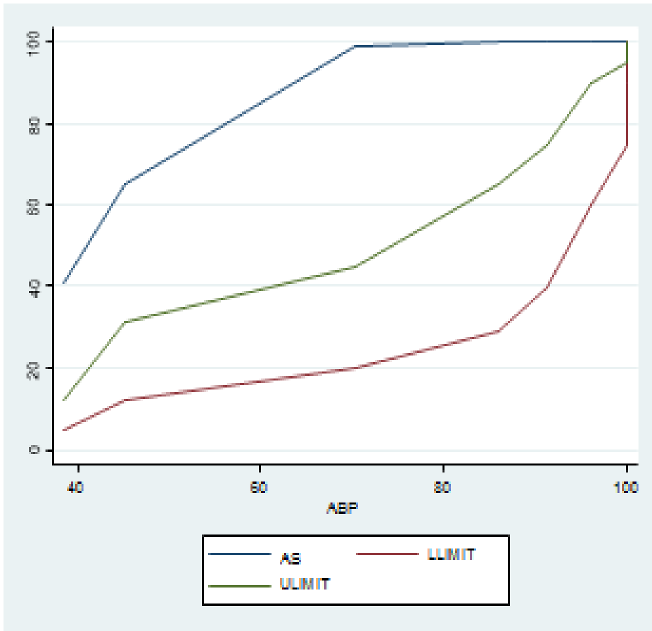

Figure 6. Arua Sediment Samples under Gravel Specifications.

3.4 Comparison between USLE and EMMOGR

Finally, a brief comparison between two models was done by use of the data from the field and laboratory. One of these models is the original empirical model developed for agricultural plots. The other model was developed recently in [1], [5] & [6] as an Erosion Model rilling and duning on gravel roads. These two models were used in the generation

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of the Erosion Model for the Maintenance of Gravel Roads (EMMOGR) in Uganda. It should be noted that only the rill sub-model formulation in EMMOGR was considered in this study. The aim of this comparison was to exclusively see how the models work in relation to each other and to give a brief background to EMMOGR. A brief review of how each of the models works was done and analysis was taken and conclusions made.

3.4.1 Universal Soil Loss Equation (USLE)

This equation is one of the first empirical models and was developed in the United States of America (U.S.A) during the 1950's [3] & [2]. It was based on erosion plots of 9% slope with length 22.13m, width 1.83m, and considered for a period of 1 year. It has the form:

$$A = RKLSCP \tag{5}$$

Where *A* = average annual soil loss over the area of a hill slope that experience net loss, *R* = rainfall erosivity (driving forces of rain), *K* = soil erodibility (soil resistance term), *L* = slope length factor, *S* = slope steepness factor, *C* = cropping factor, *P* = conservation practices factor. These factors have since generated valuable foundations to modeling erosion empirically and by process.

3.4.2 Erosion Model for the Maintenance of Gravel Roads (EMMOGR)

The model took in to account the rate of development of simple rills on the road to big rills or even gorges. It also considered the rate of deterioration of constructed drainage channels [2], as rills eat them up. The deterioration of the road side drainage channels also catered for the dunning (blocking) of the channels or enlarging rills (road squeezing). The model is a one-dimensional model with mathematics, physics, hydrology, and geo-engineering as the main subjects. The following were considered in the formulation: nature or make of the structure (*M*)(soil type, design standards, and sediment type or size, the strength of flow, sediment size, volume, and density issues [1], [5], [3], & [11]; size of channels (erosion paths) (S*c*) (the volume, velocity [3] & [13], and the repairs (or maintenance). The main parameters *M* and S*c* in equation (1) were modeled in [1] & [5]. The parameter *p* was modeled to:

$$p = \frac{k\tau_c}{\alpha(t+1)} \tag{6}$$

Where factor, p = repair factor, t = time effect, τ_c= critical shear strength, and α = initial rill/dune size after some erosion, k = proportionality constant.

Noted also was that the model formulation embedded the rill/dune formulation model which formed the basis for this comparison. Some of the parameters above were constructed to the following rill/dune model:

$$\frac{\partial S_c}{\partial t} = \frac{q}{\tau_c} - k_e C_i \tau S_c \tag{7}$$

$$\tau = \tau_o - \tau_c, \qquad \tau_c \geq \rho_i .$$

Where C_i= Compaction index, S_c = Specific rill area affected by erosion (m^2/kg), gorge, dune, t = time effect, q= flow rate/discharge rate, k_e= erodibility parameter, τ_c = critical shear stress, ρ_i is some value depending on the size class i of the sediment particles.

S_c depends on various factors like volume of water, frequency of runoff, erodibility factor, runoff speed, and shear strength. The assumption here is that the rill is already an initiated feature by road constructors, and some erosion ('first' erosion). The flow rate or discharge rate was modeled as Manning's equation with its related parametisation[4].

Shear stress was modeled by the equations (8) below:

$$\tau_o = \gamma DS \quad \text{and}$$

$$\tau_c(N/m^2) = 0.155 + \frac{0.409 d_p^2}{\sqrt{(1+0.177 d_p^2)}} \tag{8}$$

Where γ (kN/m^3) is the unit weight of water or the specific gravity of water, D(m) is the depth of the flow (sometimes taken as a hydraulic radius), and S (%) is the energy gradient. The second equation in (8) was developed by Mittal and Swamee[12]. It gives results within +0.05 of the values given by Shield's curve for all particle diameter, d_p. The particle diameter classifications by Rijn [13] for this formulation and were comparable to that of Muni [14]. This gives another major classification of $A_i, i = 1(1)7$ that is used in several engineering projects.

The model partial differential equation was evaluated by mathematical methods to the following S_c:

$$S_c = \frac{qt+\alpha}{\tau_c(1+k_e c_i \tau t)} \tag{9}$$

The erodibility parameter (k_e) was evaluated for the maximum value in the interval 0.002 to 0.05 $m^{-1}s$ for the rilling process. Laboratory results showed an average of $1757.6kg/m^3$ for the dry density.

3.4.3 Comparison between USLE and EMMOGR

The two models were compared basing on the evaluation perspective as follows:

a) USLE related erosion issue on flood plains and specifically on agricultural plots of area 40.5m^2. It also relates deposition but most specifically on how much is eroded from the given area. On the other hand, the rill model applies to gravel roads erosion and deposition within an area of 646m^2 or 860m^2 or 1000m^2 relating the roadway width.

b) The slope considered for USLE was restricted to 9% compared to the slope range of 3.5%-90% considered in the rill model. The highest values were used for rilling and the smallest used for duning. Noted was that the USLE slope fits within the EMMOGR slope range.

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c) The factors in USLE are related to each other in a multiplicative fashion and can run to zero if any one factor is zero. This is not the case for the roads model considered. The factors are modeled logically to signify the parametisation.

d) The product formulation implies that the annual soil loss increases if at least one of these factors increases. The factors used in the rill model do not behave that way. In fact a reduction in the discharge q followed by a reduction in the critical shear stress τ_c may imply a reduction in erosion effect towards rilling. It should be noted that the shear stress factor is a better predictor of the erosion potential than velocity. This is because it considers the actual force of water on the boundary of the channels[14].

e) RUSLE or USLE considers the initial erosion effect α as zero unlike the rill sub-model in EMMOGR. The road model assumes that there is an initial effect of erosion arising from the construction of the road side ditches which erosion facilitates.

4. DISCUSSION

The density for sediments being lower is normal because eroded soils are sandier than they were before erosion (on the road surface). It should be noted however that it is a small percentage difference of 10.4% which justifies the fact that soils used in the making of the gravel roads are eroded by a bigger percentage according to this study.

Equations (1) and (2) above are reliable according to the high R^2 values (that is $R^2 = 0.8133$ and $R^2 = 0.8750$ for borrow pit and sediment soils respectively). This is an indication that sediments from these roads are a result of easy eroding. This further suggests that insufficient compaction and possibly poor blending of these soils are done. It was also observed that regarding road construction, the borrow pit samples are better as compared to the sediments as seen in figures 1 and 2.

Similarly, the model in equation (3) for the cone penetration to the moisture content is supported by this equation. In the same line, sediment soils tested in this liquid limit analysis was not supported by equation (4). Figures 3, 4, 5 and 6 showed that the borrow pit soils used to make the gravel roads are out of the gravel specifications.

5. CONCLUSION

Various engineering processes like road design pavement practices have been typically based on empirical procedures like the California Bearing Ratio (CBR). The rill model in this study was constructed and tested by using empirical data and aimed at checking the development and effects of rills as they occur on roads. It should be noted that non-paved roads in most developing countries suffer from the effects of rilling even with well-designed non-concrete drainage. The model suggests various methods of controlling such effects. They include among others, controlling the discharge factors like stress through controlled drainage perennial grassing [3] to increase the roughness coefficients. Others are increased and applied compaction, or using soils with higher dry density profiles or using repeated load CBR [15].

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