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Temporal and elevation trends in rainfall erosivity on a 149 km² watershed in a semi-arid region of the American Southwest

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Abstract

Temporal changes in rainfall erosivity can be expected to occur with changing climate, and because rainfall amounts are known to be in part of a function of elevation, erosivity can be expected to be influenced by elevation as well. This is particularly true in mountainous regions such as are found over much of the western United States. The objective of this study was to identify temporal and elevation trends in rainfall erosivity on a 149 km^2 (58 $miles^2$) watershed in a semi-arid region of southeastern Arizona. Data from 84 rain gages for the years 1960–2012 at elevations ranging from 1231 to 1644 m (4038–5394 ft) were used in the analyses. The average annual erosivity over the watershed as a whole was 1104 MJ mm ha^{-1} h^{-1} yr^{-1} (65 hundreds of foot ton inch $acre^{-1}$ h^{-1} yr^{-1}), and ranged from approximately 950 to 1225 MJ mm ha^{-1} h^{-1} yr^{-1} (56–72 hundreds of foot ton inch $acre^{-1}$ h^{-1} yr^{-1}), with a statistical trend showing greater erosivity at the higher elevations. No statistically significant temporal changes in annual or summer erosivities were found. This result stands in contrast to recent modeling studies of runoff and erosion in the area based on downscaled GCM information that project significant levels of erosivity changes over coming decades. These results are consistent with known orographic rainfall effects, but contrast with recent studies that presented projections of significant trends of increasing erosivity in the future based on downscaled GCM outputs for the area. The results illustrate the need for testing and developing improved techniques to evaluate future erosion scenarios for purposes of making targeted soil conservation decisions.

Keywords: Climate change; *R*-factor; RUSLE; Semiarid; Soil erosion; Walnut Gulch

1. Introduction

Rainfall erosivity is the capacity of rain to erode soil. Wischmeier (1959) used statistical analysis on data from erosion plots and found that the amount of soil loss measured was related to the value of EI, which is the energy of the storm, as estimated with a logarithmic function of rainfall intensity, multiplied by the maximum 30 min rainfall intensity during the storm. The EI index was used in the Universal Soil Loss Equation (Wischmeier & Smith, 1978) and then in the Revised Universal Soil Loss Equation (Renard, Foster, Weesies, McCool, & Yoder, 1997) to compute

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the annual average erosivity, or *R*-factor, for the entire United States. In cases where this relationship has been evaluated against independent erosion data it has been found to be statistically valid (e.g., Campos, Dasilva, Deandrade, & Lepurn, 1992; Salehi, Pesant, & Lagace, 1991), though variations have been proposed (e.g., Petan, Rusjan, Vidmar, & Mikos, 2010; Usan & Ramos, 2001), usually suggesting a shorter time period for the maximum prolonged intensity where such data are available.

Global precipitation has changed. Rainfall amounts and daily rainfall intensities generally increased in the United States between 1910 and 1996 (Karl & Knight, 1998). More than half of observed increases in total annual precipitation for the United States measured during that time were caused by increases in the frequency of heavy events, which were considered to be those in the upper 10 percentile of daily amount values. Also, the proportions of precipitation falling in heavy (> 95th percentile), very heavy (> 99th percentile), and extreme (> 99.9th percentile) daily precipitation events increased during the years 1910–1999 by 1.7%, 2.5%, and 3.3% per decade, respectively, on average across the United States (Soil and Water Conservations Society, 2003). This is a pattern that appears to be occurring in many parts of the world (Groisman et al., 2005; Meehl et al., 2007).

Future projections of climate suggest that rainfall amounts will continue to change. Seager et al. (2007) reported the results for the American Southwest of 19 General Circulation Models (GCM) included in the 4th Assessment Report of the Intergovernmental Panel on Climate Change, which they defined as "including all land between 125°W and 95°W and 25°N and 40°N." The overall averaged results showed a drying trend, as indicated by the value of precipitation minus evaporation, of 0.86 mm day^{-1} from the periods 1950 to 2000 compared to 2021 to 2040. However, their maps of the individual components of change, which included mean atmospheric circulation, specific humidity, and transient-eddy moisture convergence also showed significant spatial variation within the area, indicating both wetting and drying trends. It is not clear that the direct outputs of the GCMs can provide the spatial resolution needed to look at change in an area the size of the USDA-ARS Walnut Gulch Experimental Watershed (WGEW).

Historical rainfall erosivity is generally more difficult to assess than is rainfall amount because erosivity calculations require temporally high-resolution, breakpoint data. Such precipitation data from across the U.S. were compiled for the revision of the Universal Soil Loss Equation (Renard et al., 1997), and subsequently used to assess changes in annual and seasonal rainfall erosivity over the time period from 1972 to 2002 (Angel, Palecki, & Hollinger, 2005). Results for the interior western U.S. showed a statistically significant increase of 17% in rainfall erosivity during the summer months over the study period of 1972–2002, but it is not possible to pull out results from that study for specific areas such as Arizona or even the entire Southwest.

Rainfall erosivity has its special challenges in relation to interpretation of future climate projections. Global Circulation Model (GCM) outputs generally provide monthly outputs, and hence one must either use statistical relationships between erosivity and monthly rainfall (Nearing, 2001) or temporal downscaling methods must be used (Zhang, 2005, 2007; Zhang, Chen, Garbrecht, & Brissette, 2012; Zhang, Nearing, Garbrecht, & Steiner, 2004). There have been several studies that have used downscaled Global Circulation Model (GCM) outputs for projected future rainfall to look at the potential impacts of climate change on soil erosion (e.g., Zhang, 2012; Zhang, Nearing, Zhang, Xie, & Wei, 2010; Zhang & Liu, 2005). One recent such study conducted in southeastern Arizona (Zhang, Hernandez, et al., 2012) used output from seven GCMs for projections for the 2050s and 2090s. The results indicated that for southeastern Arizona, though there were no projected, statistically significant trends in total rainfall, erosion could increase by more than 100% over the next century. Since that study assumed no changes in vegetation, slopes, or soils, that projected shift can be interpreted to be due to projected rainfall erosivity changes, within the context of the GCM data and downscaling method used.

Humans living in mountainous areas have probably always been cognizant of the effects of elevation on rainfall. The effect has been scientifically documented and was discussed in the literature as early as 1945 (Bonacina, 1945), at which time it was referred to as an orographic effect, from the Greek work "*oros*" for mountain. Since that time the orographic effect has been identified and studied across the world (e.g., Al-Ahmadi & Al-Ahmadi, 2013; Goldreich, 1994; Katzfey, 1995; Sarker, 1966, 1967). Osborn (1984) analyzed data from across the state of Arizona and found a trend of increasing total, winter, and summer rainfall as a function of gage elevation. Karnieli and Osborn (1988) used data from 158 rain gages across Arizona to show that elevation explained between 67% and 94% of the variation in summer precipitation. They also reported that slopes of southerly aspect in southeastern Arizona had greater than otherwise expected summer precipitation. Michaud, Auvine, and Penalba (1995) developed a statistical model based on latitude, longitude, and elevation for the entire southwestern United States that explained between