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Scale effects on sediment yield from badland areas in Mediterranean environments

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Abstract: This study investigates area-specific Sediment Yield (SY) in Mediterranean badland areas at different spatial scales using a SY-database compiled from scientific literature. Relationships between the plot and catchment characteristics and the corresponding SY-data are analyzed. Results indicate that in Mediterranean environments SY is larger than in other environments, especially in badlands where a high variability of SY is observed depending on the spatial scale. In intensively gullied badlands, a complex plot or drainage area (A) – SY relationship is observed: for A ranging between 10^{-5} and 10 ha, SY is very high (mean SY equals 475 t ha^{-1} yr^{-1}), whereas for A > 10 ha, SY decreases with increasing A (mean SY < 100 t ha^{-1} yr^{-1}).

Keywords: badlands, sediment yield, drainage area, spatial scale

Introduction

The term badland was originally used to describe: "*an extremely dissected landscape difficult to cross on horse-back and agriculturally useless*" (Fairbridge 1968; p. 43). The term currently refers to areas of unconsolidated sediments or poorly consolidated bedrock with little or no vegetation, which are useless for agriculture because of their intensely dissected topography (Gallart et al. 2002).

Badlands develop in many climatic regions on a wide range of substrata (Bryan & Yair 1982, Howard 1994), but extensive badland development is usually associated with unconsolidated or poorly cemented materials. Badlands in Mediterranean environments are characterized by both strong climatic contrast and considerable human influence (Fairbridge 1968). These areas are commonly affected by intense processes of soil erosion, including gulling, rilling, piping, sheet erosion and mass movements. The intense weathering (Schumm 1956) and erosion process dynamics explain why erosion rates and sediment yield (SY) in badlands are much higher than those in surrounding areas, underlain by different lithologies. Several studies exist on geomorphological process rates in badlands. However, they mostly focus only on one specific area and/or on one specific scale. An integrated analysis of these findings at various spatial scales is currently missing.

The aim of this study is to investigate SY in Mediterranean badland areas at different spatial scales (A) and to analyse the relationship between the study area and the area-specific sediment yield data.

Methods

A total of 55 studies carried out in Mediterranean environments were collected from different sources: i.e. international and national journals, PhD. theses, reports and through correspondence with researchers. Based on this information, a database of SY-measurements was constructed. For each recorded entry, the database contains the following data: reference, measurement locations (country, region, catchment, subcatchment, latitude and longitude), climate characteristics (mean annual precipitation and mean annual air temperature), measurement site details (lithology and land use), measurement techniques (erosion pins, detail topographic surveys, runoff plots, sediment transport at gauging stations or bathymetric surveys in reservoirs), measurement period (years), number of plot-year or catchment-year data, plot characteristics (type, length width, area and slope), catchment characteristics (area and mean slope gradient), specific sediment yield data (SY, t ha^{-1} y^{-1}) or erosion rate data (mm y^{-1}), bulk density (kg m^{-3}), and information on the dominant erosion processes.

Results

A database is currently compiled with 154 entries. The compiled database contains 16 565 plot- and catchment-year data on area-specific sediment yield (i.e. data collected at one plot or one catchment during one year) at 87 study sites in the Mediterranean area (Fig. 1). This includes the regions located in the transition from temperate to arid zones, from 30° to 45° latitude N, covering from West to East: Morocco, Spain, France, Italy, Tunisia, Albania, Greece, Turkey and Israel (Fig. 1). However, the distribution of the study areas over the countries is not homogenous; the highest number of study sites is recorded in Spain, France and Italy. Also, the largest fraction of data (in terms of plot- and catchment-year data) was measured in Spain, followed by France and Italy, where plot data predominate. For Albania, Greece, Israel, Morocco and Turkey only catchment studies were found. For Tunisia both plot and catchment data were found.

In general, all sites are affected by a Mediterranean climate; however, a high variability was observed. Mean annual precipitation ranges between 91 (arid conditions in Israel) and 1,246 mm (humid conditions in Scrivia, Italy) and mean annual air temperature varies between 3.3°C (in Southern Alps, France) and 18.6°C (in North Morocco). Relief usually is featured by steep slopes with slope gradients ranging between 30° and 45°. Badland development is associated with soft or unconsolidated geological materials, normally marls and clay rocks. Finally, the type of land use and vegetation cover vary greatly with spatial scale, from completely bare soils to a variety of mosaics with scrublands, rangeland, cultivated and abandoned fields and forested areas.

The sediment yield data discussed in this review were obtained by bathymetric surveys in reservoirs, sediment transport measurements at gauging stations, detailed topographic surveys, erosion pins and runoff plots. Figure 2 illustrates the distribution of the number of study sites, plot-year and catchment-year data for each measuring method. The data set comprises a large number of study sites from gauging station at catchment outlets (n = 34), erosion pins (n = 25), bathymetric surveys in reservoirs (n = 22), topographic surveys (n = 13) and runoff plots (n = 11). The dataset contains more than 13,000 plot-years of erosion pin measurements.

Figure 3 combines all data of area-specific sediment yield (SY, t ha^{-1} yr^{-1}) and drainage area (A, ha) in badland areas reported in the literature. Study areas in the database range between 0.000024 and 2,766,760 ha, while the area-specific SY varies between 0.16 t ha^{-1} yr^{-1} (registered in a large catchment in Turkey) and 4,300 t ha^{-1} yr^{-1} (registered in a small catchment in the SE Spain). A high SY-variability is

Fig. 1. Location of sediment yield measurement sites in the badlands: circle – topographic surveys; triangle upward – runoff plots; triangle downward- bathymetry (i.e. surveys in reservoirs); star – sediment yield at gauging station; rhombus – erosion pin at stations

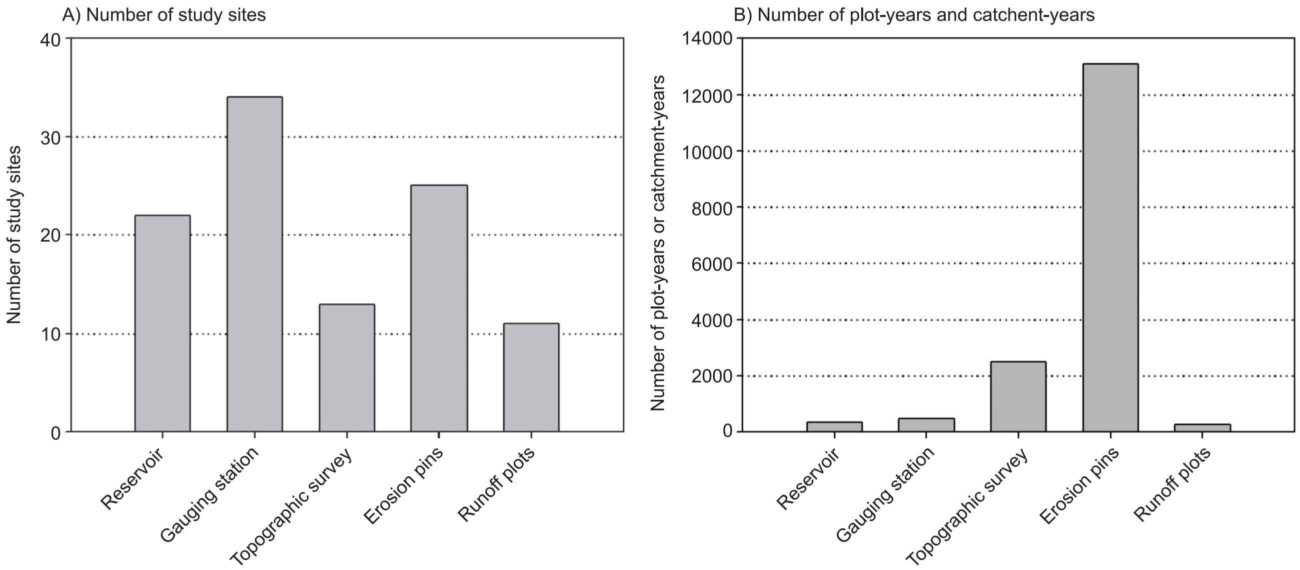

Fig. 2. Number of study sites (A) and plot-years and catchment-years (B) in relation to the methods used to collect SY data

observed in the different area-groups. Figure 3 shows that for areas ranging between 0.000024 and 10 ha, SY remains very high and constant (mean SY equals 475 t ha^{-1} yr^{-1} and median SY equals 193.8 t ha^{-1} yr^{-1}), whereas for areas > 10 ha, SY decreases (mean SY < 100 t ha^{-1} yr^{-1} and median SY equals 6.7 t ha^{-1} yr^{-1}).

Discussion and conclusions

In Mediterranean areas, sediment yield is higher than in other environments (Woodward 1995). But, there is still much uncertainty about the sediment yields in badland areas, although the database for these parameters is steadily increasing.

Several studies conducted in different environments, have investigated the relationships between SY and catchment area (Gögüs & Yener 1997, Poesen and Hooke 1997, García-Ruiz et al. 2004, de

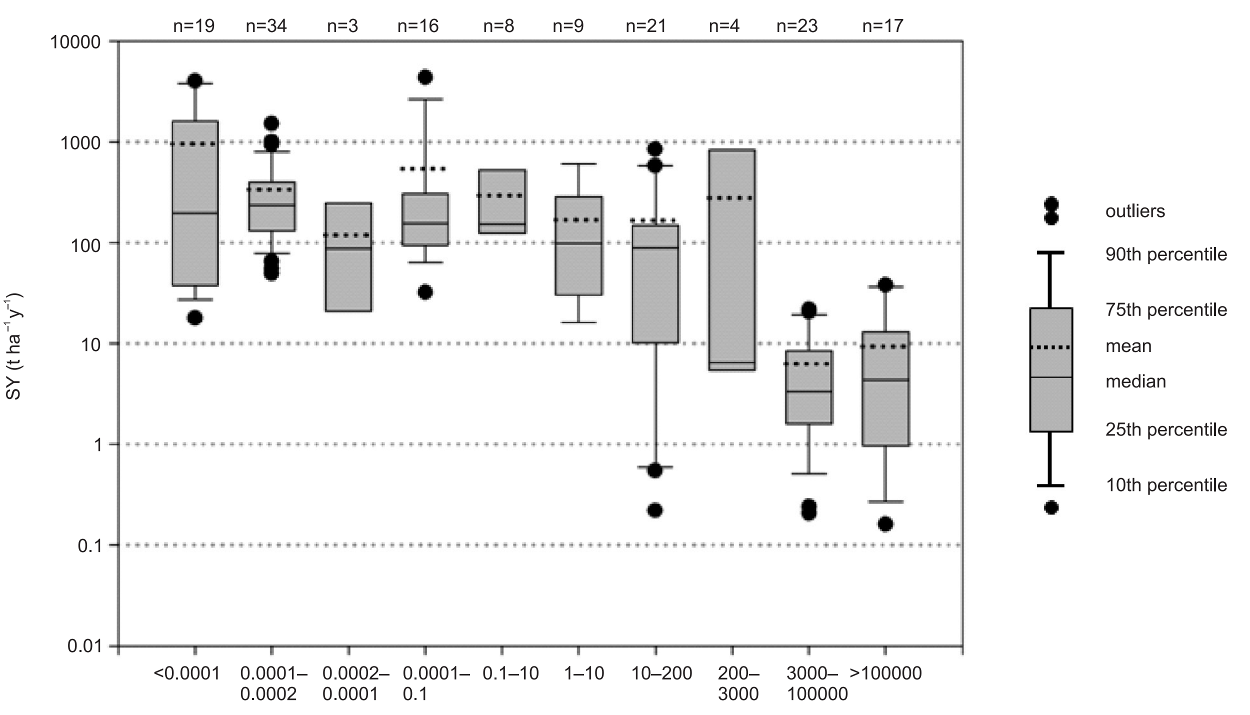

Fig 3. Box plot of area-specific sediment yield (SY) for Mediterranean badlands against drainage area (A). Boxes represent 25th-quartile and 75th-quartile of the distribution, dashes maximum and minimum values and point the outliers. For more information about the data you have to see Nadal-Romero et al. (in prep)

Vente & Poesen 2005, Beguería et al. 2007, de Vente et al. 2007, Vanmaercke et al. in prep.).

García-Ruiz et al. (2004) and Beguería et al. (2007) showed a positive relationship between catchment area and SY in Central Spanish Pyrenees and Gögüs & Yener (1997) showed a positive relationship in catchments larger than 100 km^2 in Turkey. For Mediterranean environments, de Vente & Poesen (2005) and de Vente et al. (2007) report that SY first increases with drainage area (*A*) due to the importance of other sediment sources (e.g. gullying, landsliding) and then decreases due to an increased probability of deposition. A complex and different A-SY relationship is identified in badland areas.

A high variability of sediment yield from badlands was observed. For intense gullied badlands, a complex A-SY relationship is identified: for areas ranging between 10^{-5} and 10 ha, SY is very high (mean SY equals 475 t ha^{-1} yr^{-1}), whereas for areas > 10 ha, SY decreases with increasing A (mean SY < 100 t ha^{-1} yr^{-1}). For areas < 10 ha there is little or no possibility for sediment storage within the badland areas and land use is more homogeneous compared to areas > 10 ha where catchments often consist of a mosaic of land uses and geomorphic units. For A > 10 ha, the SY decrease with increasing A is explained by the fact that, with increasing catchment area, progressively more sediment is trapped in footslopes, concavities, alluvial plains and other sinks, while erosion rates do not increase or even decrease due to decreasing average hillslope gradients. In addition, with increasing A, the probability of having vegetated badland slopes in south-facing slopes (Bochet et al. 2009) which produce little or no sediment increases.

The variability of SY will be further investigated in relation to drainage area, dominant geomorphic processes, annual rainfall, mean air temperature and erosion and sediment yield measuring technique (Nadal-Romero et al. in prep).

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