SPATIAL PATTERNS OF SOIL EROSION AND DEPOSITION IN TWO SMALL, SEMI-ARID WATERSHEDS

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Abstract: This work investigates spatial patterns of hillslope erosion in a semiarid ecosystem considering influences of vegetation, slope, rocks, and landscape morphology. ^{137}Cs inventories were measured on one shrub and one grassed watershed in southeastern Arizona. Mean erosion rates in eroding areas were 5.6 and 3.2 t ha^{-1} yr^{-1}, and net erosion rates for the entire watershed, including depositional areas, were 4.3 and nearly zero t ha^{-1} yr^{-1} for the shrub and grass watersheds, respectively. Differences in hillslope erosion rates between the two watersheds were apparently due to vegetation and erosion rates within the watersheds and were not correlated to slope gradient or curvature, but were correlated to rocks in the upper soil profile. The study showed that measurement of sediment yield from a watershed can be a poor indicator of erosion taking place within the watershed.

INTRODUCTION

Surface cover associated with vegetation and rocks is known to be an important influence on the generation of sediment in semi-arid landscapes. Greater vegetative cover relates to a more protected soil surface and decreased erosion rates. In semi-arid regions it has been documented that in some cases greater patchiness translates to greater runoff and erosion. Slope gradient is generally considered to be a factor that influences soil erosion in most environments, but in uncultivated environments the situation is more complex. A part of the reason for this may be due to the mechanics of erosion caused by overland flow on relatively undisturbed sites. Studies of flow induced erosion in southeastern Arizona have indicated that the hydraulic roughness of slopes of different gradients may evolve in such a way that a slope-velocity equilibrium is established through differences in rock cover on different slopes (Nearing et al., 1999). Those measurements have shown that overland flow velocities became independent of slope gradient because of differential rock cover, which had evolved as a result of previous, preferential erosion of fine material.

The purpose of this study was to evaluate and compare the rates and spatial patterns of soil erosion and deposition in two small, semiarid watersheds by using ^{137}Cs measurements. ^{137}Cs was measured on a 1.9 ha grass-dominated watershed (Kendall), and a 3.7 ha shrub-dominated watershed (Lucky Hills), both located in the Walnut Gulch Experimental Watershed, southeastern Arizona, USA. A portion of the results of the study in the Lucky Hills watershed was reported previously [Ritchie et al., 2005]. In an attempt to understand the processes controlling the erosion and sediment yield in these watersheds, we also investigated the relationships between erosion and slope gradient, slope curvature, and the percent of rock fragments in the soils.

METHODS

The Lucky Hills watershed (3.7 ha) and the Kendall watershed (1.9 ha), which are sub-watersheds of the larger Walnut Gulch Experimental Watershed, are located in southeastern Arizona, USA, near Tombstone. Mean hillslope gradients of the Lucky Hills and Kendall watersheds are 7.7% and 12.3%, respectively. The Lucky Hills watershed is a shrub dominated, semi-arid rangeland with approximately 25% canopy cover. The Kendall watershed is largely vegetated with grass at approximately 35% canopy cover, with a trace of shrubs and forbs. Both of these watersheds have historically served as grazing land for cattle and horses. Managed grazing has occurred in the area since the establishment of Spanish ranches in the early 1800s, and intensive grazing in the area began in the 1880s. Lucky Hills is currently not being used for agriculture, while Kendall continues to be grazed.

Soil surface samples to measure ^{137}Cs inventories were collected at 68 sampling points in Lucky Hills and at 62 points in Kendall by using a bucket corer with 50 mm diam. to a depth of 25 cm. Sample locations were uniformly distributed over both watersheds. Twenty reference soil surface samples were also taken at sites with assumed negligible erosion in the area. Soil samples were dried and sieved. The less than 2-mm soil fraction was placed into beakers and sealed. Analyses for ^{137}Cs were made by gamma-ray spectrometry. Measurement precision for ^{137}Cs was $\pm$ 5%.

Soil erosion and deposition rates were calculated using the Diffusion and Migration Model for Erosion and Deposition on Undisturbed Soils [Walling and He, 1999], which compares ^{137}Cs of the samples to the ^{137}Cs of the un-eroded reference sites.

RESULTS

The spatial patterns of computed soil erosion rates in the two watersheds are shown in Figure 1. Basic results with respect to the measured erosion rates were:

1. 85% of all of the sampling points in Lucky Hills showed erosion, compared to 53% for Kendall, while 15% of all of the points in the Lucky Hills watershed showed deposition, compared to 47% for Kendall.
2. There was more net soil loss from the Lucky Hills watershed than from the Kendall watershed. The mean of the soil erosion and deposition in Lucky Hills was -4.3 t ha^{-1} yr^{-1}, while the mean in Kendall was +0.1 t ha^{-1} yr^{-1} (which was not significantly different from zero).
3. Erosion rates were greater in Lucky Hills than in Kendall. The mean for points of erosion in Lucky Hills was -5.6 t ha^{-1} yr^{-1} and for Kendall was -3.2 t ha^{-1} yr^{-1}.
4. Deposition rates were greater in Kendall. The mean for points of deposition in Lucky Hills was +3.4 t ha^{-1} yr^{-1} and for Kendall was +3.9 t ha^{-1} yr^{-1}.
5. There was a significant positive linear relationship between soil erosion and percent rock fragments in both Kendall and Lucky Hills (Fig. 2).

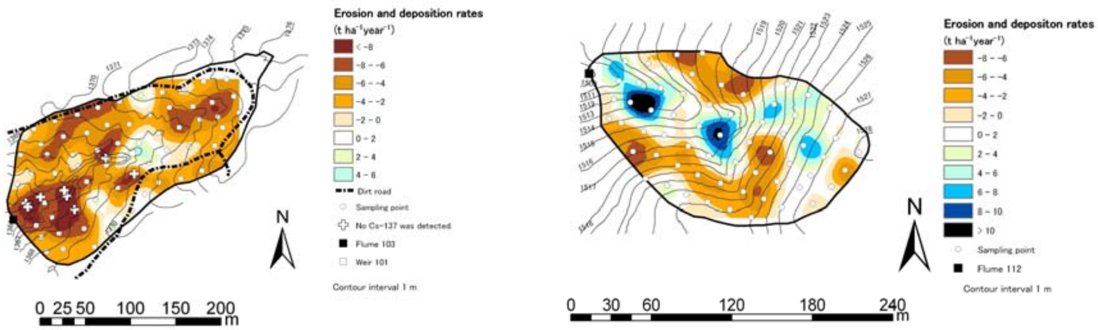

Figure 1 Spatial pattern of erosion and deposition in the Lucky Hills and Kendall watersheds.

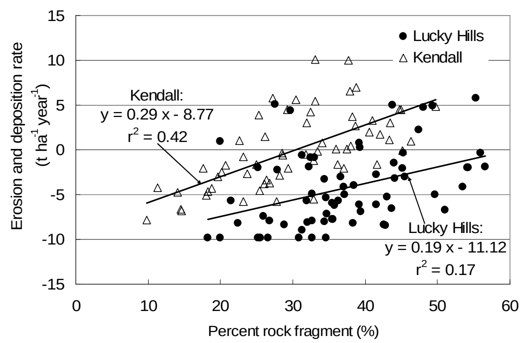

Figure 2 Relationships between percent rock fragments in the upper 25 cm of the soil profile and calculated erosion and deposition rates in the Lucky Hills and Kendall watersheds.

DISCUSSION

The evidence here suggests that the differences in hillslope erosion rates between the two watersheds were controlled largely by the vegetation differences, while within watersheds variation in hillslope erosion rates appeared to be dominated by rocks. The interpretation regarding vegetation is consistent with the interpretations related to the degree of patchiness of the vegetation. The grass cover in the Kendall watershed was certainly less patchy than that of Lucky Hills, wherein the shrubs were essentially lone plants separated by relatively wide inter-plant open spaces. Less erosion in the areas with higher percentages of rock fragments may be explained by the reduction of sediment transport capacity of flow with increasing hydraulic resistance on stony surfaces (Nearing et al., 1999; Poesen et al., 1999). Slope at sampling points and slope curvature did not appear to have a dominant influence on the hillslope erosion rates.

The delivery of eroded soil to the outlet of each watershed appears to have different controls than those controlling hillslope erosion rates. The difference in deposition between the two watersheds was due to differences in the watershed and drainage network morphology. The Lucky Hills watershed has a strongly incised channel network which facilitated transport of eroded sediments from the watershed. Conversely, the Kendall watershed had a swale area in which runoff slowed, allowing much of the sediment in the runoff from the hillslopes to deposit before it left the watershed outlet.

An important implication of the results of this study is that sediment yield from a watershed may have little to do with the rates of erosion within the watershed. The results from this study for the Kendall watershed are illustrative of the point. Even though the net erosion in the watershed was small, and even though past measurements show sediment yield rates to be quite small, there was net erosion taking place on 50% or more of the Kendall watershed area at rates as high as 7.9 t ha^{-1} yr^{-1}. Hillslopes at Kendall have been eroding over the past 40 years, even though very little sediment is being exported.

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