Methods and scales in soil erosion studies in Spain: problems and perspectives

José M. García-Ruiz

Instituto Pirenaico de Ecología, CSIC, Campus de Aula Dei, Apartado 13034, 50.080-Zaragoza, Spain. humberto@ipe.csic.es

ABSTRACT
Soil erosion is a major problem in some areas of Spain. Research groups have studied a variety of aspects of this problem in different environments, and at a range of scales using a diversity of methods, from piquettes and rainfall simulation to experimental plots, catchments and large regional areas. This has increased knowledge and identified the main problems: farmland abandonment, badland erosion, the effects of land use changes, and the role of extreme events and erosion in certain crops (particularly vineyards). However, comparison of results among various research groups has been difficult, posing problems in developing solutions from State and Regional administrators. The main problems arise from the use of differing scales, methods and study periods. Each scale is useful in analysis of a particular erosion process, but results obtained at small scales can not be easily upscaled. For instance, experimental plots can provide information on relationships among precipitation, runoff and sediment yield under different land uses, but no on rill or gully erosion, or sediment transfer to fluvial channels. In addition, the extreme interannual variability of Mediterranean precipitation makes it difficult to (i) compare erosion data from different periods, and (ii) elaborate comparable sediment balances. Soil erosion is a global problem with very complex causes, and potential solutions have political and social implications, and necessitate major changes in land management. Among issues involved, the effects of the changing policy on subsidies in the European Community, the consequences of local activities, the effects on soil erosion of changes in plant cover, the identification of eroded areas and their connectivity with the fluvial network, and the interrelations between the various sub-systems at a catchment scale. These issues require approaches at catchment or large basin scales, with finer scales (rainfall simulations, experimental plots) to address particular problems.

Key words: Soil erosion, Rainfall simulation, Experimental plots, Experimental catchments, Upscalling, Spatial scales, Temporal scales, Spain.

1. INTRODUCTION

Soil erosion studies in Spain underwent a major increase after 1981 and particularly during the decade 1991-2000 (García-Ruiz, 1999). This coincided with a change in focus of geomorphology studies in Spain to a more environmental perspective, driven particularly by consolidation of the Commission of Experimental Geomorphology (IGU) at the beginning of the 1980's, and increasing awareness of the effects of human activity on landscape functioning and transformation (Goudie, 1986). From 1983 a number of Spanish geomorphologists devoted much effort to studies of the consequences of land use changes, the characteristics of the Mediterranean environment, and the effect of climate change on the development of badlands, reservoir silting and soil degradation. The creation of the Spanish Society of Geomorphology (SEG) in 1987 enhanced soil erosion studies, which were published primarily in the proceedings of the biennial national meetings of the SEG (a total of 195 papers on soil erosion from 1990 to 2008, that is, 23.4% of the total) and the journal *Cuaternario & Geomorfología* (44 papers since 1987, i.e., 14.2% of the total) (García-Ruiz, 2008). Geomorphologists from outside Spain have also been encouraged to undertake soil erosion studies in Spain, applying new techniques, methods and perspectives. Among geomorphology papers included in the reference list of the recent book on *Soil Erosion in Spain* (García-Ruiz and López-Bermúdez, in press), 49 were authored by non-Spanish researchers, and 21 more involved collaboration between non-Spanish and Spanish scientists. An analysis of that reference list confirms the ongoing publication of research by Spanish geomorphologists in international (SCI) journals, including *Catena, Geomorphology, Journal of Hydrology, Zeitschrift für Geomorphology, Earth Surface Processes and Landforms, Land Degradation and Development, Mountain Research and Development, Hydrological Processes,* and *Agriculture, Ecosystems & Environment*.

The total number of papers on soil erosion studies in Spain exceeds 500, and some of the Spanish geomorphologists are internationally recognized. Spanish laboratories, field experimental stations and research catchments) provide the opportunity for young scientists to work in consolidated research groups with sound infrastructures. Figure 1 shows the distribution of Spanish groups studying soil erosion and sediment transport in both universities and research institutions, differentiating consolidated and emergent groups (García-Ruiz and López-Bermúdez, in press). A large proportion of the groups are concentrated in Barcelona, Zaragoza, Valencia, Murcia, Almería and Madrid, coinciding with areas that have important soil erosion problems, and also reflecting the historical development of studies in geomorphology.

Several questions arise from a comprehensive review of papers published on soil erosion in Spain. As it occurs in soil erosion studies worldwide, methods and scales (both temporal and spatial) vary markedly. This makes comparison of results very difficult, particularly because much data obtained in the field depends very heavily on the scale and methods used. In this context, to what extent are we in the right way? Are the diversity of methods and scales contributing to improved knowledge of soil erosion, such that the main challenges in reducing soil erosion and reclaiming degraded landscapes can be addressed? Are we prepared fort future land use changes and the possible effects of climate change on rainfall intensity, soil humidity and plant cover evolution? Are soil erosion studies in Spain cutting-edge, or have they become repetitive in recent years. Producing few original results? Are we sure there is a good correlation between objectives, methods and scales? Do we have a global perspective of the problem or is the focus too localized? The main purpose of this paper is to address these questions by analyzing soil erosion studies in Spain from a variety of aspects including the diversity of topics studied, the various spatial and temporal scales investigated, and the range of methods used.

2. THE STUDY TOPICS AND THEIR SPATIAL VARIABILITY

The enormous environmental variability of Spain influences the soil erosion topics studied and the climatic and lithological conditions of the study areas. The badlands are a major study focus, due to their dramatic landscapes, their consequences for sediment transport (including reservoir silting), and the rapid evolution of hillslopes and channels, which provide the opportunity for studying short-term weathering, soil erosion and sediment transport. The badlands have been studied studied in sub-humid environments, including the eastern and central Pyrenees (Regüés *et al*., 1995; Nadal-Romero *et al*., 2008), in semi-arid environments, particularly southeastern Spain (Cantón *et al*., 2001), in the Central Ebro Depression (Benito *et al*., 1993) and in Valencia (Alexander and Calvo, 1990; Cerdà and García-Fayos, 1997). The results confirm (i) the greater activity of sub-humid badlands, where contrasts in both temperature and humidity result in more intense weathering, (ii) the extreme dependence of badlands on certain lithologies (particularly lutites and marls), and (iii) the occurrence of lags among weathering, soil erosion and sediment transport processes, such that erosion mainly occurs in spring, after the preparation of the material in winter.

Other studied aspects of soil erosion have been directly related to land use-land cover changes. These include the effects of farmland abandonment, the consequences of reforestation, the erosive and hydrological functioning of different plant covers, and soil erosion under different crops (particularly dry farming of cereals, vineyards, and olive groves and almond tree orchards), and on irrigated lands. Studies of farmland abandonment have been carried out on both sloping and terraced fields in mountain areas (central Pyrenees, northwest Iberian Range) (Ruiz-Flaño *et al*., 1992; Llorens *et al*., 1992; Ruiz-Flaño, 1993; Lasanta *et al*., 2001), and in southeast Spain (Lesschen *et al*., 2007 and 2008; Romero-Díaz *et al*., 2007). Reforestation has also been studied in the Pyrenees (Ortigosa *et al*., 1990), the Iberian Range (Ortigosa, 1991) and southeast Spain (Romero-Díaz and Belmonte-Serrato, 2008), in humid, sub-humid and semi-arid environments. Studies of plant cover effects in the Pyrenees, Valencia, Murcia and Andalusia have included comparisons of soil erosion rates and runoff from differing densities of vegetation, plant cover structures and different types of vegetation. It is noteworthy that some studies have demonstrated the importance of plant architecture and spatial organization in explaining the different hydromorphological behaviors of shrub communities (Puigdefábregas *et al*., 1996; Puigdefábregas, 2005). Plant cover density is a major explainatory factor, particularly if bare soil is compared with shrub plant cover in experimental plots. Soil erosion after forest fires has also been a major area of study, mainly in Galicia (Soto and Díaz-Fierros, 1998), Catalonia (Úbeda *et al*., 2006) and Valencia (Rubio et al., 1997); however, long-term studies are needed to assess plant recovery and the role of recurring fires.

Increasingly, studies have focused on soil erosion under varying land uses. Such studies are gaining importance, because soil erosion threatens short-term and long-term crop productivity, and in some cases has led to farmland abandonment and in others to increased chemical fertilizers. The problem is particularly severe in vineyards, due to the low plant cover (and thus soil protection) during most of the year, and the fact that cultivation frequently occurs on steep slopes (e.g. in northwest Spain, La Rioja and Catalonia) (Martínez-Casasnocas and Sánchez-Bosch, 2000; Ramos and Martínez-Casasnovas, 2006; Arnáez *et al*., 2007; Casalí *et al*., 2009). This problem has extended to olive groves and almond tree orchards in recent few years (Gómez *et al*., 1999; Van Wesemael *et al*., 2006), as these crops occupy progressively marginal lands due to subsidies under the European Agrarian Policy. For dry farming of cereals, which is a practive that has been less studied than is warranted on the basis of its extent, the main aspects studied have been the effects of extreme events and tillage practices (De Alba *et al*., 2003). Finally, irrigated areas have been studied primarily because they are very important non-point sources of pollution by effluents loaded with salt and fertilizers. The new irrigated lands in the Ebro Depression have been a particular focus of study (Lasanta *et al*., 2001b; Causapé *et al*., 2004). Extreme environments (e.g. forest tracks, mining slag heaps) have also been incorporated into soil erosion studies in recent years (Nicolau, 2003; Arnáez *et al*., 2004).

In summary, soil erosion studies have addressed most of the natural and disturbed environments in Spain, including the high mountains (the Izas catchment, in the Pyrenees), the semi-arid environments of Murcia and Almería, the middle and low mountains, and the lowlands. Cultivated lands, abandoned fields and semi-natural shrubs and forests have also been investigated. The areas near the Mediterranean coast, the Ebro Depression, the Pyrenees and Galicia have been most intensively studied.

Figure 1: Distribution of the main soil erosion research (consolidated and emergent) groups in Spain.

3. FROM EROSION PIQUETTES AND RAINFALL SIMULATION TO LARGE BASINS

Soil erosion studies in Spain have been carried out at varying spatial scales, related to the techniques used in the field. This is important as the results obtained are in general only valid for those scales, and are not be applicable at other scales (Ceballos *et al*., 1996; Puigdefábregas *et al*., 1999; Boix-Fayos *et al*., 2006; Beguería *et al*., 2007). It has also been recognized that the methods and scales selected have typically been determined by the availability of financial and manpower resources, and not by the problem being studied; this was particularly true during the 1980's, when most of the research groups were small. As a consequence, the methods and scales used by the large and small research groups have differed, with the former being able to integrate different scales and to work with a regional perspective, whereas the smaller groups have tended to work at finer scales.

Erosion piquettes have typically been used in badland areas for studying spatial differences in soil erosion rates over short distances, comparing, for instance, erosion in rill and inter-rill areas (Benito *et al*., 1993). This has been possible because of the high erosion rates in badlands, which allow the estimation of erosion with a relatively low margin of error. Data from piquettes were complemented with micro-topographic profilers, to study the seasonal evolution of rills (Sancho et al., 1991; Benito *et al*.,1993)

(Figure 2). A larger version of the profiler was used to estimate bedload transport at an experimental catchment scale (Lana-Renault and Regüés, 2007).

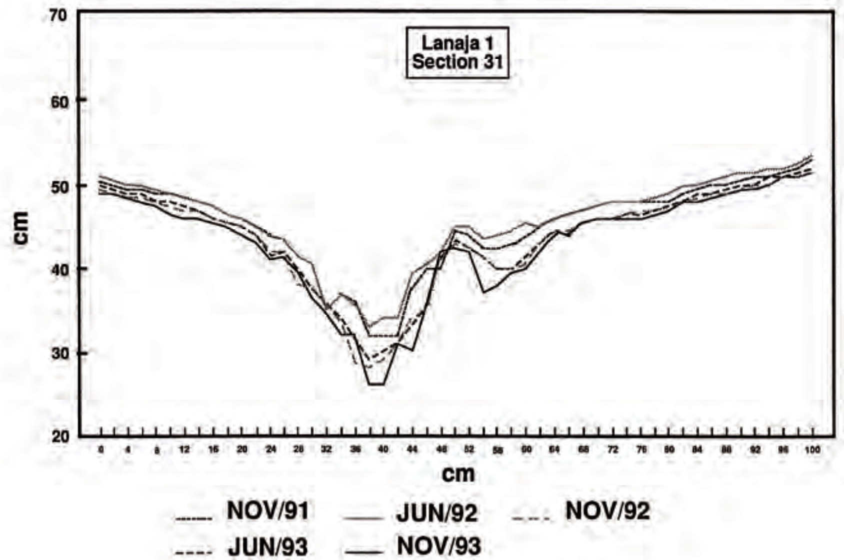

Figure 2: Rill evolution at the Lanaja experimental station using a micro-profiler. (Source: Benito *et al*., 1991).

One of the most successful techniques used has been rainfall simulation, which has been applied in environments ranging from cultivated fields and shrubs to badlands (Calvo *et al*., 1988; Cerdà, 1999). The generalized use of rainfall simulation relies on: (i) maintaining the same rainfall intensity and duration in different tests; (ii) the relatively low cost of the infrastructure; (iii) the facilities used in varying environments; and (iv) the potential for use under different seasonal conditions (i.e. with different soil humidity or plant cover development), or after an extraordinary event, such as a forest fire. The latter need to be studied for a long time to analyze the evolution of various soil parameters, soil erosion and runoff. For this reason, rainfall simulation has been widely used in soil erosion studies, including those into possible effects of climate change on plant cover, soil erosion and runoff at a regional scale. Nevertheless, it is important to note that (i) rainfall simulation applies only to a very small area (in general, less than 0.5 m^2), (ii) the surface characteristics are markedly affected by the placement of the simulation ring, and (iii) only splash processes really occur in the simulated area, making it impossible to reproduce sheet wash, rill or gully erosion. These disadvantages reduce the usefulness of rainfall simulation, and influence the results and conclusions. In particular, it is surprising that in some cases erosion rates and runoff coefficients have been published for different environments, and it is questionable whether these erosion rates have any significance.

Experimental micro-plots, plots and stations have been used in Spain since the 1980's for comparison of different plant coverc and land uses. Most of the plots have been closed, drained well-delimited areas (in general less than 30 m^2), and used varying equipment connected to data loggers for controlling runoff and sediment transport (Gerlach boxes, tipping buckets, divisors, deposits for runoff). In some cases plots have been grouped at experimental stations (La Concordia, Aísa Valley, El Ardal, Abanilla, Rambla Honda, El Teularet-Sierra de Enguera, Lanaja, Las Bardenas, Mediana de Aragón, La Puebla de Alfindén, Albaladejito, Marchamalo, El Encín), and have supplied good comparative information for some years, although the relatively small size of the plots and the disturbance involved in their use means that the resulting data need to be analyzed with caution (López-Bermúdez *et al*., 1993). Boix-Fayos *et al*. (2006, 2007) studied the temporal and spatial variability of results from 30 m^2 plots in the Sierra de Picarcho, Murcia. They concluded that (i) sediment exhaustion occurred after four years of experimentation, resulting in an increase of the rainfall thresholds necessary to yield erosion; (ii) differing distributions of plant cover, bare soil and stones within each plot can lead to different results from apparently similar plots (Puigdefábregas, 2005), resulting in estimates of soil loss that differ up to nine-fold due to the differing patterns of certain superficial features (Boix-Fayos *et al*., 2007); and (iii) the size of the plot also influences the quality of the results, making comparisons amongexperiments from different research groups difficult or impossible. Boix-Fayos *et al*. (2006) also concluded that larger plots better represent the heterogeneity of natural or cultivated environments, and argued that it is not possible to extrapolate results on erosion and sediment yield from experimental plots to catchments. For this reason experimental plots are only useful for certain purposes, particularly the testing of some hydrological and geomorphological parameters, and for comparison of different plant cover densities or land uses, as is the case for the Aísa Valley Experimental Station (García-Ruiz *et al*., 1995). Experimental plots can-not reproduce water fluxes, the connectivities of hillslopes, the development of rills and gullies, or the long-term sediment stores at the foot of versants or in alluvial fans. Nevertheless, experimental plots have made significant contribution to improving understanding of runoff generation processes in different environments of Spain.

The progressive consolidation of research groups and the increasing complexity of the aspects of soil erosion studies have resulted in the development of experimental catchments, between 30 and 300 ha in size. Studies of experimental catchments in Spain started in the second half of 1980’s in both the eastern (Vallcebre, upper Llobregat) and the central Pyrenees (Izas). Additional catchments were subsequently monitored in southeast Spain (Sierra de Picarcho in Murcia, Petrer in Alicante, and El Cautivo in Almería), central Pyrenees (Arnás, San Salvador and Araguás), southwest Spain (Guadalperalón and Parapuños, in Extremadura), western Spain (Rinconada, Morille and Villamor in Salamanca), Navarre (Latxaga, La Tejería and Oskotz-Muskitz) and the Basque Country (Aixola, Barrendiola and Añarbe). Nested catchments are located in Vallcebre, Araguás and El Cautivo. These catchments represent very varied environments, from largely undisturbed forests to intensively degraded badlands, cultivated lands, abandoned farmlands in middle mountain environments, and extensive livestock systems in open forests *(dehesas)*. The experimental catchments are equipped with weather stations, flumes, and instruments for continuously measuring discharge, suspended sediment concentration, solute concentration and, in some cases, bedload. More recently, rainfall interception, water table oscillations and soil humidity have also been studied, as have the main soil, plant cover and relief characteristics. The temporal and spatial variability of runoff and sediment sources have been analyzed in only a few catchments (Vallcebre, Arnás).

Experimental catchments tend to be relatively homogeneous environments (forests, crops, abandoned lands, semi-arid shrubs, sub-alpine grasslands), and for this reason they provide information on the hydrological and sediment transport functioning of such environments, which enables sediment budgets and balances to be developed, and sediment and runoff sources to be identified. Experimental catchments can also be used to define the factors that govern runoff and erosion responses under varying precipitation conditions, including the role of soil humidity, water table fluctuations, the spatial and temporal variability of runoff and sediment generation, and the temporal variability in sediment carried by the fluvial channel (García-Ruiz and Gallart, 1997). They thus allow facilitate understanding of how the system works, by integrating information from hillslopes and channels, and providing the potential to hydrological models to predict the effects of climate or land cover changes on both discharge and sediment transport. In some cases, rainfall simulation tests and experimental plots within catchments have improved knowledge of certain soil erosion aspects. Nevertheless, the measurements of parameters have varied from experimental catchment to another, as has the treatment of the information, such that comparison of information from different catchments is problematic. For instance, some catchments are viewed as “black boxes” in which inputs (precipitation) and outputs (runoff, sediment) are studied. In others the internal processes are intensively studied, particularly the spatial and temporal organization of water within the soil. The study period and the temporal length of the datasets differ markedly amongst catchments, a problem that is particularly important in Mediterranean environments, and the complexity and intensity of the studies is related to the size and continuity of the research groups involved, even at catchment scales.

Finally, some research groups have undertaken hydrological and geomorphological studies at a regional scale, through investigations of large basins covering hundreds or thousands of square kilometers. In such cases there is a complete change in focus: the main aspects studied include the evolution of streamflow in relation to climate and land cover changes (Beguería *et al*., 2003), and the location of eroded areas and their connectivity with fluvial channels (Beguería, 2005), typically based on remote sensing, GIS and discharge data from gauging stations. Sedimentation in reservoirs has also been used to estimate erosion rates (Poesen and Hooke, 1997), or to study the evolution of erosion and sediment transport (Valero *et al*., 1998). This approach is absolutely necessary, but it rarely considers information obtained at more detailed scales, particularly when reservoir silting is studied.

4. FROM INDIVIDUAL EVENTS TO LONG TEMPORAL RECORDS

One of the most important problems in experimental hydrology and geomorphology studies is discontinuities in data series and the short duration of such series. Data discontinuities are normal for extreme events, which are studied to explain the erosion associated with the most intense Mediterranean rainfall events. This provided the rationale for studying the Biescas disaster in the central Pyrenees, which occurred in August 1996 (White *et al*., 1997; Gutiérrez *et al*., 1998; Benito *et al*., 1998; Alcoverro *et al*., 1999), the large flood in November 1982 in the eastern Pyrenees (Clotet *et al*., 1989), the Rivillas Ravine (Badaloz) flood, in November 1997 (Ortega-Becerril and Garzón, 2006), and intense rainstorms that affect cultivated fields (De Alba *et al*., 2003; Martínez-Casasnovas *et al*., 2002). Rainfall simulations can also be considered as individual events, because they are used sporadically for certain purposes. However, in the case of experimental plots and catchments, a long monitoring period is needed to gather information on the temporal (both seasonal and interannual) variability of runoff, erosion and sediment transport. It is important to note that Mediterranean precipitation is subject to extreme fluctuations at different temporal scales, and that inadequate monitoring can markedly reduce the quality of the information obtained. For instance, it is possible to calculate sediment balances (average annual sediment carried out each year, and the proportion of each type of sediment in the annual balance) after three or four years of monitoring of an experimental catchment; however this information must be considered provisional, given the important influence of extreme rainfall and hydrological events on sediment transport. Monitoring over a long time period enables data to be gathered from events of different intensity that have occurred under varying conditions of soil humidity. Consequently, the comparison of results from different research groups studying plots and catchments in different areas and groups can be problematic, depending on the coincidence of the study period and the occurrence of more or less intense rainfall events. In the case of experimental plots there is the added problem that some plots can show signs of sediment exhaustion after a few years of functioning (Boix-Fayos *et al*., 2006), thus reducing the significance of the results for comparative purposes.

The longest data series from experimental catchments in Spain come from the Vallcebre (eastern Pyrenees) and Izas (central Pyrenees) catchments, with more than 20 years. Data for 15 years are available for the Arnás catchment, but from other catchments the datasets do not exceed 5-10 years. In addition, data for some years, months or individual events have been lost due to failure of field instruments (e.g. the Arnás catchment), or the lack of manpower. Catchments have different histories, problems, and consistency of data collection. Instrument reliability functioning has varied among catchments during parallel data collection periods, and complete monitoring has not always been possible from the beginning of experimentation. Typically, installation of instrumentation has been intermittent, and governed by a complexity of factors related to the availability of manpower and financial resources.

Tus, the temporal scale of studies on soil erosion in Spain has varied from the event scale to datasets of up to 20 years, with little coincidence among the periods, the instruments and the parameters studied. The commencement of the RESEL (Network of Experimental Stations for the Study of Soil Erosion in Spain), driven by the Spanish Ministry of Environment (Rojo-Serrano and Sánchez-Fuster, 1997), has somewhat mitigated this problem, although it is far from being solved.

5. A GLOBAL DISCUSSION ON SOIL EROSION STUDIES IN SPAIN: CHALLENGES FOR THE FUTURE

Studies on soil erosion in Mediterranean countries underwent significant growth during the 1980's, and many research groups formed and projects developed particularly in Spain but also in Israel, France and Italy and, to a lesser extent, in Greece, Turkey and North Africa. However, signs of stagnation are increasingly evident. Specialists have been able to analyze the processes in detail, deepening understanding of soil and rain drop characteristics, and improving field and laboratory instruments, but our understanding of soil erosion as a global process is improving only slowly: the body of knowledge is basically the same as it was 20 years ago. Some mistakes in the past continue to be made (e.g. the use of erosion rates, the comparison of results from different methods, scales, and dates), and a holistic approach is increasingly needed to understand the spatial and temporal organization of soil erosion and sediment delivery problems. The importance of both empirical and simulation approaches to the problem of erosion and sediment transport is now known, but efforts are needed to link the processes acting at various temporal and spatial scales. This will allow us to address uncertainties such as the relative importance of climate and land use practices on soil erosion, and to evaluate global change scenarios for the purpose of land planning.

A review of the scientific literature in the field of soil erosion (García-Ruiz and López-Bermúdez, in press) has demonstrated that (i) a number of research groups exist among different institutions, and have access to a variety of field infrastructure, (ii) these groups are producing important results, and their publication output is amongst the best in the world, and (iii) the factors that explain soil erosion in Spain have been adequately identified and ranked. Nevertheless, a new conceptual and methodological approach is needed to efficiently provide short- and long-term technical, economic, social and environmental solutions. For instance, it is not necessary to use experimental plots or rainfall simulations to demonstrate the close relationship between plant cover density and soil erosion, or the occurrence of higher erosion rates from bare soil than soil protected by vegetation.

At a time most Spanish environments (from high mountain to semi-arid regions, and forests to cultivated lands) are being studied and the main issues addressed, it is timely to question (i) whether our focus is correct from methodological and conceptual viewpoints, and (ii) if we will be able to solve the main soil erosion problems in a sustainable manner and at relatively low cost. Three main problems arise as challenges for the future:

(i) The need to consolidate research groups to ensure continuity of information from each experimental station and catchment. Scientific research on soil erosion requires a long term approach, and consolidated groups can provide the necessary field and laboratory equipment. The fact that relatively strong groups exist has been the result of individual efforts that have not been sufficiently valued by public administrations and academic institutions. Monitoring activities and maintance of an experimental station or a network of experimental catchments requires a great personal effort and continuity of financial and manpower resources. Interruption in the collection of field data, even if only brief, can represent the loss of high value data, and in some cases can undermine the research. Soil erosion and runoff generation need to be acknowledged by the State Administration as major problems requiring a long-term scientific and technical policy.

(ii) The use of different methods and scales is one of the most important scientific problems in soil erosion studies. It is evident that different methods and scales are needed, but it is necessary to identify those methods and scales most appropriate for addressing particular research questions. At present it seems that the selection of methods is driven more by the availability of financial resources and manpower than by the scientific problem needing to be solved. For this reason rainfall simulations have generally been used, because they do not involve regular and ongoing continuity of field data collection, or the maintenance of the field equipment. Rainfall simulations can be performed intermittently, under the best climatic conditions, and with almost no restrictions. Although difficult work, it yields immediate results from any land cover, altitude, gradient or aspect. Micro-plots have also frequently been used because of their very low cost, but have been largely substituted by larger plots and stations.

It is important to take into account that erosion processes are scale-dependent, i.e. each process tends to act at a given scale, and consequently each scale provides information about a limited range of erosion processes. Thus, the study objecvtives determine the scale to be used. Thus, rainfall simulations do not really provide information about overland flow and sheet wash erosion. Runoff in the small area of the test plots used (generally less than 0.5 m^2) does not generate sufficient power to detach soil particles or develop small rills, as occurs under natural conditions. Rainfall simulations are useful for assessing the tendency of soil to be removed by rainsplash, infiltration capacity, and the velocity necessary to yield surface runoff. As such they provide very interesting and necessary hydromorphological results, providing theyare consistent with respect to rainfall intensity and raindrop size.

In experimental plots, the processes studied are clearly affected by the area of the plot and its border. Plots provide useful information on sediment transport by sheet wash erosion, and on the relationships between rainfall and runoff under different plant covers. Nevertheless, they do not reproduce the complex processes of runoff and sediment transfert at a hillslope scale; under natural conditions soil particles can re-sediment as a consequence of slope changes or a greater density of plant cover. For this reason Boix-Fayos *et al*. (2006) stressed the difficulties in extrapolating data from small plots to large areas (experimental catchments). A linear upscaling from one scale to another is unreliable, given that soil erosion involves many non-linear processes. Experimental plots also tend to be homogeneous, whereas catchments are essentially heterogeneous, with variability in gradient, aspect, soil types and plant cover.

At an experimental catchment scale all erosion, sedimentation and sediment transport processes can be considered as a whole. Overland flow has sufficient power to produce rills, gullies and mass movements on the hillslopes, and the topography is heterogeneous enough to generate temporal sediment storages on both the hillslopes and the alluvial plain. The runoff and soil erosion processes in a catchment are very different from those on the slopes, reflecting natural hydromorphological functioning. For this reason catchments are better than other experimental scales for (i) determining sediment balances and budgets, (ii) studying of interactions between erosion on the hillslopes and sediment transport in the channels, and (iii) analyzing the spatial and temporal variability of runoff and areas contributing sediment (including mass movements and sediment from the alluvial plain) during events of varying magnitude and duration (Wainwright and Thornes, 2004).
Where soil erosion studies involve hundreds or thousands of square kilometers, erosion and hydrological processes can-not be studied in detail. In such cases, the use of remote sensing and models such as USLE enable the mapping of soil erosion "intensity", and can provide information about the most eroded areas and the areas most susceptible to sediment generation. Bathymetry in reservoirs does not provide information on soil erosion processes in the basin, but aids in quantification of sediment transport. Thus, studies at regional scales are not typically focused on the processes.

It is evident that the choice of scale depends on the scientific questions. This relationship can be summarized as follows: (i) Rainfall simulations: What are the main differences in infiltration rates, wetting front and runoff under different plant covers? (ii) Experimental plots: What are the relationships between rainfall, runoff and sediment yield under different land uses and land covers? What will be the trend in runoff and soil erosion under certain land use changes? What is the evolution of runoff and sediment yield after farmland abandonment or a forest fire? (iii) Experimental catchments: How do areas contributing runoff and sediment vary with the characteristics of the rainstorm event and the preceding soil humidity conditions? What is the role of temporal sediment storage? What is the relationship between runoff and suspended sediment concentration during individual rainstorm events? Where does the sediment come from? What is the effect of rainstorm events of different magnitude on the annual and interannual sediment balance? What are the hydrological and geomorphological consequences of different land covers at the catchment scale? What is the effect of different types of sediment (bedload, suspended sediment and solutes) on the annual and interannual sediment balance, and how do they vary from year to year? What is the role of the fluvial channel and taluses in storing and delivering sediment? (iv) Regional scale: Which areas are most likely to yield sediment? What is the relationship between eroded areas and those contributing sediment to the fluvial channels? Which basins have the highest sediment load? How do eroded areas evolve in relation to the evolution of plant cover (farmland abandonment, decreasing livestock pressure)?

From the previous discussion and the questions that need to be answered, it could be interpreted that the detailed scales (rainfall simulations, experimental plots) should be abandoned in future studies, in preference to concentrated efforts based on experimental catchments and regional studies. This is not the case; detailed scales should be increasingly integrated into the larger scales, to provide information on the spatial variability of various hydrological parameters. Rainfall simulations could help to identify runoff and sediment sources at the catchment scale, and experimental plots could clarify relationships among rainfall, runoff and sediment yield under different plant covers within a catchment. In some cases, experimental plots outside catchments will be still necessary to study particular erosion problems. Such studies may include the evolution of soil, plant cover, runoff and sediment yield after a forest fire; the hydromorphological behavior of different types of shrubs for land reclamation purposes; the consequences of adding urban refuse to degraded soils; or soil erosion under different types of crop management (e.g. tillage, crop rotations, various fertilizers). These problems are, in general, more agronomic geomorphological.

(iii) The issue of scales in geomorphology leads to another important problem: the reliability of erosion rate estimates. If each method and scale provides information about specific processes, it is clear that any resulting data on erosion and sediment transport will be related to those processes. It follows that if erosion rates vary from scale to scale, it is absolutely unreliable to compare erosion rates among scales. Despite this, the geomorphology literature is full of reports on erosion rates from, for instance, rainfall simulation tests and experimental plots. Unfortunately, erosion rates determined from rainfall simulations are meaningless, and can-not be compared with erosion data from piquettes, plots or catchments, or even with other rainfall simulation experiments, given the variable intensities used in rainfall simulators and the varying prior soil humidity conditions. A progressive decrease in water and sediment yield is usually expected when moving from small to large study areas (Figure 3) (Thornes, 1999; De Vente and Poesen, 2005). In general, for a similar erosion problem, microplots (< 10 m^2) provide low estimates of soil erosion rates. The highest rates are typically recorded from areas of about 100 m^2-1 km^2, and a clear and progressive decrease in erosion rates estimate come from catchments larger in area, as demonstrated by Batalla *et al*. (1995) in the Riera d'Arbucies. However, this general rule does not hold true in all cases, as has been shown for erosion estimates based on plots, experimental catchments and sediments for a large reservoir in a basin in the Spanish Pyrenees with plots (Figure 4).

It can be concluded that estimated of erosion rates are only comparable if the same scales and methods are used. A further extension of the problem is establishing what constitutes an erosion rate. This is superficially easy, that is, the quantity of sediment moved or exported from a given area during a given period (for instance, Mg or tons km^{-2} yr^{-1}, or Mg ha^{-1} yr^{-1}, even g m^{-2}). However, in reality the measurement may be of marginal use. In some cases erosion rates have been calculated for a single gully or a particularly eroded sector of a cultivated field, and not for a large area encompassing a variety of environments, where different erosion and sedimentation processes are integrated. In other cases, even where catchments of a similar size are studied, a small eroded area in one catchment can increase the erosion rate, even if most of the catchment is relatively well protected by plant cover, as was demonstrated in the Vallcebre catchments (Gallart *et al*., 2002). In catchments subject to plant re-colonization after farmland abandonment, the sediment sources tend to be more spatially restricted, whereas the channel itself and its taluses can continue yielding large volumes of sediment (Lana-Renault *et al*., 2007; García-Ruiz *et al*., 2008).

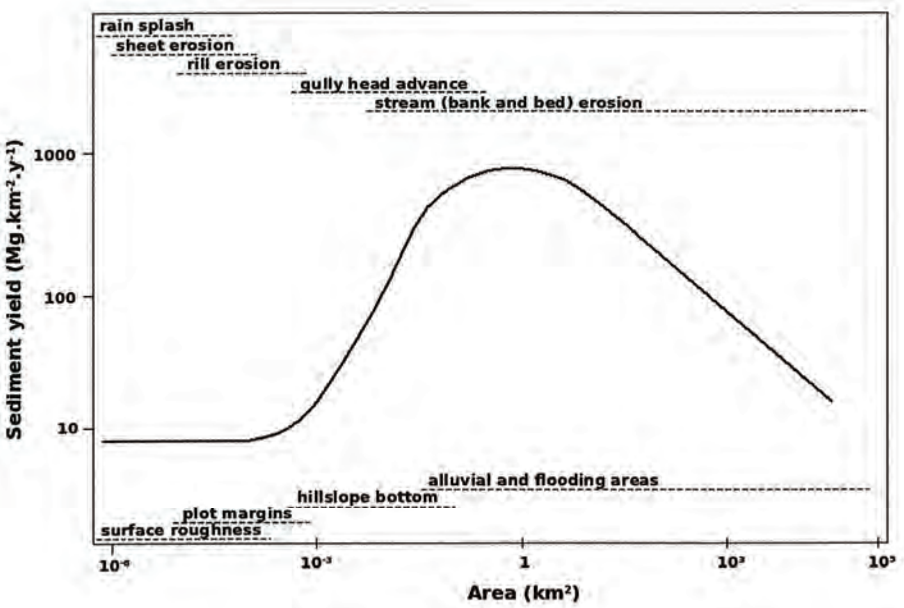

Figure 3: Variations in sediment yield as a function of catchment size (conceptual sketch): sediment yield at a given spatial scale depends on the interplay of several erosion processes, and different processes prevail at characteristic scales. The role of the major sediment sinks (deposition areas) changes according to the size of the area of interest. The main erosion processes and sediment sinks are shown. (Source: Beguería *et al*., 2008).

Discharge from Mediterranean rivers and ravines concentrates in brief flood events having high interannual variability, posing difficulties in accurately measuring some crucial parameters: Thus, the quantification of suspended sediment in the field can be subject to an uncertainty of several orders of magnitude, particularly in basins of hundreds of square kilometers or more (Liquete *et al*., 2009). Nevertheless, erosion rates are usually estimated over very short periods (in general less than five years, and frequently one or two years). This is frequently a consequence of pressure to increase publication results. In some cases equipment fails during the most extreme events (that is, the most interesting ones from a hydrological or geomorphological point of view), and bedload is almost impossible to measure when flood occur with long return periods. Erosion rates are clearly controlled by the occurrence of extreme rainfall events during an experimental period. Thus, Desir (2001) demonstrated that when the study period was reduced from several months to nine years in an experimental badland area of the Central Ebro Depression, the estimates erosion rate declined by an order of magnitude. Similarly, one extreme rainstorm event in the Izas catchment in October 1987 yielded as much sediment as was carried over the following 10 years, confirming that sediment transport is very complex and highlighting that sediment exhaustion and availability is another important factor affecting sediment balances and erosion rates (Alvera and García-Ruiz, 2000); this problem also demands a long term perspective. The reliable estimation of erosion rates is more difficult in agricultural environments, because of the complexity of different crop management systems for a given crop: for instance, vineyards are cultivated on different slope gradients, on terraced hillslopes, on surfaces of varying stoniness, and with a variety of tillage systems). A similar variability occurs for cereal crops (where the same research groups have estimated erosion rates ranging from 2 to 190 Mg ha^{-1} yr^{-1}), and for olive groves. Again we can query whether these erosion rates are representative, and question if it is possible to reliably estimate any long-term erosion rate in Spain. In this regard, reservoirs are a good information source, although not without problems: for example, the need to consider reservoir operating rules, and the inability to assess sediment sources or study the internal hydromorphological processes of the basin. The use of USLE for calculating erosion rates has also been discarded as it overestimates values (Martínez-Fernández and Esteve, 2005).

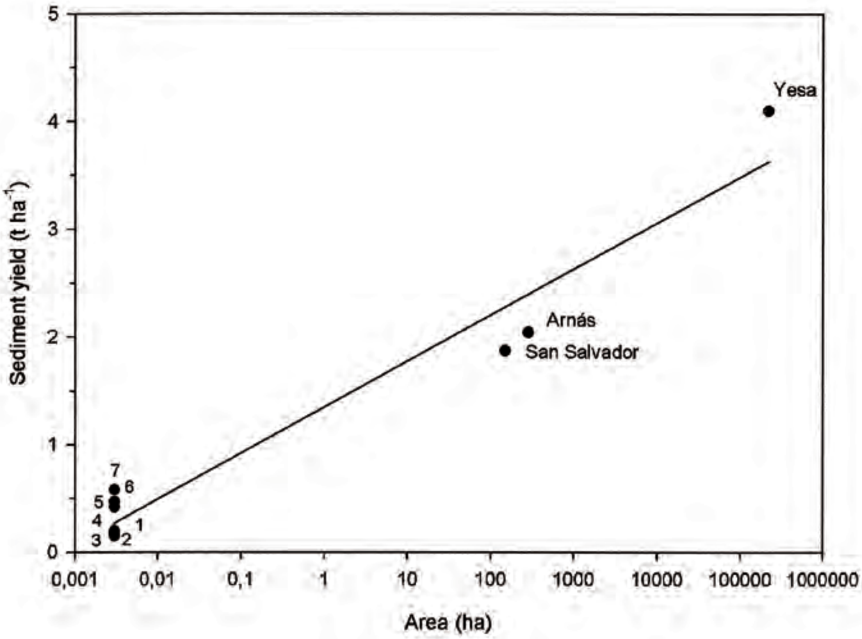

Figure 4: Relationships between catchment area and sediment delivery in the central Spanish Pyrenees. 1-7: experimental plots at the Aísa Valley Experimental Station. In contrast with the typical findings, the results from the central Spanish Pyrenees show a positive relationship between sediment delivery and the size of the catchment. (Source: García-Ruiz *et al.*, 2004).

From the above analysis it is evident that an increased coordination among the various research groups in Spain is needed. Some research projects (for instance, PROBASE, a Consolider Project financed by the Spanish Commission of Science and Technology) are taking a concerted approach, although more effort will be needed to overcome some inadequay. A review of the most recent literature on soil erosion reveals (i) an absence of available solutions to address the major problems, (ii) a lack of consistency among results from short research campaigns and spatially limited studies, some of which have been focused on very detailed aspects of a broader problem, and (iii) contradictory results, particularly in the case of estimates of soil erosion in cultivated fields. Most of these problems are probably related to the lack of integration among objectives, scales and methods, and the extreme variability of field conditions (gradient, aspects, soil types and land management). A more holistic perspective will be essential in the future, including changes in the spatial and temporal scales studied (i.e. larger study areas, longer study periods).

Soil erosion has been identified as a major problem in Mediterranean countries (Poesen and Hooke, 1997), causing changes in soil characteristics, loss of productivity, reservoir silting and changes in the quantity and quality of water resources (Beguería *et al*., 2003 and 2006). Soil erosion is a global problem with very complex causes, and potential solutions have political and social implications, and necessitate major changes in land management. Among the issues involved are the effects of the changing policy on subsidies inj the European Community, the consequences of local activities (ski resorts, mining, long-term effects of new irrigated areas), the effects of changes in plant cover on soil erosion due to changing agricultural and livestock pressures on the environment, the identification of eroded areas and their connectivity with the fluvial network, and the interrelations between soil erosion on hillslopes, temporal sediment stores, sediment transfer to channels, and sediment outputs. To address these issues, a catchment or large basin scale approach is required, with finer scale studies (rainfall simulation, experimental plots) being usded to investigate particular but more limited problems. The most important task for the future is to identify the present and future soil erosion problems, and the methods and scales to be used to develop solutions. The time of studying soil erosion problems using approaches determined by non-scientific constraints is past.

6. CONCLUSIONS

1. An increase in the number of research papers published on soil erosion in Spain is evidence of the positive evolution of research groups, sometimes involving collaboration with foreign scientists.

2. Most environments in Spain, from humid forests and high mountain areas in the north Spain to the semi-arid areas of the southeast are now being studied, providing information on runoff, soil erosion, sediment transport and the internal functioning of the natural and human-transformed environments.

3. Complex infrastructure has been installed in the field to continuously monitor runoff, sediment transport, water table fluctuations, and the variability of runoff and sediment contributing areas.

4. The most important soil erosion problems in Spain have been adequately identified, at least by some research groups. This include the hydromorphological consequences of farmland abandonment and the consequent effects of plant re-colonization on streamflow, erosion and sediment transport; badlands as the main sediment sources; relationships between weathering, erosion and sediment transport in badland areas; the effects of plant cover structure on infiltration, runoff and erosion; soil erosion in vineyards; and the erosive effects of extreme rainfall events.

5. The study of soil erosion problems has frequently been carried out using different methods at different spatial scales. The consequence is that the results are not always comparable, as each method or scale provides information on different erosion and sediment transfer processes.

6. The temporal scales of studies have also been very variable, from the event scale to studies over several years. Extreme events are very important in Mediterranean environments, and for this reason their study is encouraged. However, the interannual variability of precipitation in the Mediterranean region requires a long period to develop sediment balances and budgets, and to analyze the relationships among rainfall, runoff and sediment transport. Studies over short periods may be good for publication output, but not for solving soil erosion problems.

7. The publication of soil erosion rates should be re-considered because of variability due to the methods used and the period considered. Erosion rates determined from simulated rainfall studies over several months are very different from those determined from experimental catchments or plots over several years.

8. Soil erosion studies require the continuity provided by consolidated groups with sophisticated field and laboratory infrastructure. This will enable a holistic approach to soil erosion studies, using new methods and appropriate scales.

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8. REFERENCES

- Alcoverro, J., Corominas, J. y Gómez, M. (1999): The Barranco de Arás flood of 7 August 1996, Biescas, Central Pyrenees, Spain). *Engineering Geology*, 51: 237-255.

- Alexander, R.W. and Calvo, A. (1990): The influence of lichens on slope processes in some Spanish badlands. In: *Vegetation and erosion. Processes and environments* (J.B. Thornes, edr.), John Wiley & Sons, pp. 385-398, Chichester.

- Alvera, B. and García Ruiz, J.M. (2000): Variability of sediment yield from a high mountain catchment, Central Spanish Pyrenees. *Arctic, Antarctic and Alpine Research*, 32 (4): 478-484.

- Arnáez, J., Larrea, V. and Ortigosa, L. (2004): Surface runoff and soil erosion on unpaved forest roads from rainfall simulation tests in northeastern Spain. *Catena*, 57: 1-14.

- Arnáez, J., Lasanta, T., Ruiz-Flaño, P. and Ortigosa, L. (2007): Factors affecting runoff and erosion under simulated rainfall in Mediterranean vineyards. *Soil & Tillage Research*, 93: 324-334.

- Batalla, R.J., Sala, M. and Werrity, A. (1995): Sediment budget focused in solid material transport in a subhumid Mediterranean drainage basin. *Zeitschrift für Geomorphologie*, 39 (2): 249-264.

- Beguería, S. (2005): *Erosión y fuentes de sedimento en la cuenca del embalse de Yesa (Pirineo Occidental) : Ensayo de una metodología basada en teledetección y análisis SIG.* Instituto Pirenaico de Ecología, 158 pp., Zaragoza.

- Beguería, S., López-Moreno, J.I., Lorente, A., Seeger, M. and García-Ruiz, J.M. (2003): Assessing the effect of climate oscillations and land-uses in the Central Spanish Pyrenees. *Ambio*, 32 (4): 283-286.

- Beguería, S., Lana-Renault, N., Regüés, D., Nadal-Romero, E., Serrano-Muela, P. and García-Ruiz, J.M. (2008): Erosion and sediment transport processes in Mediterranean mountain basins. In: *Numerical modelling of Hydrodynamics for water resources* (M.P. García-Navarro and E. Playán, eds.), Taylor & Francis, pp.175-187, London.

- Beguería, S., López-Moreno, J.I., Gómez-Villar, A., Rubio, V., Lana-Renault, N. and García-Ruiz, J.M. (2006): Fluvial adjustments to soil erosion and plant cover changes in the Central Spanish Pyrenees. *Geografiska Annaler*, 88A(3): 177-186.

- Benito, G., Gutiérrez, M. and Sancho, C. (1991): Erosion patterns in rill and interrill areas in badland zones of the middle Ebro basin (NE Spain). IN: *Soil erosion studies in Spain* (M. Sala, J.L. Rubio and J.M. García-Ruiz, eds.), Geoforma Ediciones, pp. 41-54, Logroño.

- Benito, G., Gutiérrez, M. and Sancho, C. (1993): The influence of physico-chemical properties on erosion processes in badland areas, Ebro basin, NE-Spain. *Z. Geomorphologie,* 37: 199-214.

- Benito, G., Grodek, T. and Enzel, Y. (1998): The geomorphic and hydrologic impacts of the catastrophic failure of flood-control dams of the 1996-Biescas flood (Central Pyrenees, Spain). *Zeitschrift für Geomorphologie*, 42: 417-437.

- Boix-Fayos, C., Martínez-Mena, M., Arnau-Rosalén, E., Calvo-Cases, E., Castillo, V. and Albaladejo, J. (2006): Measuring soil erosion by field plots: understanding the sources of variation. *Earth Science Reviews*, 78: 267-285.

- Boix-Fayos, C., Martínez-Mena, M., Calvo-Cases, A., Arnau-Rosalén, E., Albaladejo, J. and Castillo, V. (2007): Causes and underlying processes of measurement variability in field erosion plots in Mediterranean conditions. *Earth Surface Processes and Landforms*, 32: 85-101.

- Calvo-Cases, A., Gisbert, J.M., Palau, E. and Romero, E. (1988): Un simulador de lluvia portátil de fácil construcción. In *Monografías de la SEG*, 1 (M. Sala and F. Gallart, eds.), Sociedad Española de Geomorfología, pp. 6-15, Zaragoza.

- Cantón, Y., Domingo, F., Solé Benet, A. and Puigdefábregas, J. (2001): Hydrological and erosion response of a badlands system in semiarid SE Spain. *Journal of Hydrology*, 252: 65-84.

- Casalí, J., Giménez, R., De Santisteban, L., Álvarez-Mozos, J., Mena, J. and Del Valle de Lersundi, J. (2009) : Determination of long-term erosion rates in vineyards of Navarre (Spain) using botanical benchmarks. *Catena*, 78 : 12-19.

- Causapé, J., Quílez, D. and Aragüés, R. (2004): Salt and nitrate concentrations in the surface waters of the CR-V irrigation district (Bardenas I, Spain): diagnosis and prescriptions for reducing off-site contamination. *Journal of Hydrology*, 295: 87-100.

- Ceballos, A., Schnabel, S. and Cerdà, A. (1996): El efecto de la escala sobre los procesos de escorrentía superficial. *Cadernos Laboratorio Xeolóxico do Laxe*, 21: 91-102.

- Cerdà, A. (1999): Seasonal and spatial variations in infiltration rates in badland surfaces under Mediterranean climatic conditions. *Water Resources Research*, 35: 319-328.

- Cerdà, A. and García-Fayos, P. (1997): The influence of slope angle on sediment, water and seed losses on badland landscapes. *Geomorphology,* 18: 77-90.

- Clotet, N., García-Ruiz, J.M. and Gallart, F. (1989): High magnitude geomorphic work in Pyrenees Range: November's 1982 unusual rainfall event. *Studia Geomorphologica Carpatho-Balcanica*, 23: 69-91.

- De Alba, S., Benito, G., Lacasta, C. and Pérez-González, A. (2003): Erosión hídrica en campos de agricultura extensiva de clima mediterráneo. Influencia del manejo del suelo en Castilla-La Mancha. *Edafología*, 10 (3): 103-113.

- Desir, G. (2001): *Erosión hídrica de terrenos yesíferos en el sector central de la Depresión del Ebro.* Consejo de Protección de la Naturaleza en Aragón, 326 pp., Zaragoza.

- De Vente, J. and Poesen, J. (2005): Predicting soil erosion and sediment yield at the basin scale: Scale issues and semi-quantitative models. *Earth-Science Reviews*, 71: 95-125.

- Gallart, F., Llorens, P., Latron, J. and Regüés, D. (2002 b): Hydrological processes and their seasonal controls in a small Mediterranean mountain catchment in the Pyrenees. *Hydrology and Earth System Sciences*, 6 (3): 527-537.
- García-Ruiz, J.M. (1999): *La producción científica de la Geomorfología española y su impacto, a través de las publicaciones periódicas*. Instituto Pirenaico de Ecología, 104 pp., Zaragoza.
- García-Ruiz, J.M. (2008): *Una historia de la Sociedad Española de Geomorfología*. Sociedad Española de Geomorfología, 119 pp, Cádiz.
- García-Ruiz, J.M. and López-Bermúdez, F. (in press): *La erosión del suelo en España*.
- García-Ruiz, J.M. and Gallart, F. (1997): Las cuencas experimentales como base para el estudio de la erosión y la desertificación. En *El paisaje mediterráneo a través del espacio y del tiempo. Implicaciones para la desertificación* (J.J. Ibáñez, B.L. Valero Garcés and C. Machado, eds.), Geoforma Ediciones, pp. 221-238, Logroño.
- García-Ruiz, J.M., Lasanta, T., Ortigosa, L., Ruiz-Flaño, P., Martí, C. and González, C. (1995): Sediment yield under different land uses in the Spanish Pyrenees. *Mountain Research and Development,* 15 (3): 229-240.
- García-Ruiz, J.M., Lana-Renault, N., Beguería, S., Valero-Garcés, B., Lasanta, T., Arnáez, J., López-Moreno, J.I., Regüés, D. and Martí-Bono, C. (2004): Temporal and spatial interactions of slope and catchment processes in the Central Spanish Pyrenees. *Sediment transfer through the fluvial system, IAHS Publ.,* 288: 21-28.
- García-Ruiz, J.M., Regués, D., Alvera, B., Lana-Renault, N., Serrano-Muela, P., Nadal-Romero, E., Navas, A., Latron, J., Martí-Bono, C. and Arnáez, J. (2008): Flood generation and sediment transport in experimental catchments affected by land use changes in the Central Pyrenees. *Journal of Hydrology*, 356: 245-260.
- Goudie, A. (1986): *The human impact on the natural environment*. Blackwell, 338 pp., Oxford.
- Gutiérrez, F., Gutiérrez, M. and Sancho, C. (1998): Geomorphological and sedimentological análisis of a catastrophic flash flood in the Arás drainage basin (Central Pyrenees, Spain). *Geomorphology*, 22: 265-283.
- Lana-Renault, N. and Regüés, D. (2007): Bedload transport under different flow conditions in a human-disturbed catchment in the Central Spanish Pyrenees. *Catena*, 71: 155-163.
- Lana-Renault, N., Regués, D., Martí-Bono, C., Beguería, S., Latron, J., Nadal, E., Serrano, P. and García-Ruiz, J.M. (2007): Temporal variability in the relationships between precipitation, discharge and suspended sediment concentration in a Mediterranean mountain catchment. *Nordic Hydrology*, 38 (2): 139-150.
- Lasanta, T., Arnáez, J., Oserín, M. and Ortigosa, L. (2001a): Marginal lands and erosion in terraced fields in the Mediterranean mountains: A case study in the Camero Viejo (Northwestern Iberian System, Spain). *Mountain Research and Development*, 21 (1): 69-76.
- Lasanta, T., Pérez-Rontomé, M.C., Machín, J., Navas, A., Mosch, W. and Maestro, M. (2001b): La exportación de solutos en un polígono de regadío de Bardenas (Zaragoza). *Cuaternario y Geomorfología*, 15 (3-4): 51-66.
- Lesschen, J.P., Kok, K., Verburg, P.H. and Cammeraat, L.H. (2007): Identification of vulnerable areas for gully erosion under different scenarios of land abandonment in Southeast Spain. *Catena*, 71: 110-121.

- Lesschen, J.P., Cammeraat, L.H. and Nieman, T. (2008): Erosion and terrace failure due to agricultural land abandonment in a semi-arid environment. *Earth Surface Processes and Landforms*, 33: 1574-1584.

- Liquete, C., Canals, M., Ludwig, W. and Arnau, P. (2009): Sediment discharge of the rivers of Catalonia, NE Spain, and the influence of human impacts. *Journal of Hydrology*, 366: 76-88.

- Llorens, P., Latron, J. and Gallart, F. (1992): Analysis of the role of agricultural abandoned terraces on the hydrology and sediment dynamics in a small mountainous basin. *Pirineos*, 139: 27-46.

- López-Bermúdez, F., García-Ruiz, J.M., Romero-Díaz, M.A., Ruiz-Flaño, P., Martínez-Ferrnández, J. and Lasanta, T. (1993) : Medidas de flujos de agua y sedimentos en parcelas experimentalers. *Cuadernos Técnicos de la SEG*, 6 : 38 pp., Geoforma Ediciones, Logroño.

- Martínez-Casasnovas, J.A. and Sánchez-Bosch, I. (2000): Impact assessment of changes in land use / conservation practices on soil erosion in the Penedès-Anoia vineyard region (NE Spain). *Soil & Tillage Research*, 57: 101-106.

- Martínez-Casasnovas, J.A., Ramos, M.C., y Ribas-Dasi, M. (2002): Soil erosion caused by extreme rainfall events: mapping and quantification in agricultural plots from very detailed digital elevation models. *Geoderma*, 105 (1-2): 125-140.

- Martínez-Fernández, J. and Esteve, M.A. (2005): A critical view of the desertification debate in Southeastern Spain. *Land Degradation and Development*, 16: 529-539.

- Nadal-Romero, E., Latron, J., Martí-Bono, C. and Regüés, D. (2008b): Temporal distribution of suspended sediment transport in a humid Mediterranean badland area. The Araguás catchment, Central Pyrenees. *Geomorphology*, 97 (3-4): 601-616.

- Nicolau, J.M. (2003): Trends in relief design and construction in opencast mining reclamation. *Land Degradation and Development*, 14: 215-226.

- Ortega Becerril, J.A. and Garzón, G. (2006): Interpretación de los depósitos de avenida como clave para establecer la dinámica de la llanura de inundación. In: *Geomorfología y Territorio* (A. Pérez-Alberti and J. López-Bedoya, eds.). Universidade de Santiago de Compostela, pp., 629-644, Santiago de Compostela.

- Ortigosa, L. (1991) : *Las repoblaciones forestales en La Rioja : Resultados y efectos geomorfológicos*. Geoforma Ediciones, 149 pp., Logroño.

- Ortigosa, L., García-Ruiz, J.M. and Gil, E. (1990): Land reclamation by reforestation in the Central Pyrenees. *Mountain Research and Development*, 10 (3): 281-288.
- Poesen, J.W.A. and Hooke, J.M. (1997): Erosion, flooding and channel management in Mediterranean environments of southern Europe. *Progress in Physical Geography,* 21 (2): 157-199.

- Puigdefabregas,J. (2005): The role of vegetation patterns in structuring runoff and sediment fluxes in drylands. *Earth Surface Processes and Landforms*, 30: 133-147.

- Puigdefábregas, J., Solé, A., Gutiérrez, L., Del Barrio, G. and Boer, M. (1999): Scales and processes of water and sediment redistribution in drylands: results from the Rambla Honda field site in Southeast Spain. *Earth Science Reviews*, 48: 39-70.

- Puigdefábregas, J., Alonso, J.M., Delgado, L., Domingo, F., Cueto, M., Gutiérrez, L., Lázaro, R., Nicolau, J.M., Sánchez, G., Solé, A., Torrentó, J.R., Vidal, S., Aguilera, C., Brenner, A.J., Clark, S.C. and Incoll, L.D. (1996): The Rambla Honda field site: interactions of soil and vegetation along a catena in semi-arid SE Spain. In : *Mediterranean desertification and land use* (J.B. Thornes and J. Brandt, eds.), Wiley, pp. 137-168, New York.

- Ramos, M.C. and Martínez-Casasnovas, J.A. (2006b): Impact of land levelling on soil moisture and runoff variability in vineyards under different rainfall distributions in a Mediterranean climate and its influence on crop productivity. *Journal of Hydrology*, 321: 131-146.

- Regués, D., Pardini, G. and Gallart, F. (1995): Regolith behaviour and physical weathering of clayey mudrock as dependent on seasonal weather conditions in a badland area at Vallcebre, Eastern Pyrenees. *Catena,* 25: 199-212.

- Rojo-Serrano, L. and Sánchez-Fuster, M.C. (1997): *Red de estaciones experimentales de seguimiento y evaluación de la erosión y la desertificación, RESEL.* Ministerio de Medio Ambiente, 298 pp., Madrid.

- Romero Díaz, A., Marín Sanleandro, P., Sánchez Soriano, A., Belmonte Serrato, F. and Faulkner, H. (2007a): The causes of piping in a set of abandoned agricultural terraces in Southeast Spain. *Catena*, 69: 282-293.

- Romero-Díaz, A. and Belmonte-Serrato, F. (2008): *Erosión en forestaciones aterrazadas en medio semiáridos: Región de Murcia*. Universidad de Murcia, 191 pp., Murcia.

- Rubio, J.L, Forteza, J., Adreu, V. and Cerni R. (1997): Soil profile characteristics influencing runoff and soil erosion after forest fire: a case study (Valencia, Spain). *Soil Technology* 11: 67–78.

- Ruiz-Flaño, P. (1993): *Procesos de erosión en campos abandonados del Pirineo.* Geoforma Ediciones, 191 pp., Logroño.

- Ruiz-Flaño, P., García-Ruiz, J.M. and Ortigosa, L. (1992): Geomorphological evolution of abandoned fields. A case study in the Central Pyrenees. *Catena,* 19: 301-308.

- Sancho, C., Benito, G. and Gutiérrez-Elorza, M. (1991): *Agujas de erosión y perfiladores microtopográficos*. Cuadernos Técnicos de la SEG, Geoforma Ediciones, 28 pp., Logroño.

- Soto, B. and Díaz-Fierros, F. (1998): Runoff and soil erosion from areas of burnt scrub: comparison of experimental results with those predicted by the WEPP model. *Catena*, 31: 257–270.

- Thornes, J.B. (1999): The hydrological cycle and the role of water in Mediterranean environments. En: *Rural planning from an environmental systems perspective* (F.B. Golley and J. Bellot, eds.), Springer, pp. 85-107.

- Úbeda, X., Outeiro, L.R. and Sala, M. (2006): Vegetation regrowth after a differential intensity forest fire in a Mediterranean environment, northeast Spain. *Land Degradation and Development*, 17: 429-440.

- Valero-Garcés, B.L., Navas, A., Machín, J. and Walling, D. (1998): Sediment sources and siltation in mountain reservoirs: a case study from the Central Spanish Pyrenees. *Geomorphology*, 28: 23-41.

- Van Wesemael, B., Rambaud, X., Poesen, J., Muligan, M., Cammeraat, E. and Stevens, A. (2006): Spatial patterns of land degradation and their impacts on the water balance of rainfed treecrops: A case study in South East Spain. *Geoderma*, 133: 43-56.

- Wainwright, J. and Thornes, J.B. (2004): *Environmental issues in the Mediterranean. Processes and perspectives from the past and present*. Routledge, 479 pp., London.

- White, S., García-Ruiz, J.M., Martí-Bono, C., Valero-Garcés, B., Errea, M.P. and Gómez-Villar, A. (1997): The 1996 Biescas campsite disaster in the Central Spanish Pyrenees, and its temporal and spatial context. *Hydrological Processes*, 11: 1797-1812.