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Review

Erosion in Mediterranean landscapes: Changes and future challenges

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ABSTRACT

Intense erosion processes are widespread in the Mediterranean region, and include sheet wash erosion, rilling, gullying, shallow landsliding, and the development of large and active badlands in both subhumid and semi-arid areas. This review analyses the main environmental and human features related to soil erosion processes, and the main factors that explain the extreme variability of factors influencing soil erosion, particularly recent land use changes. The importance of erosion in the Mediterranean is related to the long history of human activity in a region characterized by low levels of annual precipitation, the occurrence of intense rainstorms and long-lasting droughts, high evapotranspiration, the presence of steep slopes and the occurrence of recent tectonic activity, together with the recurrent use of fire, overgrazing and farming. These factors have resulted in a complex landscape in which intensification and abandonment, wealth and poverty can co-exist. The changing conditions of national and international markets and the evolution of population pressure are now the main drivers explaining land use changes, including farmland abandonment in mountain areas, the expansion of some subsidized crops to marginal lands, and the development of new terraces affected by landslides and intense soil erosion during extreme rainstorm events. The occurrence of human-related forest fires affecting thousands of hectares each year is a significant problem in both the northern and southern areas of the Mediterranean basin. Here, we highlight the rise of new scientific challenges in controlling the negative consequences of soil erosion in the Mediterranean region: 1) to reduce the effects and extent of forest fires, and restructure the spatial organization of abandoned landscapes; 2) to provide guidance for making the EU agricultural policy more adapted to the complexity and fragility of Mediterranean environments; 3) to develop field methods and models to improve the identification of runoff and sediment contributing areas; 4) to contribute to the conservation of landscapes (i.e. bench-terraced fields) having high cultural and productivity values; 5) to improve knowledge of the hydrological and geomorphological functioning of badlands, with the aim of reducing sediment yield and accessibility; 6) to better understand the effect of climate change on soil erosion in the Mediterranean region; and 7) to improve quantitative information on long-term soil erosion.

1. Introduction

Since at least the second half of the 19th century, erosion has been recognized as one of the most significant environmental problems worldwide (Bakker et al., 2007), particularly in areas having seasonally contrasted climate and a long history of human pressure. This is the case for the Mediterranean region, where concerns about soil loss and its consequences emerged as natural forests disappeared because of the expansion of livestock rearing, recurrent fires and the cultivation of steep slopes (López-Bermúdez, 2008). The landscape in many Mediterranean areas, especially in south-east Spain, Greece and northern Africa, suggests that the interaction between climate, topography, soil characteristics and human activity has led to short- and mid-term unsustainability. In addition, the development of a highly specialized flora and the emergence of a large number of endemic species make a return to natural conditions difficult following perturbation (Alados et al., 2011).

A recent review of European sediment yields demonstrated that Mediterranean rivers have higher yields than those in the rest of Europe, which has been attributed to climate, topography, lithology and land use (Vanmaercke et al., 2011). The presence of active badlands, gullies and eroded torrential headwaters, bedrock-exposed hillslopes, soil surfaces having abundant pebbles and cobbles, thin soils, rill and inter-rill erosion in cultivated fields, shallow landsliding, evidence of soil redistribution, overloaded streams and aggrading sedimentary structures is among the geomorphic problems that

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receive most attention from geomorphologists, agronomists and forest engineers. Nevertheless, in the Mediterranean region these problems occur in close proximity to areas that are very well preserved, with dense shrub or forest cover, complex soil conservation structures and the absence of water erosion. The co-existence in the Mediterranean region of areas of extremely high ecosystem productivity with areas showing dramatic soil erosion and degradation processes is directly or indirectly related to the ways in which human societies in the region have organized land management throughout history.

The study of soil erosion in the Mediterranean region is also the study of geomorphic extremes. The occurrence of extremely intense and high volume rainstorms, and the consequent floods, have few parallels in other areas of the temperate zone, and the erosion rates recorded in some badland areas are well beyond those in other parts of Europe. There are rarely intermediate conditions: many of the rivers are almost dry for most of the year, but periodically are subject to catastrophic floods that change the channel morphology, destroy bridges, and cause heavy loss in terms of human lives, houses and infrastructure (Poesen and Hooke, 1997; Belmonte and Beltrán, 2001; Wittenberg et al., 2007; Ortega and Garzón Heydt, 2009; Machado et al., 2011). Each landscape is a palimpsest, with features inherited from the activities of past cultures and remnants of geomorphic processes that partially determine the management of the land and its subsequent geomorphic processes. For this reason, complexity is another key Mediterranean characteristic. Thornes (2002) noted that one of the major difficulties in understanding and studying the Mediterranean region is that it has one of the world's most complicated landscapes, because of local variations in topography, soils and surface water conditions, which result in extremely rapid changes in soil depth, infiltration capacity, gradient, and plant cover characteristics. Very productive irrigated fields having flat or undulating relief contrast over distances as little as hundreds of metres or several kilometres with areas having steep slopes affected by various water erosion processes and shallow landslides, with a variety of plant communities. The presence of areas markedly disturbed by fires contrasts with areas where there has been expansion of natural vegetation following farmland abandonment (Hill et al., 2008). The simple difference between a shadowed and a sunny aspect on a small hill can be reflected in a dramatic change from a geomorphic and hydrological perspective. On other words, wealth and poverty are near. These factors explain the long-term and increasing interest of geomorphologists worldwide in studying soil erosion in the Mediterranean region: the enormous spatial and temporal variability, and the challenge of unravelling the various parts of the palimpsest. Understanding of many Mediterranean geomorphic processes has been aided by several seminal publications, particularly those of Brandt and Thornes (1996), Conacher and Sala (1998a), Mairota et al. (1998), Geeson et al. (2002) and Wainwright and Thornes (2004).

Here we provide a review of soil erosion problems in the Mediterranean region, and the knowledge gaps and challenges for the immediate future. The main objective was to provide a global perspective on the factors that explain the spatial diversity of erosion processes and the complexity of erosion landscapes, as a basis for identifying the most important gaps in information. We identified the main research areas studied and analysed the distribution of such studies throughout the Mediterranean, and the methods used. We then focused on: (i) the particular geomorphic-like characteristics that make the landscape so complex, and the occurrence of processes at various spatial scales; (ii) the key characteristics of soil erosion in the Mediterranean region (i.e. the contrast between intensification and abandonment); and (iii) the challenges for the future in addressing erosion in the Mediterranean region. The review is centred on countries adjacent to the Mediterranean Sea, and not on Mediterranean-type areas in California, central Chile, southern Australia and the Cape region of South Africa, although most of the problems discussed are common to these regions.

2. Erosion in the Mediterranean region: an overview of the literature

Soil erosion is one of the most intensively studied subjects in the Mediterranean region. A total of 670 papers in this area were identified using the ISI and Scopus databases. The information obtained enabled classification of the papers according to topic, country and methods. Within the Mediterranean region, the importance of soil erosion studies in Spain has been stressed by García-Ruiz (1999): soil erosion and hydromorphological studies, represented 16.8% of the total number of papers, and constituted a larger proportion than studies of more classical topics, including coastal geomorphology, glacial geomorphology, Quaternary deposits, karst, fluvial geomorphology, regional geomorphology, palaeoforms and structural geomorphology. The number of soil erosion and hydromorphological studies peaked during the 1990s, when they represented 22.7% of the total, suggesting recent recognition of soil erosion as a crucial environmental problem. Soil erosion studies have constituted a very substantial part of the recent evolution of geomorphology in other Mediterranean countries, although to a lesser extent than in Spain. Fig. 1 shows the distribution of soil erosion studies by country. Most of the studies published in SCI journals relate to Spain (380), followed by Italy (88), France (52 of relevance to Mediterranean France), Portugal (28), Israel (19), and Greece (17 papers). Together, the countries in North Africa account for 40 papers.

Fig. 2 shows that for the entire Mediterranean region, studies of badlands dominated (233), followed by studies on soil erosion related to agriculture (soil erosion in various crops or under different tillage techniques: 119 papers). The other research areas are also relevant for geomorphologists, although they remain far from the first two topics: the relationships between vegetation and erosion, including deforestation and afforestation (100 papers), erosion after forest fires (74), soil erosion modelling (50), the role of extreme events (47), the consequences of farmland abandonment (42), reservoir silting (27), and the connectivity between hillslopes and channels (12). The evolution of the major topics is represented in Fig. 3, which shows a remarkable increase since 1990. The first increase occurred in studies of badlands, which accounted for the greatest number of studies each year. Papers on the effects of agriculture increased after 1995, with a new pulse evident after 2003, and studies on the consequences of farmland abandonment increased after 2005. Positive temporal trends are also evident for the remaining topics, although these have not been as consistent as for the studies of badlands and agriculture.

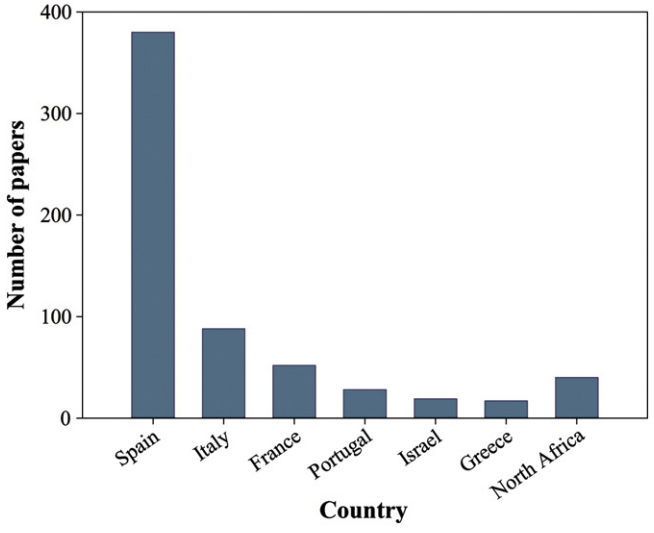

Fig. 1. Distribution of soil erosion studies by country.