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Understanding the factors influencing 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 the potential of causing 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, percentage of vegetation cover and soil texture) 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 roadcut significantly determine the rill dimensions. The widths and depths of the rills increase with the increase in slope gradient and decrease with an increase in percentage of 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 on-site and off-site effects.

1 Introduction

Soil erosion is regarded as one of the most critical environmental problems worldwide (e.g. 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 soil erosion is a natural process, it has been accelerated by 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). The construction of roads, railways and other infrastructures also result in 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).

The study of soil erosion, particularly in South Africa, has, however, been limited to agricultural and pastoral land, and research investigating road-related soil erosion is scarce, despite much literature having been produced on combating soil erosion per se. Roads result in the permanent alteration of the geomorphic and hydrological settings of the landscape, leading to increased soil erosion (Ramos-Scharron and Macdonald, 2007). Previous studies have shown that roads result in the creation of roadcuts that contribute to runoff and high sediment production that cause extreme land degradation (e.g. Arnáez et al., 2004; Megahan et al., 2001; Xu et al., 2009). Arnáez et al. (2004) recorded a significant generation of runoff and sediment from roadcuts in the Iberian Range, Spain, and this was attributed to steep gradients and low vegetation cover. Megahan et al. (2001) evaluated the effects of slope gradient, slope length, slope aspect, rainfall erosivity and ground cover density on erosion on roadcuts in Idaho, USA. The results of multiple regression analysis demonstrated that the slope gradient was the most significant of all site variables in affecting erosion on the roadcuts. Moreover, Xu et al. (2009) evaluated the effects of rainfall and slope length on runoff and soil loss on the Qinghai–Tibet highway sideslopes in China and found that rainfall intensity correlated with sediment concentration and soil loss, while soil loss decreased with increasing slope length. In summary, these studies highlight that slope properties (viz. slope gradient and length, vegetation cover and soil properties, particularly soil texture) of the roadcuts are critical in determining the degree of soil erosion along these areas. However, to the best of our knowledge, no study has investigated why certain roadcuts are eroded while others are not, and none has explored the relationship between the roadcut slope characteristics and the dimensions of the rills. Moreover, most of the studies of erosion on roadcuts have been conducted outside southern Africa.

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 $\mathrm{t\,ha^{-1}\,yr^{-1}}$ (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 70–90 % 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, a large volume of soil is lost annually through water erosion in South Africa. It is estimated that South Africa loses approximately 400 million tons of soil per year, of which roadcut erosion is 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 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 and non-degraded roadcuts to understand why rills are present on some roadcuts but not others, and to investigate the relationship between the characteristics of the roadcuts and the dimensions (width and depth) of the rills in the south eastern region of South Africa.

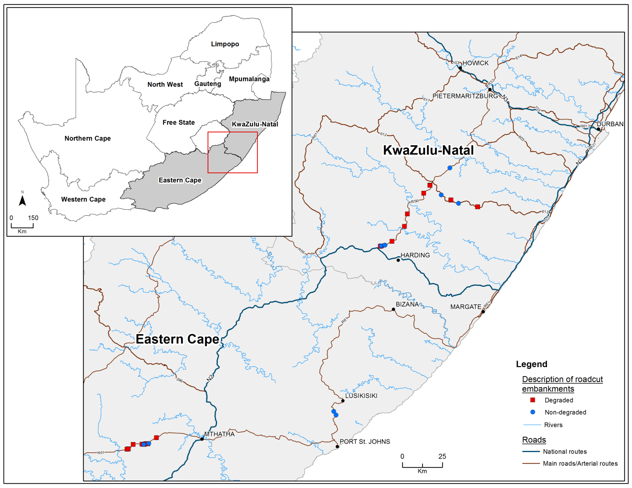

Figure 1. The location of the studied roadcuts in the south eastern region of South Africa.

2 Materials and methods

2.1 Site description

The roadcuts used in this study are located in the south eastern part of South Africa within the KwaZulu-Natal (KZN) Province and the former Transkei region of the Eastern Cape Province (Fig. 1). In this study, roadcuts are defined as roadslopes that result from excavation of high areas. The study area is characterised by a high level of erosion (Hoffman and Todd, 2000; Le Roux et al., 2007) and road construction has provided roadcuts that could exacerbate the problem. The terrain of the area is undulating; it consists of a series of dissected steps that rise from a relatively flat coastal plain in the east of South Africa, to the Drakensberg mountains which reach over 3000 metres above sea level and form the western boundary of the region (Beckedahl, 1996).

KZN has a subtropical climate characterised by high humidity, high temperatures and high rainfall (900–1200 mm) (Fairbanks and Benn, 2000). Summers are warm and wet, while winters are cool and dry. The climate changes gradually from the coast to the westerly plateau. On the other hand, the greater part of the Transkei is characterised by a sub-humid warm climate with summer-dominant rainfall (Jeschke et al., 1990). Annual rainfall varies between 500 and 1400 mm, with a mean temperature of 20 °C (Madikizela, 2000). This region has among the highest values of rainfall erosivity index ($\mathrm{EI_{30}}$) ($\sim 300\,\mathrm{MJ\,mm\,ha^{-1}\,h^{-1}\,yr^{-1}}$) in southern Africa (Beckedahl, 1996). The $\mathrm{EI_{30}}$ shows the potential ability for rainfall to cause soil erosion (da Silva, 2004). It is the product of the total storm kinetic energy and the maximum 30 minutes rainfall intensity (Le Roux et al., 2008). The biomes of KZN and Transkei range from coastal tropical forest along the coast and inland along the riverine gorges, to temperate transitional forest and scrub

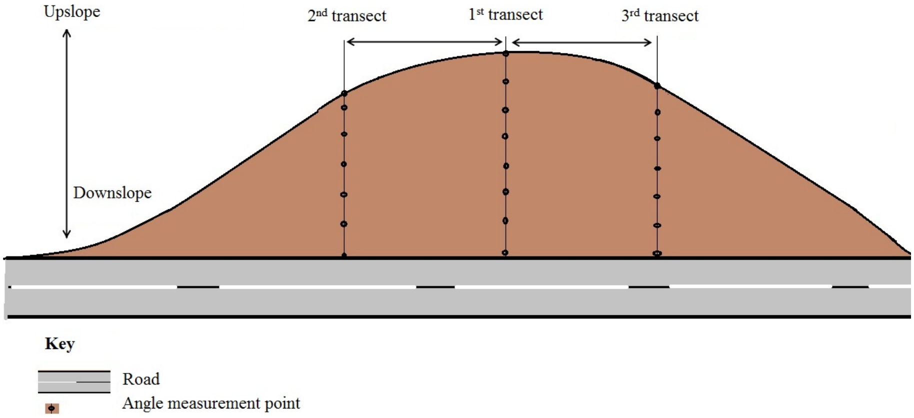

Figure 2. Schematic representation of slope angle and length measurements on the roadcuts.

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 metre 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) and were characterised by natural 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. Moreover, these roadcuts were chosen because precipitation across the study region did not vary significantly; hence it was assumed that the selected roadcuts received approximately the same amount of rainfall.

2.2.2 Measurement of the roadcut characteristics

The gradient, length, percentage of vegetation cover and soil texture (i.e. percentage of sand, silt and clay content) were measured on the degraded and non-degraded roadcuts identified in the south eastern region of South Africa. Slope profile measurements were done along three cross-profile transects on each roadcut by using an Abney level, a 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. The maximum lengths of the roadcuts were then considered as overall lengths of the roadcuts.

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 length 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).

Soil samples obtained from the rill complex of the roadcuts were placed in labelled sample bags. All sample bags were stored in dry conditions until they were transported to the laboratory for determination of the soil texture (i.e. percentage sand, silt and clay content). Soil texture was de-

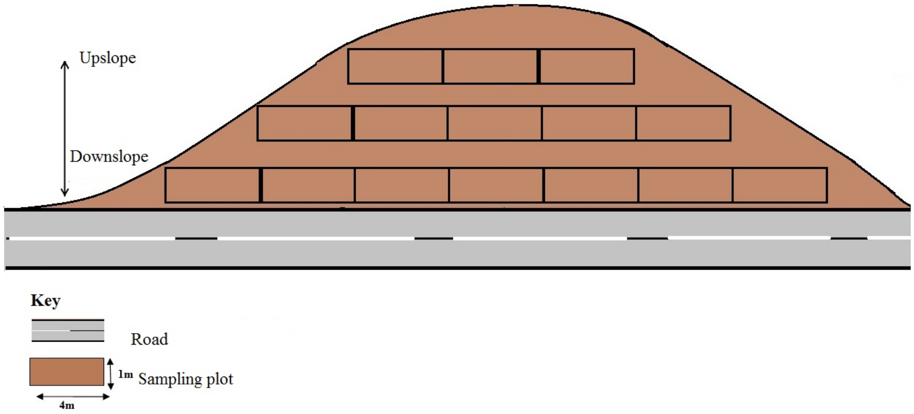

Figure 3. Schematic representation of rill survey plots on the roadcuts.

Table 1. Descriptive statistics for slope characteristics.

	Degraded roadcuts				Non-degraded roadcuts			
Slope characteristics	min	max	mean	SD	min	max	mean	SD
Gradient (°)	24.5	78.3	52.5	13.1	13.2	42.9	28.2	9.5
Length (m)	5.1	20.0	10.7	4.0	5.7	14	6.4	3.3
Veg. cover (%)	0.0	45.5	24.1	24.5	50.4	100	91.7	14.0
Sand (%)	44	78	66	9.73	6	84	39.5	26.4
Silt (%)	8	47	22	11.4	2	60	20.4	16.1
Clay (%)	6	12	8.7	1.9	8	70	39.1	22

SD = standard deviation

termined by the pipette/hydrometer method for the fraction of particles with a diameter less than 2 µm (clay fraction) by sieving for particles between 200 and 2000 µm (coarse sand) and between 20 and 200 µm (fine sand), while the fraction between 2 and 20 µm (silt) was obtained by difference (Mesquita et al., 2005).

2.2.3 The measurement of rill dimensions

Measurements of rill dimensions were made from 4 m^2 plots located upslope, midslope and downslope of the roadcuts (Fig. 3). The widths and depths of the rill were measured using a measuring tape and a 30 cm ruler respectively, at regular intervals (i.e. 0.01 m) along the sinuous length of the rill, and the averages were 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 a 95 % confidence level ($P < 0.05$) 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 (gradient, length, percentage of vegetation cover and soil texture) and rill dimensions. Similarly, one-way ANOVA ($P < 0.05$) with a Tukey'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 a higher mean percentage of vegetation cover of 91.71. The

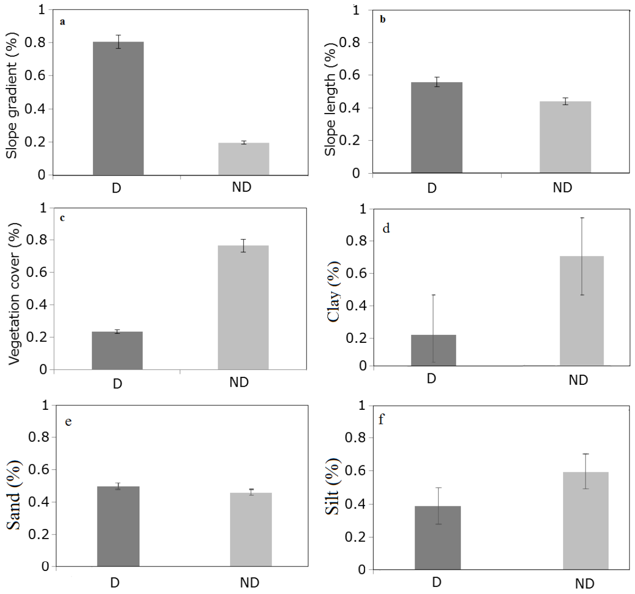

Figure 4. Proportions of slope gradient, length, vegetation cover, sand, silt and clay for non-degraded (ND) and degraded (D) roadcuts. Bars represent proportions of different roadcut characteristics and whiskers represent 95 % confidence intervals.

mean sand content of degraded roadcuts was 66 % while the non-degraded had a mean of 39.5 %. Additionally, mean silt contents of 22 and 20.4 % were observed for degraded and non-degraded roadcuts, respectively. Moreover, the mean clay content for degraded roadcuts was 8.7 %, while the non-degraded roadcuts had a percentage of 39.1.

The results in Fig. 4 show the significant differences of slope gradient, length, percentage of vegetation cover, and the percentage of sand, silt and clay content between non-degraded (ND) and degraded (D) roadcuts. It can be observed that the slope gradient and length of degraded roadcuts are 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 percentage of clay content was higher for degraded roadcuts than that of the non-degraded roadcuts, while the percentage silt and clay contents were not significantly different.

On the other hand, the results of ANOVA with post-hoc test showed that there were no significant differences ($p > 0.05$) amongst the site variables (slope length, gradient, percentage of the vegetation cover, sand, silt and clay) of the slightly, moderately and extensively degraded roadcuts.

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 the percentage of 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.

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

		Width	Depth
Slope length	Pearson correlation	0.210	0.221
	Significance	0.190	0.110
Slope gradient	Pearson correlation	0.371	0.339
	Significance	0.018*	0.033*
Vegetation cover (%)	Pearson correlation	−0.621	−0.637
	Significance	0.000*	0.000*
Sand (%)	Pearson correlation	0.37	0.41
	Significance	0.05*	0.03*
Clay (%)	Pearson correlation	−0.50	−0.46
	Significance	0.04*	0.01*
Silt (%)	Pearson correlation	−0.23	−0.28
	Significance	0.23	0.13

* Correlation is significant at 0.05 level.

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

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

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.

4.1 The characteristics of roadcuts

The results of this study have shown that the characteristics of the degraded roadcuts were significantly different from those of the non-degraded. For instance, it was noted that degraded roadcuts were characterised by high slope gradients and lengths, low vegetation cover and lower clay content percentage, when compared to the non-degraded roadcuts. These results are comparable with previous studies which indicated that these conditions increase the vulnerability of

Table 4. The results of ANOVA using a Tukey'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 ns	0.104 ns
US vs DS	0.000	0.000
MS vs DS	0.024	0.041

US = upslope; MS = midslope; DS = downslope; ns = non-significant

roadcuts to erosion (Arnáez et al., 2004; Bochet and García-Fayos, 2004; Flanagan et al., 2002). This is true because literature shows that an increase in slope gradient reduces the infiltration rate, hence increasing runoff (Arnáez et al., 2004; Manyatsi and Ntshangase, 2008; Megahan et al., 2001). A study by Arnáez et al. (2004) in the Iberian Range, Spain, demonstrated a significant positive relationship ($r = 0.76$; $p = 0.004$) between roadcut slope gradients and runoff which could result in a substantial increase in the formation of rills (Fox and Bryan, 2000). Formation of rills results from the increased scouring capacity of concentrated runoff (Haile and Fetene, 2012). Similarly, Jordan and Martinez-Zavala (2008) recorded a total soil loss of 106 and 17 $\mathrm{g\,m^{-2}}$ from roadcut and side-cast fills, respectively, in southern Spain. The highest erosion rate was observed on the roadcuts due to steep slopes.

The results of this study have also demonstrated that the degraded roadcuts had longer slope lengths compared to the non-degraded. To some extent, this observation is valid because longer lengths have the ability to increase runoff velocity, resulting in both increased soil particle detachment and transport efficiency downslope as compared to shorter slope lengths. For instance, a study by Chaplot and Le Bissonnais (2003) indicated that slopes associated with long lengths have the ability to increase runoff velocity as well as quantity, thereby influencing rill development. Furthermore, a study by Kinnell (2000) showed that an increase in slope length increases erosion by water, particularly when slope gradients exceed 10 %. However, these findings are in contrast with other studies. For instance, Megahan et al. (2001) concluded that slope length alone or in interaction with other variables has no detectable effects on roadcut erosion. Similarly, Luce and Black (1999) found that roadcut slope length is insignificant in determining erosion by water. Although the findings from the above two studies illustrate slope length as having an insignificant effect on runoff and rill erosion development, this may be due to other soil erosion contributing factors that do not favour rill development. For instance, areas associated with clay soil properties are bound to have less rill development despite having long slope lengths, when compared to those that are characterised by sandy soils.

The mean percentage of vegetation cover (predominantly herbaceous) for non-degraded roadcuts was high (91.7 %) when compared to degraded roadcuts (24.12); hence limited soil erosion was noted. This observation stands because vegetation cover has been found to stabilise and protect slopes against erosion since the roots hold soil particles together (Bochet and García-Fayos, 2004; Mohammad and Adam, 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 stabilises 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) protects the soil because of their high basal cover, dense and very fine root systems that bind the soil.

The higher percentage of clay content for non-degraded roadcuts could be an indication of the role of clay in reducing soil erosion. An increase in clay content of the soil has been associated with the increase in aggregate stability, thereby decreasing soil erodibility (Dlamini et al., 2011). Haile and Fetene (2012) indicated that fine-textured soils such as clays are not readily detached because of the strong cohesive forces that keep them aggregated. Yýlmaz et al. (2008) also observed a higher susceptibility of soil to erosion where the content of clay was low.

4.2 The relationship between slope characteristics and rill dimensions

The roadcut embankment 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 and silt content 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 indicates 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 more complex than being merely slope gradient-dependent. Similarly, a moderate negative correlation between clay content and rill dimensions implies that an increase in clay content of the soil could reduce the sizes of the rills on roadcuts. This finding is similar to the study of

Marquisee (2010), who found a negative correlation between clay content and the percentage cover and number of gully channels.

The dimensions of rills that extended continuously from the top to the bottom of the roadcuts changed significantly downslope. Previous research has 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 between upslope and downslope position, and between midslope and downslope positions. This suggests that detachment is active between upslope and midslope, while downslope positions are efficient in transporting the eroded sediment. The results are comparable with other studies available in literature (Bennett et al., 2000; Cochrane and Flanagan, 1997; Lei et al., 2001; Merten et al., 2001). Cochrane and Flanagan (1997) found that detachment decreases with the introduction of sediment at the top of the rill. Additionally, Bennett et al. (2000) observed that bed degradation was high in the upslope section of the channel, while Merten et al. (2001) reported a decrease in detachment, with an increase in sediment load along the channel length due to the suspended bed load that reduced the detachment capacity. In this study, a decrease in rill width downslope implies that the scouring of the rill side walls decreased as a result of the limited scouring capacity of flow, due to increase in the sediment load downslope (Bewket and Sterk, 2003). In addition, Lei et al. (2001) indicated that sediment load decreases the detachment rates particularly on slopes greater than 15°. However, the findings of this study are in contrast with the study by Okoba and Sterk (2006), who observed a consistent increase in rill width and depth downslope, and attributed this to cumulative runoff volume and velocity along the slope.

5 Conclusion

This study aimed to assess the characteristics (gradient, length and vegetation cover) of degraded and non-degraded roadcuts and investigate the relationship between the characteristics of roadcuts and the dimensions (width and depth) of rills in the south eastern region of South Africa. Degraded roadcuts were steeper, longer and had a lower percentage of vegetation cover when compared to non-degraded roadcuts. The results have shown that the widths and depths of the rills increase with an increase in slope gradient and a decrease in percentage of vegetation cover. Hence, low gradient and establishment of vegetation on roadcuts is recommended. Overall, while this study has contributed to the understanding of the relationship between the characteristics of roadcuts and rill erosion, explicit investigations are required that would help maximise the quality of observations. Future research should focus on the measurement of the actual soil loss from the rills and the contribution of bulldozer teeth impressions on roadcuts and on the development of rills. Additionally, repeated observations should be made for an accurate description of rill evolution and to determine any significant change in the rill cross sections. The results of this study can help road construction planners, engineers and site constructors to design roadcuts that are less vulnerable to erosion. Additionally, they could help the Transport Department and road maintenance agencies in planning for roadcut embankment rehabilitation work.

Author contributions. This study was conducted with the input of the co-author (H. R. Beckedahl), while the bulk of the design and analysis were conducted by the main author (K. E. Seutloali).

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