

Assessing the determinants of rill erosion on roadcuts

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Assessing the determinants of rill erosion on roadcuts in the south eastern region of South Africa

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Abstract

Erosion on roadcuts is a concern due to potential to cause environmental degradation which has significant economic costs. It is therefore critical to understand the relationship between roadcut characteristics and soil erosion for designing roadcuts that are less vulnerable to erosion and to help road rehabilitation works. This study investigated the characteristics (i.e. gradient, length and percentage of vegetation cover) of degraded (i.e. with rills) and non-degraded roadcuts (i.e. without rills) and explored the relationship of the roadcut characteristics with the dimensions (widths and depths) of the rills. Degraded roadcuts were steep (52.21°), long (10.70 m), and had a low percentage of vegetation cover (24.12) when compared to non-degraded roadcuts which had a gradient of 28.24° , length of 6.38 m and 91.7 % of vegetation cover. Moreover, the gradient and percentage of vegetation cover of the roadcuts significantly determined the rill dimensions. The widths and depths of the rills increased with the increase in slope gradient and decreased with an increase in percentage of the vegetation cover. Moreover, the widths and depths of the rills decreased downslope of the roadcuts. Based on these results, re-vegetation of roadcuts as well as construction of gentle gradients could minimise rill erosion and hence the negative onsite and offsite effects.

1 Introduction

Soil erosion is regarded as one of the most critical environmental problems worldwide (Meadows, 2003; Le Roux et al., 2007, 2008; Schönbrodt-Stitt et al., 2013; Ma et al., 2014; Wei et al., 2007). It mainly occurs in the form of sheet, rill and/or gully erosion (Morgan, 2005; Le Roux et al., 2008). Amongst the three forms, rill erosion remains the main cause for concern since it is a precursor of gully erosion. Rill erosion mainly occurs as a result of concentrated overland flow of water leading to the development of small well-defined channels (Haile and Fetene, 2012). These channels act as sediment sources and transport passages leading to soil loss (Wirtz et al., 2012). Although

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soil erosion is a natural process, it has been accelerated by the human impact on the landscape due to agriculture, grazing, mining, and fire (García-Orenes et al., 2009; Giménez-Morera et al., 2010; Leh et al., 2013; Lieskovský and Kenderessy, 2012; Mandal and Sharda, 2013; Zhao et al., 2013; Ziadat and Taimeh, 2013). Roads, railways and other infrastructures also results in the soil degradation and changes in the landforms (Cao et al., 2013; Cerdà, 2007; Cheng et al., 2013; Jimenez et al., 2013; Lee et al., 2013; Villarreal et al., 2014).

Construction of roads in South Africa, has resulted in the creation of roadcuts, some of which have developed extensive rills and fluting (or incipient gullies). Soil erosion on roadcuts is significant since soil loss can reach magnitudes of $247.6 \text{ t ha}^{-1} \text{ yr}^{-1}$ (Megahan et al., 2001). Moreover, roadcuts have been regarded as the main source of erosion than other parts of the road system since they account for 70 to 90 % of soil loss (Grace III, 2000). The off-site loss of sediment material may lead to river and reservoir siltation where sediment is deposited (Cerdà, 2007; Zhao et al., 2013). This can exacerbate water management problems particularly in a semi-arid region such as South Africa, where water scarcity is frequent (Marker and Sidorchuk, 2003). Moreover, erosion on roadcuts may cause roadside slope instability (De Ona et al., 2009; Osorio and De Ona, 2006). At present, large volume of soil is lost annually through water erosion in South Africa. It is estimated that South Africa losses approximately 400 million tons of soil per year, of which roadcut erosion is also a major contributor (Dlamini et al., 2011). The economic costs associated with the negative impacts of erosion are significant. For instance, it is estimated that soil erosion costs approximately USD 200 million annually including the off-site costs of purification of silted dam water in South Africa (Le Roux et al., 2008). Additionally, slope instability could create excessive maintenance costs (Robichaud et al., 2001) and in extreme cases requires re-grading or reconstruction of the site (Persyn et al., 2005). In the light of the above, understanding the relationship between the characteristics of roadcuts and the rill erosion can be important for sustainable future road construction and soil erosion control. The present study therefore aims to assess the characteristics (gradient, length, and vegetation cover) of degraded

to grassveld. Geology of the study area consists mainly of sandstones and mudstones of Beaufort and Ecca groups (Beckedahl, 1996). The geology has minor exposures of the Natal Group sandstones. The soil types vary from podzolic and duplex soils of the midlands and coastal belt (Beckedahl, 1996).

2.2 Field data collection

2.2.1 Identification of roadcuts

Roadcuts of interest were identified by first traversing main and regional roads in the south eastern region of South Africa on Google Earth. Following the above procedure, field inspection was conducted on identified sites, to assess the actual condition of the roadcuts. Roadcuts were then numbered and random samples selected using random number tables, to get actual sizes for detailed investigation. The roadcuts were then categorised into degraded and non-degraded. For the purpose of this study, the degraded were those with the presence of either rills or flutes whereas non degraded roadcuts were those with no apparent rilling. This resulted in twenty nine degraded and twenty non-degraded roadcuts. The degraded roadcuts were further classified into three erosion categories based on the mean percentage cover of rills per square meter plots established on the roadcuts: (1) slight: less than 25 %; (2) moderate: between 25 and 50 %; (3) extensive: between 50 and 75 %; and (4) very extensive: above 75 %. The selected roadcuts did not receive any form of treatment after construction (e.g. hydroseeding etc.) and were characterised by herbaceous vegetation cover. Additionally, the selected roadcuts were located along roads that were constructed at the same period to minimise the effects of the roadcuts age on erosion.

2.2.2 Measurement of the characteristics of roadcuts

The gradient, length, and percentage of vegetation cover were measured on the degraded and non-degraded roadcuts identified in the south eastern region of South

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Africa. Slope profile measurements were done along three cross-profile transects on each roadcut by using an abney level, ranging rod and a measuring tape. Transects were established from the top to the bottom of the roadcuts, with the first transect running along the maximum slope length. The next two transects were located on both sides of the first transect and halfway to the end of the roadcut width (Fig. 2). Slope profiles were measured by recording a series of measured lengths along a transect and corresponding series of measured angles. The slope gradient for each roadcut was calculated as the average of averages for each transect while the length was calculated by averaging the three transects.

Percentage of vegetation cover was measured by demarcating transects made of 1 m long and 4 m wide plots which were then numbered. Random samples were selected from the numbered plots using random number tables, to get actual sizes for detailed investigation. This resulted in selection of more than 70 % of the plots on each roadcut, of which the number of plots on each roadcut was determined by the surface area. In each plot, a 4 m string attached to two metal pins was placed at 0.5 m width of a plot. Vegetation cover was calculated as the total vegetated distance of the string to the total length of the string, and recorded as a percentage (Kercher et al., 2003). Total percentage of vegetation cover for the entire roadcut was then calculated as the mean of all plots percentage covers (Bochet and García-Fayos, 2004).

2.2.3 The measurement of rill dimensions

Measurements of rill dimensions were made from 4 m² plots located upslope, midslope and downslope of the roadcuts (Fig. 3). The widths and depths of the rill were measured at regular intervals (i.e. 0.01 m) along the sinuous length of the rill and the averages calculated (Hagmann, 1996; Sidle et al., 2004).

2.3 Field data analysis

Statistical analysis was performed using Statistical package for Social Sciences (SPSS) version 21 software. The Kolmogorov–Smirnof test was used to test data normality. A test of proportions was employed to determine whether there were significant differences between slope characteristics of the degraded and non-degraded roadcuts. One-way analysis of variance (ANOVA) at 95% confidence levels ($P < 0.05$) was used to determine whether there were significant differences between slope characteristics of the slightly, moderately, extensively and very extensively degraded roadcuts. Pearson correlation was used to evaluate whether there were any associations between slope characteristics and rill dimensions. Similarly, one way ANOVA ($P < 0.05$) with a Turkey's HSD post hoc test was used to determine if there were any significant differences of rill dimensions upslope, midslope and downslope of the roadcuts.

3 Results

3.1 Characteristics of the roadcuts

The slope characteristics of the roadcuts are presented in Table 1. Results show that these characteristics ranged widely for the roadcuts. It can be observed that the mean slope gradient of the degraded roadcuts was higher (52.51°) than that of the non-degraded roadcuts (28.24°). Similarly, the mean length of degraded roadcuts was higher (10.70 m) when compared to that of the non-degraded roadcuts (6.38 m). The vegetation cover for degraded roadcuts was low, with a mean percentage of 24.12 while non-degraded roadcuts had higher mean percentage of vegetation cover of 91.71.

The results in Fig. 4 show the significant differences of slope gradient, length and percentage of the vegetation cover between non-degraded (ND) and degraded (D) roadcuts. It can be observed that the slope gradient and length of degraded roadcuts are

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significantly ($p < 0.05$) higher than for non-degraded roadcuts. Moreover, vegetation cover for degraded roadcuts is significantly lower than that for non-degraded roadcuts.

The proportions for slope length and gradient on degraded roadcuts were also significantly higher than for non-degraded. It was noted that degraded roadcuts had significantly lower percentage of the vegetation cover. On the other hand, the results of ANOVA with post hoc test, showed that there are no significant differences ($p > 0.05$) amongst the site variables (slope length, gradient and percentage of the vegetation cover) of the slightly, moderately, extensively and very extensively.

3.2 Rill dimensions

The results show that the characteristics of the roadcuts significantly determine rill dimensions (Table 2). Significant moderate positive correlations of gradient with both rill width and depth were observed, while percentage of the vegetation cover had a strong significant negative correlation with rill depth and width. The rill width and depth, however, were not significantly influenced by the roadcut length.

The mean values for rill dimensions at different roadcut slope positions (upslope, midslope and downslope) are shown in Table 3.

The rill dimensions were significantly different at different plot positions (Table 4), with values decreasing downslope. The results showed that the rill dimensions had highly significant differences between the upslope and downslope positions.

4 Discussions

This study aimed at evaluating the characteristics of the degraded and non-degraded roadcuts as well as assessing the relationship between the rill dimensions and the roadcut characteristics.

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2010). Also, this can be explained by the ability of vegetation cover to moderate and dissipate the energy exerted by water (Lal, 2001; Ande et al., 2009). In fact, vegetation intercepts rainfall, increases infiltration of water, intercepts runoff, and stabilizes the soil with roots (Bochet and García-Fayos, 2004; Loch, 2000). The results of this study are supported by the work of Cerdan et al. (2002) who observed that the occurrence of rill erosion on fields was directly a function of vegetation cover. Similarly, Arnáez et al. (2004) found a negative correlation ($r = 0.60$, $p = 0.05$) between vegetation cover and runoff. According to Laker (2004), vegetation cover (i.e. herbaceous plants) protect the soil because of their high basal cover, dense and very fine root systems that bind the soil.

4.2 The relationship between slope characteristics and rill dimensions

The roadcuts slope characteristics were assessed for their correlation with the rill dimensions. The results indicate that vegetation cover was the foremost significant variable in determining rill dimensions on the roadcuts, while slope length had no significant effect. A strong negative correlation between vegetation cover and rill dimensions suggests that an increase in vegetation cover reduces the cross sections of the rills. Vegetation cover in a rill catchment reduces runoff and sediment yield through rainfall interception, infiltration and resistance to flow (Woo et al., 1997). A significant positive correlation of slope gradient and rill dimensions indicate that an increase in slope gradient increases the volume of rills and hence the volume of soil loss (Berger et al., 2010). However, a moderate correlation of slope gradient and rill dimensions suggests that rill configuration is complex than merely slope gradient dependent.

The dimensions of rills that extended continuously from the top to the bottom of the roadcuts changed significantly downslope. Previous research indicated that significant changes in rill dimensions are determined by soil detachment and deposition along the length of the rill (Bennett et al., 2000; Lei and Nearing, 1998). In this study, a decrease in rill depth downslope suggests that a progressive increase in sediment load downslope decreases detachment rate (Lei and Nearing, 1998). However, this was significant

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Table 1. Descriptive statistics for slope characteristics.

	Degraded roadcuts				Non-degraded roadcuts			
	min	max	mean	SD	min	max	mean	SD
Slope characteristics								
Gradient (°)	24.47	78.28	52.51	13.14	13.22	42.87	28.24	9.48
Length (m)	5.07	20.00	10.70	4.00	5.67	14.00	6.38	3.31
Veg. cover (%)	0.00	45.49	24.12	24.48	50.42	100.00	91.71	13.98

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Table 2. Significant ($p < 0.05$) relationships between slope characteristics and rill width as well as depth from Pearson correlation results.

		Slope length	Slope gradient	Percentage of the vegetation cover
Rill width	Pearson correlation	0.210	0.371	-0.621
	Significance	0.190	0.018*	0.000*
Rill depth	Pearson correlation	0.221	0.339	-0.637
	Significance	0.110	0.033*	0.000*

Note: * Correlation is significant at 0.05 level.

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**Table 3.** Mean rill width and depth values for different slope positions on roadcuts under study.

Slope position	Width (m)	Depth (m)
Upslope	0.14	0.079
Midslope	0.11	0.064
Downslope	0.08	0.045

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Table 4. The results of ANOVA using a Turkey's HSD post hoc test for rill dimensions (width and depth) and different slope positions (upslope, midslope and downslope) at 95 % confidence level ($P < 0.05$).

Slope position	Rill width	Rill depth
US vs. MS	0.149	0.104
US vs. DS	0.000*	0.000*
MS vs. DS	0.024*	0.041*

Note:

US = Upslope.

MS = Midslope.

DS = Downslope.

* Significant at 0.05 level.

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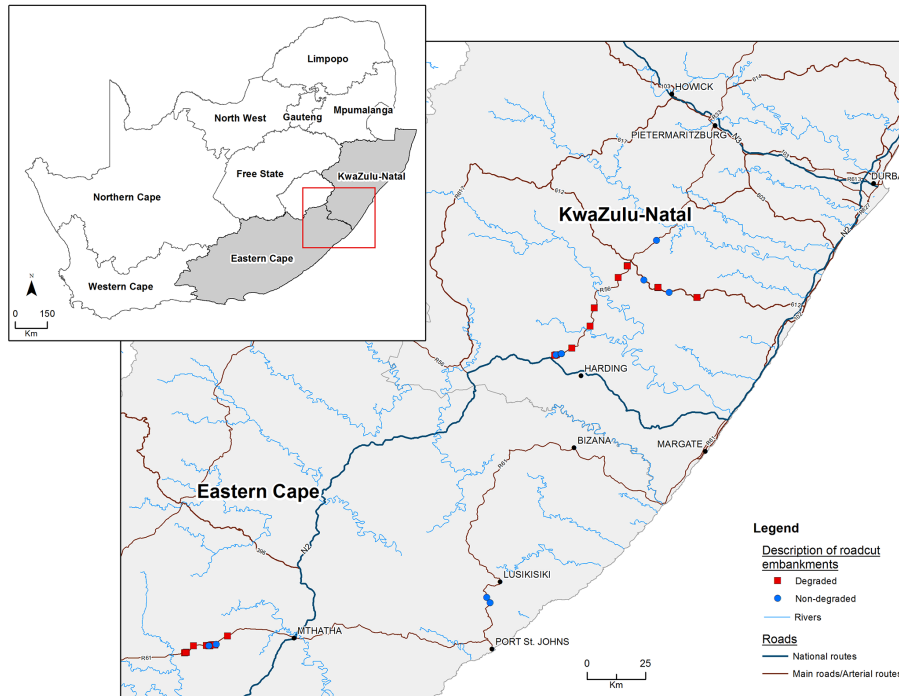


Figure 1. The location of the studied roadcuts in the south eastern region of South Africa.

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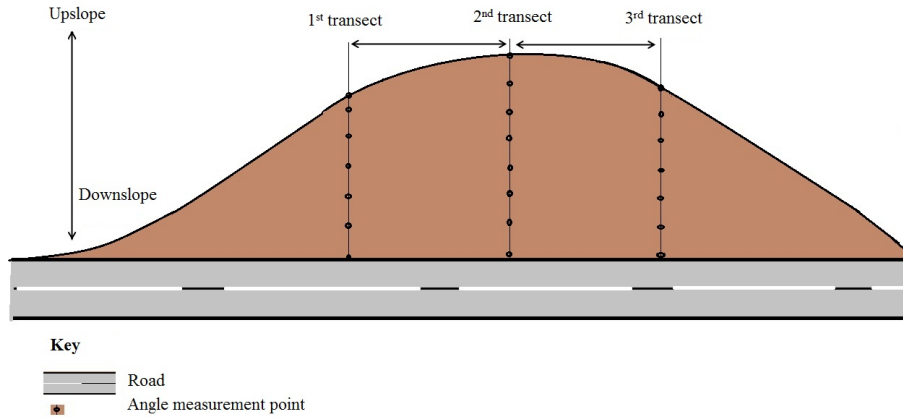


Figure 2. Schematic representation of slope angle and length measurements on the roadcuts.

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Assessing the determinants of rill erosion on roadcuts

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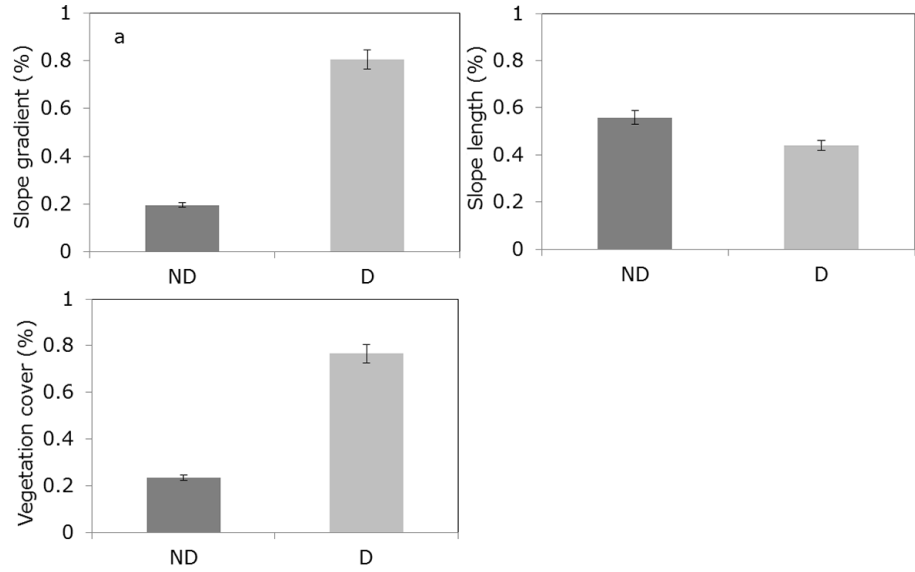


Figure 4. Proportions of slope gradient, length and vegetation cover for non-degraded (ND) and degraded (D) roadcuts.

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