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An appraisal of the sediment yield in western Mediterranean river basins

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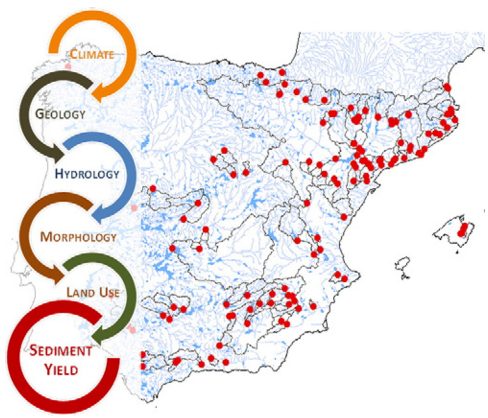
HIGHLIGHTS

- We used data on sediment yield and basin characteristics on the western Mediterranean.
- Area proved to be a limiting factor in the upper range of sediment yield values.
- Multiple regression using basin-scale variables analysis indicated model instability.
- Uncertainties prevent the use of the model in other regions.

GRAPHICAL ABSTRACT



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ABSTRACT

The number of studies assessing soil erosion and sediment transport has increased with the aim of achieving sustainable land and water management. Mediterranean rivers have been the object of many of these studies due to their naturally high values of sediment fluxes and a higher vulnerability under future climate scenarios. In this context, we attempt to use empirical relationships to (i) further assess the relation between sediment yield and basin scale and (ii) provide an update on the main drivers controlling sediment yield in these particular river systems. For this purpose, sediment yield data (from reservoir sedimentation surveys and sediment transport records) was collected from >100 locations distributed across the western Mediterranean area, with basin areas ranging from 1 to 100,000 km^2. Quantile Regression analysis was used to assess the correlation between basin area and sediment yield, while additional basin-scale descriptors were related to sediment yield by means of multiple regression analysis. Results showed the complexity in the relationship between basin scale and sediment yield, with changes in supply conditions with increasing area introducing uncertainties in the correlation. Despite the large scatter, analysis pointed towards the same direction and area appeared to be the main constrain for the maximum value of sediment yield that can be found at a specific basin scale. Results from the multiple regression indicated that variables representing basin's physiography, climate and land use were highly correlated with the basins' sediment yield. Also, a better model performance was obtained when using total sediment yield instead of specific values (per unit area). Validation showed model instability, potentially due to data limitations and the use of catchments with varying characteristics. Overall, despite providing some insights on the correlation between sediment yield and basin-scale characteristics, validation prevented direct extrapolation of the model to other catchments.

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1. Introduction

Soil is a fundamental natural system that carries out numerous ecosystem functions and services such as carbon sequestration, water regulation, habitat preservation/functioning, food provision, and fuel production (e.g. Constanza et al., 1997; Swinton et al., 2007). Erosion affects these functions through *on-site* and *off-site* impacts (Segarra et al., 1991). *On-site* impacts include soil degradation and subsequent loss of productivity (Pimentel, 2006); whereas *off-site* impacts carry an increase in drought susceptibility and flood risk (Robinson and Blackman, 1990), surplus of sedimentation in stream channels with associated effects on aquatic biota (Buendia et al., 2013), and loss of reservoir capacity due to siltation (e.g. Verstraeten et al., 2003; Navas et al., 2007; Palazón and Navas, 2014, Batalla and Vericat, 2011). In addition, sediment may transport soil-absorbed contaminants (e.g. Stone, 2000; Quesada et al., 2014). Hence, the transport of sediment throughout the watershed can cause environmental hazards to floodplains and water bodies (rivers, lakes and estuaries) and ultimately to coastal and marine environments (Westrich and Förstner, 2007). As a result, increasing attention has been paid to understand the main drivers of soil erosion and the subsequent sediment transport processes. However, soil erosion is not a recent environmental concern, but it was already reported in Antiquity. For example, Plato wrote about soil erosion at the Acropolis of Athens: "... the Acropolis was not as now [before Plato]. For the fact is that a single night of excessive rain washed away the earth and laid bare the rock..." Over time, numerous ancient ports at the mouths of rivers deteriorated economically or were even abandoned due to the accumulation of eroded material from the hinterland and the subsequent growth of deltas, as it was the case of Miletus and Ephesus on the coast of Asia Minor (Migón, 2013).

Despite the long-term concern of soil erosion and sediment production and transport, it has not been until relatively recently that studies are moving towards a sustainable management of land and water, for instance by considering the impact of land use changes on soil losses (Pacheco et al., 2014; Valle-Junior et al., 2014). One of the consequences of this new vision is the development of a myriad of models to quantify sediment loads in river basins (see de Vente et al., 2013 for a complete review). Advances in computer technology, remote sensing and geographic information systems (GIS) have contributed to significant progress of spatially distributed, process-based models. These models use grid structured information to describe soil erosion, considering their spatial variability within the basin (e.g. Schoorl and Veldkamp, 2001). They have proved useful in hydrology impact assessments (e.g. Praskievicz and Chang 2009, Bussi et al., 2014), but their ultimately application to sediment dynamics face three main drawbacks: first, the scarcity of measurements of erosion rates and, especially, sediment transport; while direct measurements are preferable, these are often difficult to obtain and data are scarce and disperse; second, deterministic models are usually data intensive and require long calibration and simulation times; and third, erosion processes depend on the selected hydrological model, and so inherent errors associated to their predictions (e.g. failing in reproducing, for instance, rainfall-runoff relationships), further propagate through the estimation of erosion and sediment transport processes (Rojas and Woolhiser, 2000; Wainwright and Parsons, 1998; Wainwright et al., 2008). Hence the use of these models at the catchment scale might be problematic, especially in large basins, where sediment deposition and transfer between landscape compartments operate at scales that models can hardly encompass (e.g. hundreds and thousands of years), and where human activities exert a large degree of control (e.g. reservoirs).

Because of these constraints, the use of regressions built upon empirical information from river basins is an alternative to identify the major drivers in sediment yield at the catchment scale. As such, empirical regressions may bring further insights on the relationships between sediment yield and catchment characteristics. These relationships can be also used to back model equations, to validate model results and to build more complex models. Regressions are the product of statistical analysis (e.g. based on stepwise linear regression) after the compilation of sediment yield data together with the associated catchment characteristics (e.g. morphology, topography, lithology, climate, discharge). Examples of such type of regressions can be found in Grauso et al., (2008) for rivers in Sicily, Haregeweyn et al. (2008) in Ethiopia, Verstraeten and Poesen (2001) in Belgium, and de Vente et al., (2011) in Spain.

Mediterranean basins are of particular interest, probably because they have been defined as highly vulnerable to global change (e.g. UNEP, 2006). They are characterised by displaying above average sediment yields (i.e. rivers may reach sediment yields above 200 t km^{-2} y^{-1}; Inbar 1992; Milliman, 2001). These high values are typically interpreted as a function of the strong seasonality of climate and hydrological regimes, the dominance of softer rocks, the presence of elevated mountain ranges close to the coast line (i.e. high gradients, short distances between catchment headwaters and the sea level), and the long history of human presence in the region (Conacher and Sala 1998). Also, the extensive anthropogenic intervention in the fluvial territory (i.e. damming, extensive agriculture and extension of urban areas) may result in a more intense disruption of the natural water and sediment fluxes than in other less arid regions of the world (Milly et al., 2005).

Understanding the response of sediment yields to global change in the Mediterranean region requires comprehending the variables controlling land erosion and subsequent sediment production and transport. Following previous studies (e.g. de Vente et al., 2011), we aim at further determining the main factors that drive sediment fluxes in western Mediterranean basins. We have therefore collected data on sediment yield at different locations across the region, including the 61 bathymetric surveys reviewed in de Vente et al., (2011), together with continuous sediment transport records found in the literature, adding up to more than one hundred locations. We have included a wide range of basin sizes (orders ranging from 1 to 100,000 km^2) given that basin area is an important factor controlling sediment yield (Walling, 1983; Dedkov, 2004). This data set provides a range of climatological, hydrological and morphological conditions to assess the sediment yield drivers in Mediterranean basins. Thus, the specific objectives of the paper are to: (i) Explore the relation between sediment yield and basin area in this climatic region; and (ii) Assess the relations between climate, basin characteristics, and sediment yield.

2. Methods

2.1. The database

The database comprises information on 116 locations across the western Mediterranean region, from the north of the Pyrenean Range (south of France) to the south of the Iberian Peninsula (Fig. 1). Sediment yield values were obtained from: (i) Sedimentation rates in 61 reservoirs in Spain, estimated from the volume of sediments retained in reservoirs using bathymetric surveys (Avendaño Salas et al., 1997a,b; Batalla and Vericat, 2011); and (ii) Sediment transport records available in the literature mostly for the Ebro basin, the Catalan Ranges, and the Pyrenean and Andalusian ranges (55 locations). The database included basin sizes from 1 to 85,000 km^2, with most of them (ca. 70%) ranging between 1000 and 10,000 km^2. Measurement periods varied from 1 to 89 years depending on the source of the data (i.e. sedimentation rates or sediment transport records). The longest periods are normally associated to sediment yields computed in reservoirs. Overall, Sediment Yield (hereafter *SY*) in the dataset varied between 3 and ca. 7,000,000 t y^{-1}, and the area-specific sediment yield (*SSY*) varied between 0.1 and 2800 t km^{-2} y^{-1}. Table 1 gives a description of the basic characteristics of each location, the source of information, as well as the time span of the available data.