1.26

Spain

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Spain is one of the countries most severely affected by soil erosion in the European Mediterranean region owing to extreme spatial and temporal variations in its physical environment, with frequent periods of drought and torrential rainfall. The presence of soils that are highly erodible because of their poor organic matter content and weak structure, and uneven relief with steep slopes, explains why a large part of Spain has a high erosion risk potential. Furthermore, a long history of anthropogenic disturbances related to temporary increases in population and its pressure on marginal lands are key factors in accelerating soil erosion processes and increasing soil loss.

1.26.1 THE PHYSICAL ENVIRONMENT

Spain occupies the largest part, about 504 000 km^2, of the Iberian peninsula, in south-western Europe (Figure 1.26.1), and similarly to other Mediterranean countries, is characterized by a particular combination of climatic, lithological, topographic and historical land-use factors that favour widespread soil erosion. The Balearic Islands in the Mediterranean have similar geographic conditions and are also treated in this chapter.

1.26.1.1 Climate

Spain can be divided into two large climatic sections (Figure 1.26.2): the humid Spain of the north, down to the central plains, called the Meseta, with a warm oceanic climate, continuously mild tempertures, and rain throughout the year, and the dry Spain, with warm winters and hot, dry summers, although Rivas Martinez (1987) found a large variety of subclimates. About 80% of the Spanish climate is Mediterranean (between

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Figure 1.26.1 General map of Spain, with main cities, mountain ranges and large basins. Hypsometric colours: grey, 0–500 m; light grey, 500–1500 m; dark grey, above 1500 m

semi-arid and sub-humid) with annual precipitation ranging from 300 to 600 mm, often in the form of local, conventional storms concentrated in autumn and spring, with frequent summer droughts. The spatial distribution of maximum rainfall intensities in 1 h is shown in Figure 1.26.3. Most of the country has rainfall intensities above 30 mm h^{-1} lasting 1 h, and in many spots along the Mediterranean coast such storms even exceed 70 mm h^{-1}. Up to 200 mm h^{-1} lasting for 10 min has been recorded in Valencia and a few other spots with a return period of 50 years (Elias Castillo and Ruiz Beltrán, 1979). Mediterranean rainfall can reach extremely high absolute values and two remarkable cases are given as examples: (a) in Gandía, in the Region of Valencia, over 1000 mm in 36 h were recorded in November 1987 and over 400 mm fell in less than 6 h (López-Bermúdez, 1992); (b) on 7 August 1996, an extreme rainfall event produced a devastating debris flow in a mountain catchment in the Central Pyrenees with a maximum rainfall intensity estimated at 515 mm h^{-1} for 8 min in a 2-km^2 subcatchment (White *et al*., 1997).

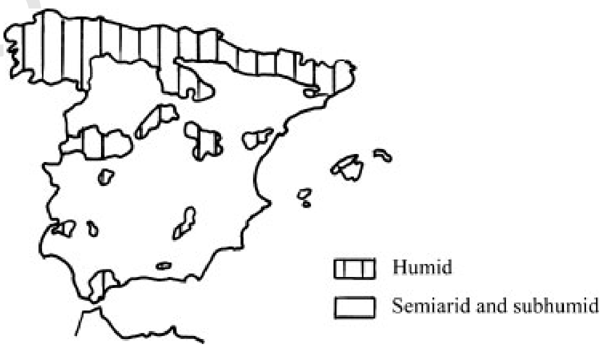

Figure 1.26.2 Climatic zones of Spain (except the Canary Islands), according the UNESCO aridity index (P/ETP): humid (>0.75), subhumid + semiarid (<0.75)

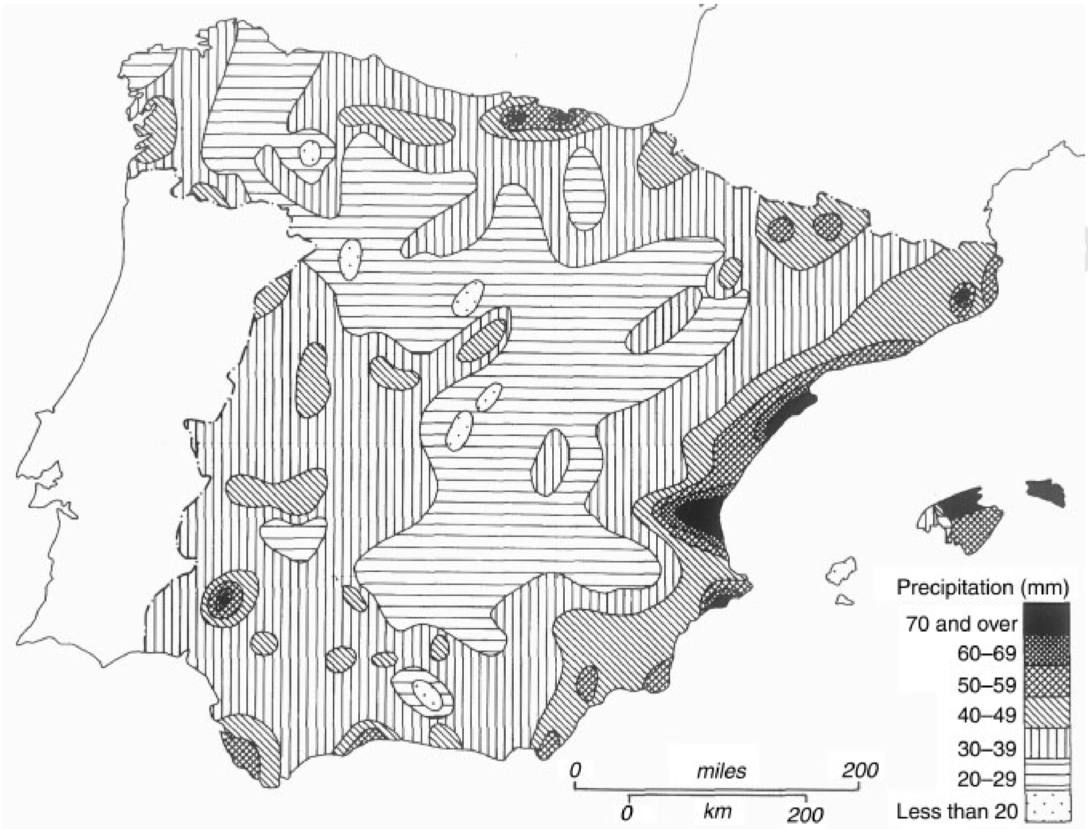

Figure 1.26.3 Distribution of maximum rainfall intensities in 1 h, according to Elias Castillo and Ruiz Beltrán (1978), in Grove and Rackham (2001). (Reproduced from Grove AT and Rackham O, The *Nature of Mediterranean Europe. An Ecological History*, 2001, with permission of Yale University Press)

As in the rest of the Mediterranean, interannual variability in precipitation and temperature are and have been important, even during the cold fluctuation of the Modern Age (Creus *et al*., 1990, cited by Puigdefábregas, 1995). However, droughts are not so widespread as in sub-Saharan regions, and are discontinuous both spatially and temporally. Under such conditions, the amount of natural vegetation is sparse and contributes little organic matter to soils, and as a consequence provides little protection from rain showers in the form of plant cover and/or well-aggregated soils.

1.26.1.2 Geology, Lithology, Physiography

Spain is a very mountainous country, with an average altitude of around 660 m (the second highest in Europe after Switzerland). This great height is due to extensive high plains, the largest in Europe, located mainly in the centre of the country, which correspond to the structural surfaces of tertiary interior basins and erosion surfaces, with occasional residual relief. All this together constitutes the Meseta, which is surrounded by *cordilleras*, or mountain ranges (Cantabrian, Iberian and Betic ranges). Most of these mountain ranges are young and often tectonically active, and most of them very close to coastal areas (Figure 1.26.1), where population is concentrated. During

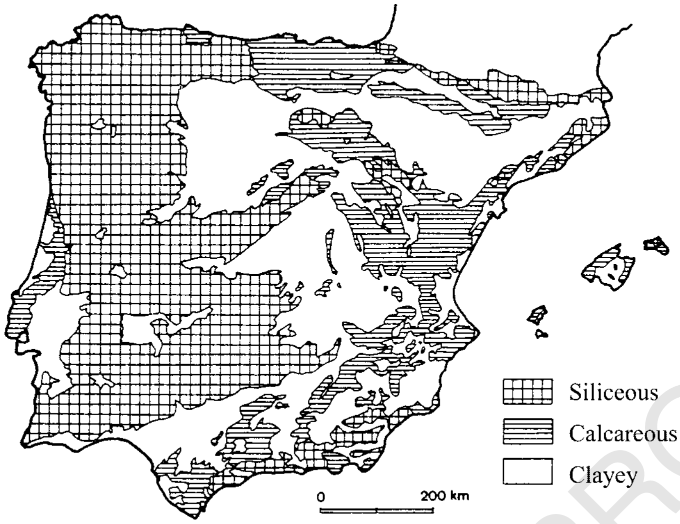

Figure 1.26.4 Main lithological units of the Iberian peninsula, according to Solé-Sabaris *et al.* (1952), in Gutiérrez Elorza (1994). (Reproduced from Gutiérrez Elorza M, *Geomorfología de* España, 1994, with permission of Editorial Rueda)

recent millenia, some coastal ranges have experienced uplift of from 50 to 1000 mm kyr^{-1}. Most coastal regions have been shaped since the Pleistocene or even older ages: neotectonics is one of the main agents of change in the present landscape, along with climatic fluctuation and one of its consequences, sea level oscillation, is responsible for the erosion–stabilization stages of most Mediterranean landscapes during the Quaternary. All this complex geology and topography determine a large variety of fluvial regimes (Masachs, 1948) and in many of them hillslopes and drainage networks are far from equilibrium and give rise to high rates of erosion and sedimentation.

Maps of the dominant lithologies in the Iberian Peninsula (Figure 1.26.4) (Gutiérrez Elorza, 1994, based on Solé Sabarís, 1952; Riba, 1969) coincide rather well with the map of the main morphostructural units (Gutiérrez Elorza, 1994; Gutiérrez and Casares-Porcel, 1994) (Figure 1.26.5), in which it can be observed how the western and central sectors of the country that make up the Hercynian base of the Meseta are mainly formed by hard, resistant materials (plutonic rock, gneiss, quartzite, schist). On the other hand, the peripheral Alpine mountain ranges present, in addition to their young relief, a softer lithology, with sedimentary rocks such as sandstones. Moreover, most of the large tertiary basins are made up of soft materials, some of them, such as marls, mudstones and shales, having a strong tendency to gullying, in both humid (Regües *et al*., 1995) and dry conditions (Gutiérrez Elorza *et al*., 1995; Gallart *et al*., 2002).

1.26.1.3 Soils and Land Use

The climatic factor determines soil and land-use behaviour through the water balance, which can be estimated from the difference between precipitation and potential evapotranspiration. Soils in the south-east have a permanent water deficit and those of the Pyrenees show little deficit or even excess. In most Mediterranean regions, complete leaching of the soil profile never occurs, only partial (Roquero, 1992). The most common soil water regime in the Mediterranean sector of Spain is *xeric* (Soil Survey Staff, 1999), but also the *aridic* regime (Soil Survey Staff, 1999) is found in the south-east, and consequently Xerochrepts and Xerorthents are the most common soils and also those most vulnerable to erosion (Roquero, 1992). Next are Torriorthents (local but even more susceptible to erosion). With regard to Aridisols, characterized by either the aridity of

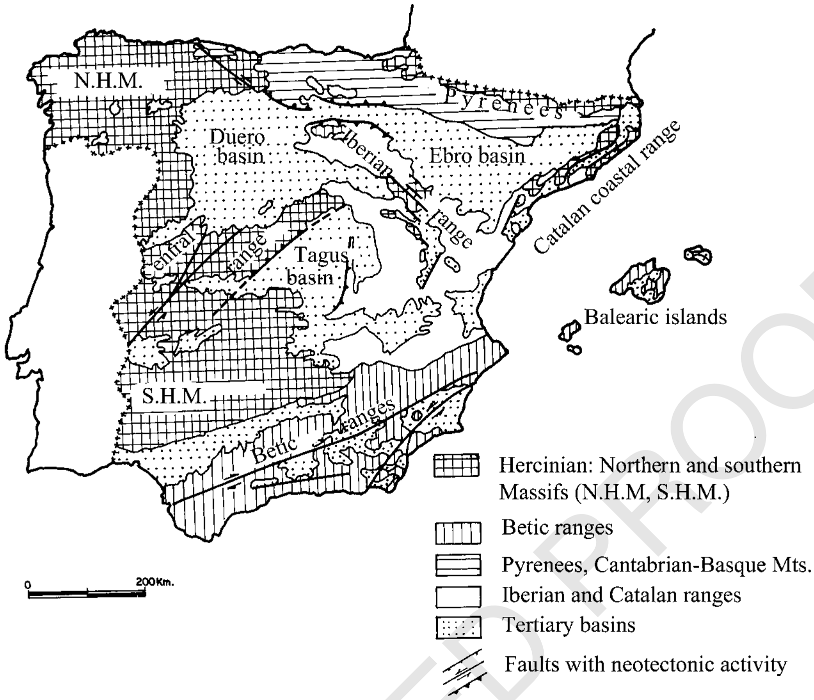

Figure 1.26.5 Morphostructural units of the Iberian peninsula, according to Gutiérrez Elorza (1994). (Reproduced from Gutiérrez Elorza M, *Geomorfología de España,* 1994, with permission of Editorial Rueda)

climate or high salinity, they are fairly frequent in the south-east and in the Ebro valley, and represented by Calciorthids, Camborthids and Paleorthids, all vulnerable to erosion. Also Argids, relict soils from Central Spain, although not occupying a large area, suffer from severe erosion. The fourth soil order is Alfisols, represented by Xeralfs, soils with an argillic horizon, fairly abundant in fluvial terraces and *rañas* in the centre or the country, and less susceptible to erosion. Within Vertisols, only Xererts are found, and within this sub-order, Chromoxererts have erosion problems. Finally, from the order of Ultisols, Xerults, fairly dispersed in central Spain, show erosion problems at the edges of platforms (Roquero, 1992).

Within the humid part of the country, most soils have *ustic* and *udic* moisture regimes (Soil Survey Staff, 1999), with a surplus water balance through the year, and consequently the complete leaching of soil profiles determines soil formation, evolution, properties and behaviour. Under these conditions, in northern (Asturias, Cantabria and part of Euskadi) and north-western Spain (Galicia), acid and podzolic soils occur.

Finally, the least represented order is that of Histosols, soils with a large accumulation of organic matter poorly evolved, present only in high mountain areas (Pyrenees, Central, Iberian and Cantabric ranges).

Except for high mountain areas, most soils in Spain have been cultivated for some time and the long sequence of agricultural clearing and abandonment has been common at least in recent millennia and accelerated with the increase of population in the first half of the 20th century. However, the trend during the second half of the 20th century has been agricultural abandonment due to mechanization.

Recent decades have witnessed an accelerated land-use change: in the period 1975–96 there has been a 10 decrease in the total cultivated surface (16% of rainfed lands, although irrigated land has increased by 26 %). Also pasture has decreased (16% in rainfed land), in addition to forest (23%) (MAPA, 1999) (Table 1.26.

TABLE 1.26.1 Total surfaces (ha) of different land uses from 1975 to 1996 in Spain

	Cultivated land		Natural pastures			
Year	Dryland	Irrigated	Dryland	Irrigated	Steppe	Timber forest
1975	18 216 800	2 616 800	1 305 200	201 200	5 719 400	9 395 900
1985	17 409 000	3 006 400	1 246 600	210 500	5 270 700	7 252 100
1996	15 342 700	3 309 600	1 095 200	292 900	5 578 600	7 240 800

As indicated above, climatic characteristics determine to a large extent the dryness of the majority of Spanish soils, with low levels of organic matter, a weak structure and consequently a fairly high level of erodibility. Many Spanish soils show the main indicators for soil erosion: shallowness, low organic carbon content, low water holding capacity and low nutrient content.

1.26.2 HISTORICAL EVIDENCE FOR EROSION

Human impact in the form of deforestation, grazing and agriculture was considerable in the Holocene, but especially acute in historic times. This combination of factors has been documented for several periods, but particularly well from the 16th to 18th centuries when cold, humid climatic fluctuations (Little Ice Age) coincided with land-use changes that left large areas exposed to erosion. The first half of the 20th century, when overpopulation of rural areas led to the expansion of agricultural land into rangelands, was another period of heavy erosion due to excessive use and high soil loss rates (Puigdefábregas, 1995).

A large part of Spain shows signs of erosion. However, not all erosive landscapes are of recent origin. As an example, in the desert of Tabernas (Figure 1.26.6), Almeria, the main drivers for erosion are not human

Figure 1.26.6 Aerial view of La Higueruela experimental station (Toledo province, central Spain), showing a mosaic of soil surfaces formed by erosion and deposition (photo from http://www.ccma.csic.es/). [Reproduced from www.ccma.c-sic.es with permission of Consejo Superior de Investigaciones Cientificas (CSIC)]

Figure 1.26.7 Erosive landscape not related to human activity: aerial view of well-developed badlands in the Tabernas desert, SE Spain (*photo*: A Solé-Benet)

activity and climate (although the driest in Spain) but tectonic activity since the begining of the Quaternary and the adjustment of the drainage network (Alexander *et al*., 1994), producing one of the most scenic badlands in Spain. A similar statement is true for the badlands of Guadix, which are about 4000 years old (Wise *et al*., 1982).

Geomorphological investigations carried out on fluvial terraces of Mediterranean rivers indicate that higher erosion and sedimentation rates prevailed in the last 2000 years (Marqués and Juliá, 1984) or even 500 years (Hoffman, 1987; Castro *et al*., 1998) (all cited by Grove and Rackham, 2001). The Andarax river, in south-eastern Spain, has a larger but very arid catchment, including the south-eastern slopes of Sierra Nevada, the northern part of Sierra de Gador and some of the largest badlands in Europe. The original Andarax estuary extended some 8 km above the present mouth (Figure 1.26.[illegible]). Boreholes have revealed marine and brackish-water lagoon sediments, just below present sea-level, representing an accumulation of about 1 m thickness per 1000 years. They are covered by coarse sediments brought down by floods within the last few millenia. A Punic sherd dating from about 600 BC was found in them at a depth of 2.4 m. Since the mid-eighteenth century, the river, owing to extensive deforestation for mining, has extended its delta by about 6 km^2 (Hoffman, 1987, cited by Grove and Rackham, 2001).

In the Ebro basin, Van Zuidam (1975) found a maximum period of erosion and alluviation between 500 and 100 BC, which he attributed to the growth of Celtic settlement and cultivation, especially of corn and wine. In the same basin, Gutiérrez Elorza and Peña-Monné (1998) found widespread slope accmulation between 900 and 300 BC, which they attributed to solifluction in a cool wet period. The two interpretations are not necessarily incompatible (Grove and Rackham, 2001).

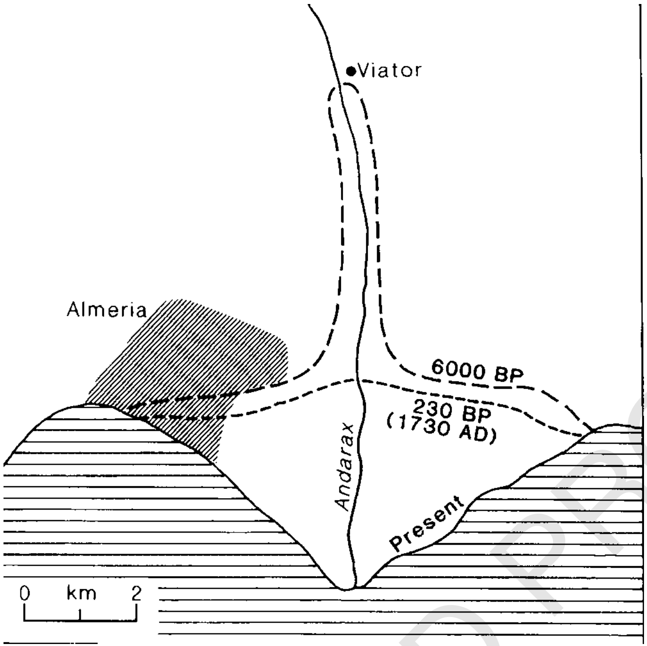

Figure 1.26.8 Map of the Andarax delta (Almeria, south-eastern Spain) showing the evolution of the coast line, according Marqués and Juliá (1984), in Grove and Rackham (2001). (Reproduced from Grove AT and Rackham O, *The Nature of Mediterranean Europe. An Ecological History*, 2001, with permission of Yale University Press)

Landscapes in many regions exhibit truncated soil profiles. Most organic horizons have been removed by erosion and B and C horizons are being cultivated. Aerial photographes of many parts of the country reveal a mosaic of coloured soil and pale subsoil, as a direct result of that process (Figure 1.26.8).

1.26.3 HOW EROSION IN SPAIN IS APPROACHED BY SCIENTISTS

The sudy of erosion has been undertaken by many reseach teams from Spanish and other European universities, from the Consejo Superior de Investigaciones Científicas (CSIC) or National Research Council, but also by the national and the regional autonomous administrations (Table 1.26.2).

Given the necessary synthetic characteristics of this chapter, it is imposible to summarize, even cite, all the studies which have been carried out on soil erosion in Spain. For this chapter, 615 specific documents have been consulted, 350 references from the author's database up to February 2003, and the rest obtained by both direct inquiries to about 50 colleagues and an Internet bibliographic search (OCLC Firstsearch Service).

This number of documents is smaller than the 850 references (Añó, personal communication, June 2003) maintained by the Centro de Investigaciones sobre Desertificación (CIDE) in Valencia, in the BIB-ERON database (Añó *et al*., 2000). The aim of BIB-ERON is to classify the large number of scientific and technical publications on water erosion in Spain and aims to be a useful tool for researchers through its availability on the Web in the near future. Classification descriptors include *state of the art*, *erosion methodologies*, *direct quantification and analysis of processes* to facilitate evaluation and retrieving. There are over 100 published documents from a recent (July 2003) symposium held in Madrid on 'Soil erosion and degradation control'.

TABLE 1.26.2 Major contributions of scientists from Spanish and other European institutions to soil erosion

Institution	Institution or Department	Leader (and other members)	Location	Type of work[a]	Materials, methods[b]
Spain					
CSIC	ICTJA	F Gallart (D. Regüés, G Pardini)	Barcelona	a, b, c, e, j	A, B, C, D, L
CSIC	IPE	JM García Ruíz (T Lasanta, B Alvera)	Zaragoza	a, b, c, e, i	A, B, C
CSIC	CIDE	JL Rubio (V Andreu, C Añó) Valenciac	Valencia	c, e, d	A, B, C
CSIC	CEBAS	J Alb[illegible]jo (V Castillo, M Martínez)	Murcia	c, e, d, j	A, B, C
CSIC	EEZA	J Puigdefbregas (A Solé, M Boer, Y Cantón)	Almería	a, b, c, d, j	A, B, C, G, L
CSIC	CCMA	G Benito (S DeAlba)	Madrid	a, b, c	A,G
CSIC	EEZ	E Barahona (J Quirantes, L García)	Granada	a, b, c, e, f	D, L
CSIC	EEAD	A Navas (J Machin)	Zaragoza	e	J, K
CSIC	EEAD	JL Arrúe (MV Lopez)	Zaragoza	a, f, k	A
CSIC	IRNA	D de la Rosa	Sevilla	j	G, K
CEDEX	Erosion	L Avendaño (J Cobo)	Madrid	e	C, G, H
CEAM	Forest Restoration	RV Vallejo (S Bautista, E Chirino)	Valencia	d, j	A, B, C, F
DGCONA		L Rojo	Madrid	k	M
JUNTA ANDALUCIA		F Moreira	Sevilla		K
IMIA		R Bienes Allas	Madrid	e, k	A
U Barcelona	Geology	MA Marquès (E Mora)	Barcelona	a, b, c, d	A, L
U Barcelona	Geography	M Sala (R Batalla)	Barcelona	a, b, d	A, L
U Girona	Soil Science	G Pardini (G Dunjó)	Girona	a, c, e	A, F
UPC	Soil Science	JA Martínez-Casasnovas	Lleida	e	G, K
U Valencia	Geography	A Calvo (E Bochet)	Valencia	a, b, c, e, i, j	A, B, D, F, K
U Valencia	Geography	A Cerdá	Valencia	a, b, c, d, e, i	A,B, D,
U Alacant	Ecology	J Bellot (S Bautista, E Chirino)	Alicante		A, B, D, G
U Murcia	Geography	F López Bermúdez (MC Romero)	Murcia	a, b, c, e, i,	A, B, D, F,
U Cartagena	Soil Science	F Ortiz Silla (A Faz)	Murcia	a, e	
U Zaragoza	Geology	M Gutiérrez (G Desir, F Gutierrez)	Zaragoza	b, c, e, i	A, L
U Zaragoza	Geography	JL Peña (M Echeverría, JC González)	Zaragoza		
U Santiago	Soil Science	F Díaz Fierros (B Soto)	Santiago	a, b, c, d	A, B, C, D, L
U Coruña	Soil Science	A Paz (E Vidal, M Taboada, M Valcarcel)	A Coruña	e, j	L
U Santiago	Geography	R Rodriguez Martínez-Conde	Santiago	e	A
UPM	Soil Science	C Roquero	Madrid	e, j, k	A
U Madrid	Geology	A Pérez	Madrid	b, c	A, B, I
U Alcala	Ecology	JM Nicolau	Madrid	1	A, B
U Extremadura	Geography	S Schnabel	Caceres	a, c, e	A, B, D, K, L

(*Continued*)

TABLE 1.26.2 (*Continued*)

Institution	Institution or Department	Leader (and other members)	Location	Type of work[a]	Materials, methods[b]
Other European countries					
TU Braunsweig	Geography	H Rohdenburg	Germany	e, j	B, C, G
Silsoe College	Geography	RPC Morgan	UK	b, c, e, j, k	A, B, C, D, G, L
King's College	Geography	JB Thornes	UK	a, b, c, d, e, h, j	A, B, C, D, F, G, K, L
U Liverpool	Geography	A Harvey	UK	b, h, i	C, G, K
U Amsterdam	Geography	AC Imeson	Netherlands	a, b, c, d, e, i, j	A, B, C, D, E, F, G, K, L
	Geography	H Scoging	UK	e, i	D
U Liverpool	Geography	H Faulkner	UK	a, c, i	
U Leeds	Geography	MJ Kirkby	UK	e, j	G
UK Leuven	Geography	J Poesen *et al.*	Belgium		
Silsoe College	Geography	JN Quinton	UK	a, b, e, j	A, B, D, F, L
UC Louvain	Geography	B Van Wesemael	Belgium	c, e, g, j	A, B, D, F, K, L

[a]*Field of work (in relation to erosion studies)*:
a land abandonment and collapse of traditional structures
b natural extreme events
c processes
d burned vegetation or forest fires
e water erosion
f wind erosion
g tillage erosion
h mass movements
i piping
j degradation of soil properties
k soil conservation, tillage methods
l mine tailings

[b]*Materials and methods*:
A experimental plots
B micro-catchments
C catchments – basins
D rainfall simulations in the field
E rainfall simulations in the laboratory
F aggregate stability (laboratory)
G models
H sediments in reservoirs
I sedimentology
J ^{137}Cs
K mapping, GIS
L direct measurements (profiles, pins, etc.)
M revegetation techniques

The 615 documents consulted have mostly been published since 1980, as there are only 12 references before that year; 110 references were found between 1981 and 1990, 356 between 1991 and 2000 and 137 after 2000, indicating a geometric progression in publications on soil erosion in Spain in the last two decades. These observations agree with a larger survey of published work on geomorphology in Spain, where erosion was one of the topics considered (García-Ruíz, 1999).

During the last decade, the European Commission has contributed notably with the funding of several international research projects in which erosion was involved (MEDALUS, EPHEDA, CORINE, PESERA, etc.).

1.26.3.1 Summary of Techniques and Approaches Used in Spain

Gerlach troughs have been used for the assessment of sediment production from non-bounded plots in different environments, essentially on steep slopes and related to (a) forest fires (Soler and Sala, 1992), (b) reforestation techniques (Olarieta *et al*., 1999), (c) vegetation types (Sala and Calvo, 1990), and (d) vegetation density (Sánchez and Puidfefábregas, 1994).

Erosion pins and microprofiles techniques have been reviewed by Sancho *et al*. (1991) and roughness indices from microtopographic techniques have been related to water erosion by Vidal Vázquez *et al*. (1999).

Bounded plots of many sizes, including USLE ones, have been used by many (Diaz-Fierros *et al*., 1987; García Ruiz *et al*., 1995; Gutierrez Elorza *et al*., 1995; Nicolau, 1996; Rodriguez Martinez-Conde *et al*., 1996; Rubio *et al*., 1994; Bienes and Torcal Sáinz 1997; Kosmas *et al*., 1997; Bienes *et al*., 2001; Chirino *et al*., 2001; De Alba *et al*., 2001; Martínez-Mena *et al*., 2001, 2002).

Different simultaneous techniques have been used by Gutiérrez Elorza *et al*. (1995) and Sirvent *et al*. (1996, 1997), and they concluded that soil loss recorded using dynamic methods is lower than that recorded by erosion pins, and both underestimate the losses recorded with micro-topographic profiles.

Rainfall simulators either with sprinklers (Benito *et al*., 1986; Calvo-Cases *et al*., 1988, 1991; Navas *et al*., 1990; Quirantes *et al*., 1991 Cerdà *et al*., 1997; Solé-Benet *et al*., 1997, 2002) or drippers have been reported.

The assessment of rain erosivity and the prediction of rainfall events have been approached by ICONA (1988), García-Ruiz (2000) and Usón and Ramos (2001).

^{137}Cs has been used in the assessment of soil erosion and sedimentation (Navas and Machín, 1991; Navas and Walling, 1992; Quine *et al*., 1994).

Dendrochronology has been used as a method of assessment of gully erosion rates (Vandekerckhove *et al*., 2001), by datable deviations of normal growth pattern.

Many authors have used soil aggregate stability in the laboratory as an indicator for soil erodibility (Solé Benet *et al*, 1992; Josa *et al*., 1994; Cerdà, 1996, Ternan et al, 1996 Boix-Fayos *et al*, 2001; Lado *et al*, 2004).

Experimental weathering procedures have contributed to explaining the mechanisms of sediment delivery, especially in badland areas (Regüés *et al*. 1993, 1995; Pardini *et al*., 1995; Cantón *et al*., 2001).

Recently, spatial technology approaches coupled with remote sensing have been used for mapping and quantification of gully erosion (Martinez-Casasnovas, 2003; Ries and Marzolff, 2003; Vandekerckhove *et al*., 2003). Modelling of gully erosion has been undertaken by Casali *et al*. (2003) and even overall erosion (Del valle Melón *et al*., 1998).

Vandekerckhove *et al*. (1998, 2000) have studied, by means of direct measurements of geometric and topographical parameters coupled with photointerpretation, the characteristics and controlling factors of gullies and the thresholds for ephemeral gully initiation in south-eastern Spain. Kirkby *et al*. (2003) have observed and modelled the distribution of channel and gully heads in south-eastern Spain.

Verstraeten *et al*. (2003), from an existing dataset of area-specific sediment yield (SSY) for 60 catchments in Spain that was retrieved from sediment deposition rates in reservoirs (Avendaño Salas *et al*., 1997), found that the catchment area alone explains only 17% of the variability in SSY. The low prediction capability of the multiple regression models and the CORINE soil erosion risk map could be attributed mainly to the fact that these methods do not incorporate gully erosion and that the land-cover data are not a good representation of soil cover. Other authors have also analysed soil erosion through the silting-up of Spanish reservoirs (Schnabel and Ergenzinger, 1987; Navas *et al*., 1998).

In recent years, the 'Soil Evaluation Group' from IRNA–CSIC has gathered in a structured format the available information about the quality of Spanish soils, and its degradation state is available online (http://www.microleis.com) (Dela Rosa *et al*., 2001). MicroLEIS is an integrated system for land data transfer and agro-ecological land evaluation, with special reference to Mediterranean regions, and is available online in both Spanish and English versions. Within this system, *ImpelERO* (De la Rosa *et al*., 1999) is a hybrid model of expert decision trees and an artificial neural network to evaluate soil erosion processes and to predict soil loss by water erosion.

SURMODES (Puigdefábregas and Del Barrio, 2000) is a project that intends to set up an operational surveillance system for early warning of desertification risk at the country scale. The system is designed as a support to mitigation programmes and integrates social, economic and landscape factors in its diagnoses and forecasts. Up to the present, a surveillance system has been developed with four modules: (i) early warning of risk, (ii) long-term monitoring of land cover change, (iii) databases and (iv) an observatory network with six terminals in representative landscapes of the country, linked through a telemetry system that works in a non-centralized way through an Internet backbone.

In recent years, soil erosion research has been heading towards the development and/or application of event-based physical models which could be validated by erosion datasets. Several researchers have applied existing models under local or regional environmental conditions, e.g. EUROSEM and WEPP. (Albaladejo *et al*., 1994), and on the development of new ones (De la Rosa *et al*., 1999).

1.26.3.2 Factors, Triggering Mechanisms and/or Other Features Associated with Soil Erosion

Extreme rainfall events (Gallart and Clotet-Perarnau, 1988; W[illegible] *et al*., 1997; García-Ruíz, 2000; Cantón *et al*., 2001; Martínez-Mena *et al*., 2001; among many others)

The influence of forest fires (Mangas *et al*., 1992; Marques and Mora, 1992, 1998; Soler and Sala, 1992, 1995; Soto *et al*., 1994; Ubeda and Sala, 1998; DeLuis *et al*., 2001, 2003; Giovannini *et al*., 2001; Perez Cabello *et al*., 2002), after the pioneering work of two teams, one from Galicia (Díaz-Fierros *et al*., 1982, 1987) and the other from Valencia (Sanroque *et al*., 1985). Soil restoration after forest fires has been studied by the CEAM team (Bautista *et al*., 1996; Sanchez, 1997; Chirino *et al*., 2001).

Vegetation den[illegible]nd its spatial distribution clearly affect sediment transport and sedimentation, as shown by Andreu *et al*. (1995), Puigdefábregas *et al*. (1996), Bellot *et al*. (1998), González-Hidalgo *et al*. (1999) and Chirino *et al*. (2001), Bochet *et al*. (2002). The effects of vegetation removal have been studied by Castillo *et al*. (1997), Albaladejo *et al*. (1998) and Solé-Benet *et al*. (2002) in semi-arid south-eastern Spain and by Benito *et al*. (2003) in Galicia.

Tillage affects the pattern of rock fragment cover (Poesen *et al*., 1997) and the effects of tillage with a mouldboard plough on erosion have been modelled by De Alba *et al.* (2001) and De Alba (2003). Minimum tillage effects on Mediterranean dry farming erosion have been estimated using the USLE: losses of over 200 t ha^{-1} with conventional tillage to less than 20 t ha^{-1} with mimimum tillage (Giraldez *et al*., 1989).

The abandonment of terraces consistently affects erosion (Arnáez *et al*., 1992; Llorens and Gallart, 1992; Marco Molina *et al*., 1996 Ruecker *et al*., 1998; Lasanta, 2001; Gisbert *et al*., 2002; Reynés *et al*., 2002; Dunjó *et al*., 2003) and the influence of soil management (De Alba *et al*., 2001). Land-use changes, especially in mountain areas (from forests to pastures and from pastures to ski resorts) greatly enhance erosion (Del Barrio and Puigdefábregas, 1987; García-Ruíz *et al*., 1990). Conversion of matorral to *Pinus* forest has been studied by Ternan *et al*. (1996) for its erosional impact.

Also the construction of new terraces, with heavy machinery, for forest revegetation purposes, has triggered water erosion in some regions (García-Pérez, 1999). Gully erosion is accelerated by runoff water shed from terrace treads (Ternan *et al*., 1996).

The effects of land reshaping mostly for agricultural purposes (Poesen and Hooke, 1997), but also for other purposes, such as ski resorts in the Pyrennees, enhance erosion and can result in mass movements or in significant increases in both surface and shallow subsurface runoff (Puigdefábregas and Alvera, 1986; García-Ruíz and Del Barrio, 1990).

The effects of crusting have been studied by Taboada Castro *et al*. (1999), Ramos *et al*. (2000) and Solé-Benet *et al*. (1997, 2002), among others.

One of the effects of mining activities, both underground and open-mine, is the removal of fertile soil, which, according to relatively recent laws, should be replaced or restored once the mining activity has ceased (Jorba *et al*., 2000). Erosion on mine tailings and on remodelled mine landscapes has been studied by Clotet *et al*. (1983), Porta *et al*. (1989), Wray (1998), Nicolau and Asensio (2000) and Nicolau (2003).

Motorway and railroad embankments have received little attention from an erosion point of view, despite the fact that they have often to be repaired and bear high associated costs (Andres and Jorba, 2000; Arnaez and Larrea, 1994). Also, roads and streets in new urban areas have had dramatic consequences for water erosion in some regions (Inbar and Sala, 1992).

The catastrophic failure of an earth dam built on gypsiferous alluvium and dispersive clays has been described (Gutierrez *et al*. 2003).

The causes of mass movements have been reviewed by Corominas (1989), and Araña *et al*. (1992) reviewed geological risks and factors, including erosion, in Spain.

Bedload transport in channels has been studied by Conesa García (1995), Batalla *et al.* (1995) and Rodriguez Martinez-Conde *et al*. (1998), among others.

1.26.4 CURRENT EROSION PROCESSES AND RATES

1.26.4.1 Water Erosion (Figure 1.26.9)

Water erosion is the most important type of soil erosion in Spain. Most severe problems occur where rainfall erosivity is high (most of the Mediterranean coast but increasing towards the north-east) and vegetation density is low (autumn is the season with the least protected agricultural soils). The main processes include splash, inter-rill, rill and gully erosion, river bank erosion and pipe erosion, although in general no quantification is provided for specific water erosion processes. Quantities are usually given for total erosion in specific gullies, or on plots, hillslopes and catchments in relation to land use, soil management, plant cover and forest fires.

1.26.4.1.1 Splash

Regüés *et al*. (1995) described the formation of pedestals as a consequence of rainfall experiments over mudstone regolith. A new type of splash cup was designed and tested by Molina and Llinares (1996). Bochet *et al*. (2002) measured in Valencia the influence of plant morphology on soil detachment and Downward (2000) in the Tabernas badlands described the splashed material produced by different types of soil crust under a variety of rainfall events.

1.26.4.1.2 Rill and Inter-rill

Rill and inter-rill erosion are the most commonly described and quantified processes based on direct measurements (profile-metres, erosion pins), experimental runoff plots and micro-catchments, with both

Figure 1.26.9 Hot spots for water erosion (areas with leaning lines), wind erosion (dotted areas) and mass movements (areas with horizontal lines)

natural and simulated rainfall. Cerdà (2001), in a review of soil erosion only in the Valencia autonomous region, provides data from 72 runoff plots and 109 rainfall simulations, with maximum values for plots of 18.46 $t\,ha^{-1}$ on a 40×8 m bare plot in a single event (Sánchez *et al*., 1994), and 8.1 $t\,ha^{-1}\,yr^{-1}$ under matorral and a total precipitation of 459 mm during one year (Table 1.26.3). For rainfall simulation, maximum values of 26 $t\,ha^{-1}\,h^{-1}$ under rainfall intensities of 55 $mm\,h^{-1}$ have been reported on marls in badlands (Cerdà and García-Fayos, 1997). These values are similar to those reported for areas of cultivated soils, matorral and forests, and also from badlands, where rates can exceed 100 $t\,ha^{-1}\,yr^{-1}$. Romero *et al*. (1999), on plots 10×2 m over 3 years under 300 mm of annual rainfall, showed an order of magnitude increase in erosion from fallow or shrubland to cereals (Table 1.26.3). Martínez-Mena *et al*. (2002) recorded on large plots (328 and 759 m^2) from less than 2 to 12 $t\,ha^{-1}$ in 3 years on shrubland with slopes of 23–35% with annual rainfall of 286 mm (Table 1.26.3). Cerdà (1997) measured sediment concentration in runoff from more than 1 to 200 $g\,l^{-1}$, the latter in badlands, but under relatively dense plant cover erosion is dramatically reduced and sediment concentrations are usually less than 1 $g\,l^{-1}$. Chirino *et al*. (2001) found on bounded erosion plots in open pine forest sediment losses of 0.020 $t\,ha^{-1}\,yr^{-1}$ and one order of magnitude higher, 0.310 $t\,ha^{-1}\,yr^{-1}$, under alpha grass and 1.9 $t\,ha^{-1}\,yr^{-1}$ on bare soil (Table 1.26.3). Plant cover reduced erosion by up to 98% and an asymptotic model was obtained for the estimation of annual soil losses for a precipitation range of 330.4 ± 105 mm : $y = a \times b^{pc} \times c^{LAI}$ (where pc = plant cover and LAI = leaf area index).

Experiments in Fuente Librilla, Murcia, showed that the soil type determines the hydrological response, regardless of rainfall intensisty, and also a time-dependent size distribution of the eroded material (decreasing coarse fractions and increasing fine fractions with runoff time) was observed (Martínez-Mena *et al*., 2002).

TABLE 1.26.3 Soil loss by sheet and rill erosion from selected runoff plots in Spain

Reference	Location	Plot size (m)	Period	Slope	Soil type	Annual precipitation (mm)	Land use	Soil loss
Scoging, 1982	Granada	30 × 6	10–75 to 10–76	15–35°	Silty regolith	n.a.	Badland	36.9–93.6 t ha^{-1}
Marquès *et al.*, 1987	NE Spain	6.4 m^2	1993	5°	Typic Xerochrept	528.5	Orchard (contour cultivation)	24 t ha^{-1} yr^{-1}
Marquès *et al.*, 1987	NE Spain	6.4 m^2	1994	5°	Typic Xerochrept	628.5	Orchard (contour cultivation)	3.58 t ha^{-1} yr^{-1}
Francis, 1990	Murcia	3 m^2	3 years	5.6–10.3°	Marly regosols	<300	Fallow terraced fields	0.8–5.3 t ha^{-1} yr^{-1}
Sirvent *et al.*, 1993	Central Ebro basin	57 m^2	07–91 to 05–92	5°	Miocene clays	320	Bare rangeland	74 t ha^{-1} yr^{-1}
Sirvent *et al.*, 1993	Central Ebro basin	24 m^2	07–91 to 05–92	23°	Miocene clays	320	Bare rangeland	112 to 180 t ha^{-1} yr^{-1}
Rubio *et al.*, 1993	Valencia	11–34 m^2	09–92 to 04–93	25–35%	Haplic Calcisol	241–497	Burned pine forest	0.11 to 4.34 t ha^{-1}
Quine *et al.*, 1994	Ebro basin	52 ha	n.a.[a]	5–15°	Rc - Bk[b]	450	Cultivated (cereals)	16–25 t ha^{-1} yr^{-1}
Quine *et al.*, 1994	Ebro basi	52 ha	n.a.	5–15°	Rc - Bk[b]	450	Shrubland	2–4 t ha^{-1}
Poesen *et al.*, 1996	Almeria	n.a.	1983–93	1–5°	Mollic Palexeralf	<200	Abandoned	2 m^3 ha^{-1} yr^{-1}
Cerdà, 1997	Valencia	0.25 m^2	One event	>10°	Marl	60 mm h^{-1}	Badland	21.98 t ha^{-1} h^{-1}
Vila García *et al.*, 1998	Galicia	25–50 m^2	04–96 to 12–96	5–10°	Humic Cambisol	850	Cultivated (20–90% plant cover)	18 t ha^{-1}
Vila García *et al.*, 1998	Galicia	25–50 m^2	1997	5–10°	Humic Cambisol	1845.6	Cultivated (50–90% plant cover)	13–18 t ha^{-1}
Romero *et al.*, 1999	El Ardal (SE Spain)	10 × 2	01–91 to 08–94	7–28%	Xerollic Paelorthid	300	Fallow	0.088
Romero *et al.*, 1999	El Ardal (SE Spain)	10 × 2	01–91 to 08–94	7–28%	Xerollic Paelorthid	300	Shrubs	0.0657
Romero *et al.*, 1999	El Ardal (SE Spain)	10 × 2	01–91 to 08–94	7–28%	Xerollic Paelorthid	300	Cereals	0.614
Romero *et al.*, 1999	El Ardal (SE Spain)	10 × 2	01–91 to 08–94	7–28%	Xerollic Paelorthid	300	Cleared shrubs	0.455
Edeso *et al.*, 1999	Euskadi	5 × 2	01–94 to 07–94	40–50%	Forest soil	1500	Three treatments[c]	39.69 t ha^{-1} h^{-1}

(*Continued*)

TABLE 1.26.3 (*Continued*)

Reference	Location	Plot size (m)	Period	Slope	Soil type	Annual precipitation (mm)	Land use	Soil loss
Edeso *et al*., 1999	Euskadi	5 × 2	01–94 to 07–94	40–50 %	Forest soil	1500	Stem-only harvested	9.32 t ha^{-1} h^{-1}
Duiker *et al*., 2001	SW Spain	0.75 × 1	1998	30 %	Vertisol	60 mm h^{-1}	Experim. field	4.15 t ha^{-1} h^{-1}
Duiker *et al*., 2001	SW Spain	0.75 × 1	1998	30 %	Yellow Alfisol	60 mm h^{-1}	experim. field	12.03 t ha^{-1} h^{-1}
de Alba *et al*., 2001	Central Spain	25 × 5	4 years (93–97)	9 %	Typic Haploxeralf	450	No tillage	3.6 t ha^{-1} yr^{-1}
de Alba *et al*., 2001	Central Spain	25 × 5	4 years (93–97)	9 %	Typic Haploxeralf	450	Conventional tillage	6 t ha^{-1} yr^{-1}
de Alba *et al*., 2001	Central Spain	25 × 5	4 years (93–97)	9 %	Typic Haploxeralf	450	Fallow	7.3 t ha^{-1} yr^{-1}
Ros *et al*., 2001	Murcia	10 × 3	8 events	15 %	Xeric Torriorthent	175 (8 events)	Control plot	3 t ha^{-1} yr^{-1}
Ros *et al*., 2001	Murcia	10 × 3	8 events	15 %	Xeric Torriorthent	175(8 events)	Sewage + compost amended	0.17 t ha^{-1} yr^{-1}
Martinez-Mena *et al*., 2002	Murcia	2 × 1	Rainfall simul.	10–15 %	Calcaric regosol	30–60 (event)	Orchard	0.03 t ha^{-1} min^{-1}
Martinez-Mena *et al*., 2002	Color (SE Spain)	328 m^2	26 events in 3 yr	35.50 %	Xeric Calcigypsid	286	Shrubland	1.89 t ha^{-1} in 3 yr
Martinez-Mena *et al*., 2002	Abanilla	759 m^2	35 events in 3 yr	22.90 %	Xeric Torriorthent	286	Shrubland	12.07 t ha^{-1} in 3 yr
Benito et al. 2003	Galicia	1 m^2	One event 1998	19 %	Distrudepts	64 mm h^{-1}	Deforested land	3.28 t ha^{-1} h^{-1}
Benito et al. 2003	Galicia	1 m^2	One event 1999	24 %	Distrudepts	64 mm h^{-1}	Woodland	0.0094 t ha^{-1} h^{-1}
De Luis *et al*., 2003	Alicante	2 × 2	One event	26–27°	Typic Calcixeroll	273 (event)	Shrubland	0.02–0.06 t ha^{-1} yr^{-1}
De Luis *et al*., 2003	Alicante	2 × 2	One event	26–27°	Typic Calcixeroll	273 (event)	Burned shrubland	0.3–8.4 t ha^{-1}
Martinez-Raya, 2003	Granada	24 × 6	One event	33–38 %	Semi-arid soil	13.7 (event)	Traditional tillage	0.173 t ha^{-1}
Martinez-Raya, 2003	Granada	24 × 6	One event	33–38 %	Semi-arid soil	13.7 (event)	No tillage	0.331 t ha^{-1}
Martinez-Raya, 2003	Granada	24 × 6	One event	33–38 %	Semi-arid soil	13.7 (event)	Full plant cover	0 t ha^{-1}

[a] n.a., Not available.
[b] Rc = Calcaric Regosol; Bk = Calcic Cambisol.
[c] tree harvested + litter removed + ploughing.

1.26.4.1.3 Gully Erosion

Gully erosion has been described and measured in several locations (Schnabel and Gómez-Amelia, 1993; Faulkner, 1995; Martínez-Casasanovas *et al.*, 1998; Vandekerkhove *et al.*, 1998, 2000; Casali *et al.*, 1999, 2003; Nogueras *et al.*, 2000; Poesen *et al.*, 2002) and most such studies conclude that gullies are a dominant sediment source. In two locations in south-eastern Spain, on abandoned agricultural land, the contribution of permanent gullies to mean sediment production over a 10-year period equals 83 % of total sediment produced by water erosion, with annual rates of 37.6 and 9.7 $t\,ha^{-1}$ (Poesen *et al.*, 2002) (Table 1.26.4).

Poesen *et al.* (2002) indicate that: 'the importance of sediment production by gullies in drylands can be assessed when comparing mean sediment deposition rates in Spanish reservoirs with the sediment production by inter-rill and rill erosion measured on runoff plots. Mean sediment deposition rate over a period of 5–101 years (Avendaño Salas *et al.*, 1997) in Spanish reservoirs with corresponding catchments ranging between 31 and 16 952 km^2 equals to 4.4 $t\,ha^{-1}\,yr^{-1}$ and can even go up to 10 $t\,ha^{-1}\,yr^{-1}$ or more (López-Bermúdez, 1990; Romero-Díaz *et al.*, 1992; Avendaño Salas *et al.*, 1997) (Table 1.26.5). These figures are significantly higher than reported short- to medium-term rates of inter-rill and rill erosion in the Mediterranean as measured on runoff plots (Andreu *et al.*, 1998; Castillo, 1999; Puigdefábregas *et al.*, 1999; Romero-Diaz *et al.*, 1999; Cerda, 2001), i.e. less than or equal to 0.1 $t\,ha^{-1}\,yr^{-1}$ for shrubland and olive groves, 0.2 $t\,ha^{-1}\,yr^{-1}$ for wheat and 1.4 $t\,ha^{-1}\,yr^{-1}$ for vines (Kosmas *et al.*, 1997)'.

Moreover, a recent study in the catchments of 22 Spanish reservoirs indicates that specific sediment yield increases when the frequency of gullies increases in the catchment (Konickx, 2000, cited by Poesen *et al.*, 2002).

The ephemeral gully erosion model (EGEM) (Woodward, 1999) did not show a good relationship between predicted and measured ephemeral gully cross-sections in south-eastern Portugal (Nachtergaele *et al.*, 2002), although good relationships were found in north-eastern Spain on vineyards (Meyer and Martinez-Casasnovas, 1999).

Piping may have an important role in the initiation and to a lesser extent, development of some gully systems such as bank gullies and gullies forming on badland areas in Mediterranean regions (Poesen *et al.*, 2002).

1.26.4.1.4 Pipe Erosion

Pipe erosion has also been studied at several locations where high-risk materials are abundant (Tertiary sedimentary basins): Harvey (1982) and Faulkner *et al.* (2000) in Almeria; López-Bermúdez and Torcal Sáinz (1986) and López-Bermúdez and Romero-Díaz (1989) in Murcia; Martín-Penela (1994) in Granada; García-Ruíz *et al.* (1997a) in the Central Pyrenees; Gutiérrez *et al.* (1997) in the Ebro valley.

1.26.4.2 Mass Movements

In Spain, owing to its geological, orographic and climatic characteristics, the risk of landslides on slopes is significant. Yearly losses due to damage by landslides is calculated to be over €120 million (Ayala *et al.*, 1987), which, updated by means of the index of consumer prices (INE 2003), would now be around €240 million. The wide variety of lithologies, morphologies and climate zones in Spain causes irregular distribution of hillside instability phenomena. The western and central sectors of the country that make up the Hercynian base of the Meseta are the least problematic owing to the resistance of its materials (plutonic rock, gneiss, quartzite, schists) and gentle morphology. In contrast, the peripheral Alpine mountain ranges record the greatest number of phenomena, owing to their young relief, high rainfall and the presence of lithologies susceptible to mass movements. Corominas (1989) inventoried all lithologies suceptible to mass movements, indicating their location and the mechanism by which mudflows are produced (Corominas and Moreno, 1988).

TABLE 1.26.4 Soil loss from selected gullies in Spain[a]

Reference	Location	Size (ha)	Period	Slope (%)	Soil type	Annual precipitation (mm)	Land use	Soil loss
Poesen *et al.*, 1996	Almeria		1983–93	n.a.	Mollic Palexeralf	<200	Abandoned	$9.7\ m^3\ ha^{-1}\ yr^{-1}$
Schnabel *et al.*, 1998	Extremadura	35.4	7.5 years	n.a.	Brown Mediterranean–Lithosols	514.3	*Dehesa*	$39.05\ m^3\ yr^{-1}$
Casali *et al.*, 1999	Navarra		2 years		Badland	Usual in the area	Badland	$26.6\ t\ ha^{-1}$
Hooke and Mant, 2000	Murcia	4110	Sep-97	0.0072	Many types	365	Grazing	$53.185\ kg\ m^{-1}$
Oostwoud Wijdenes *et al.*, 2000	Murcia		04–97 to 03–99		Quaternary fill and marls	300	Shrubs, alpha grass	$4\ m^3\ yr^{-1}$
Martinez-Casasnovas *et al.*, 2002	Catalonia	2.12	One event	8.90	[b]	215 mm event	Cultivated	$207\ t\ ha^{-1}$
Valcarcel *et al.*, 2003	Galicia	36.8	1997–99	15	Silt-loam and loam	1000–1500	Cultivated	$2.12\ m^3\ ha^{-1}$

[a]Note that soil loss is [illegible]ssed differently according [illegible]fferent studies (volume or weight per contributing area per year, weight per year or weight per gully length).
[b]Xerorthent typic, Colcixerept typic, Calcixerept petrocalcie, Haploxerept fluventic.

TABLE 1.26.5 Sediment yield from selected large basins and catchments in Spain

Reference	Location	Size (km^2)	Period	Annual precipitation (mm)	Land use	Soil loss ($t\,ha^{-1}\,yr^{-1}$)
Wise *et al*., 1982	Granada (SE)		2000 years	400	Badlands	0.16–0.4
Benito *et al*. 1991	Miño–Lugo (NW)	2303	1990?	n.a.	n.a.	4.7
Benito *et al*. 1991	Tambre-Portón (NW)	1146	1990?	n.a.	n.a.	9.3
Avendaño *et al*. 1997	Embarcaderos (SE)	18952	>10 years	600	n.a.	0.17
Avendaño *et al*. 1997	Riudecañas (NE)	31	>10 years	800	n.a.	1.12
Avendaño *et al*. 1997	Puentes (SE)	1042	101 years	400	n.a.	2.02
Avendaño *et al*. 1997	Guadalest (E)	60	>10	600	n.a.	27.03
Lajournade *et al*., 1998	Central Pyrenees	18.8	One event	160 mm in 2 h	Forest	$67\,t\,ha^{-1}$
Arnaez *et al*., 1998	Central Pyrenees	2.84	11 months	1140	Abandoned fields	$1.21\,t\,ha^{-1}$
Regüés *et al*., 1988	Eastern Pyrenees	4.16	1993–98	850	[a]	90–150
Regüés *et al*., 1988	Eastern Pyrenees	0.17	1989–98	850	[b]	0.19

[a] 43% forest, 21% terraces, 3% badlands.
[b] 55% abandoned terraces, 10% forest.

Araña *et al*. (1992), in an exhaustive review of geological risks in Spain, list the main catastrophic landslides recorded since 1620, indicating the type of movement, volume eroded and their effects. The most outstanding are a $10^7\,m^3$ complex translational slide in Pont de Bar (Lleida) in November 1982, which destroyed the entire town and the road, a $3.6 \times 10^6\,m^3$ mudflow in Olivares (Granada) in April 1986, which partially destroyed the town, and another $10^6\,m^3$ mudflow in Inza (Navarra) between December 1714 and April 1715, which destroyed the town.

There are several risk maps at different scales, from 1:1 000 000 (IGME, 1987), in which the zones affected by the different types of mass movements are shown (Figure 1.26.10), and some regional 1:400 000 maps, to the 1:100 000 maps in which the MOPU Geological Service shows problematic areas, types of movements, susceptible lithological formations and angles of stability. The IGME also has made 1:25 000 geotechnicial and geological risk maps for 15 Spanish cities, showing mechanical characteristics of the ground, and there are 1:10 000 and 1:5000 maps showing landslide risk (Araña *et al*., 1992).

There is also an extensive bibliography of specific studies of phenomena related to landslides on hillsides, especially in mountain areas (Del Barrio and Puigdefabregas, 1987; García-Ruíz *et al*., 1990; Cendrero and Dramis, 1996; González-Diez *et al*., 1999), individual studies on the prevention of risks caused by instability, inventories of landslides (Corominas, 1989) and calculations of economic losses (Ayala *et al*., 1987).

1.26.4.3 Wind Erosion

Wind erosion has been reported only locally in susceptible areas (north-western and southern coastal areas, some spots in north-eastern Spain and in the middle Ebro valley) (Figure 1.26.11). After the pioneering work of Quirantes *et al*. (1989) in the south-east, in which a series of maps at 1:400 000 were produced within the LUCDEME project, a new concern about the influence of tillage operations on wind erosion is growing in areas affected by strong W–NW winds (local name *cierzo*), mainly due to the work of Arrue's team at the Aula Dei Institute in Zaragoza. This latter has shown how in the semi-arid drylands of the middle Ebro valley, reduced

Figure 1.26.10 Water erosion in a vineyard in Catalonia (*photo*: JA Martínez-Casasnovas; reproduced with permission)

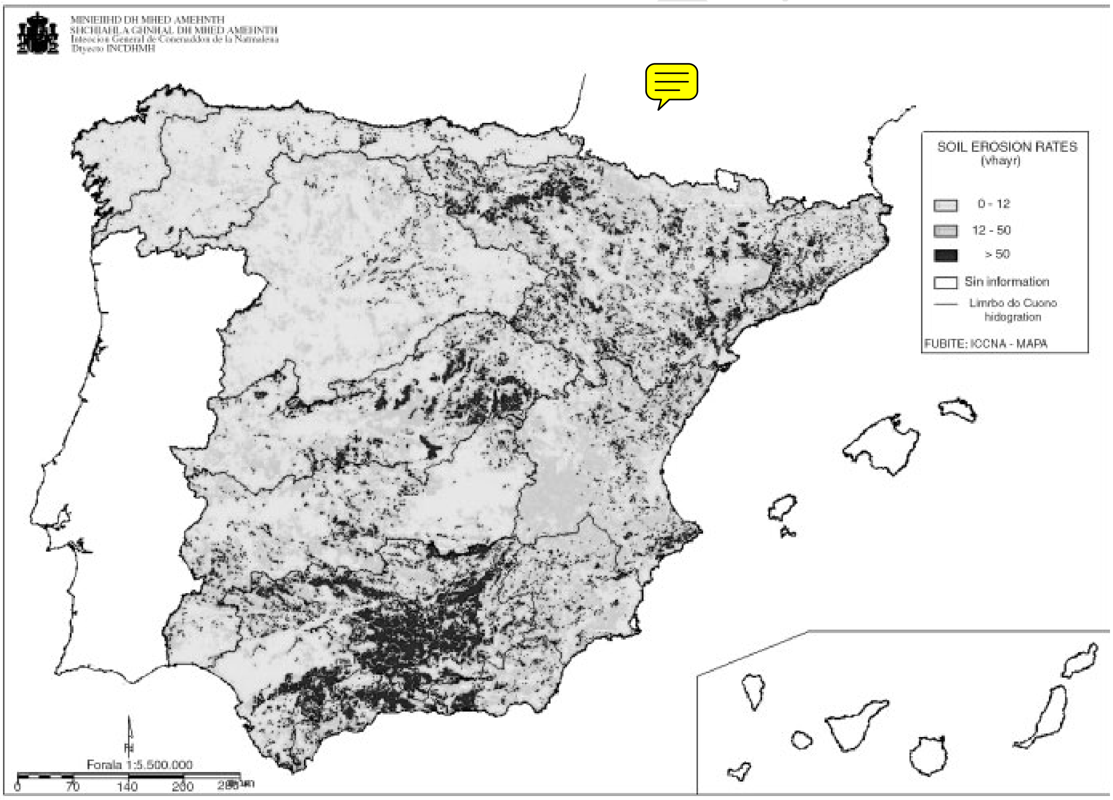

Figure 1.26.11 Erosion rates according to LUCDEME (1987). From lightest to darkest colour, erosion rates are 0–12, 12–50, $> 50\,t\,ha^{-1}$ (totally white areas have no data). (Reproduced from *Map of Soil Erosion in Spain*, 1987, with permission of LUCDEME)

TABLE 1.26.6 Wind erosion rates in Spain from selected studies

Reference	Location	Plot size (m)	Period	Slope	Soil type	Annual precipitation (mm)	Land use	Soil loss (t ha^{-1} yr^{-1})
Sterk *et al.*, 1999	Middle Ebro valley	135 × 180	1996–97	Level	Silt loam	365	Conventional tillage	0.5
Sterk *et al.*, 1999	Middle Ebro valley	135 × 180	1996–97	Level	Silt loam	365	Reduced tillage	0
Lopez., 2001	Middle Ebro valley	135 × 180	17 months	Level	Sandy	<400	Fallow, mouldboard ploughed	>20
Ries *et al.*, 2000	Middle Ebro valley	wind tunnel	Event	Level		n.a.	Fallow land	0.002–0.018

tillage produces larger soil aggregates, greater surface roughness and more protective cover (by plant residues, aggregates and rock fragments), greatly decreasing the risk of wind erosion compared with traditional soil tillage (Lopez, 1998; Lopez *et al*., 1998, 2000, 2001; Sterk *et al*., 1999; Gomes *et al*., 2003) (Table 1.26.6).

1.26.4.4 Tillage Erosion

Tillage erosion has only recently received some notice (Poesen *et al*., 1997; De Alba, 1998; Quine *et al*., 1999). Poesen and Quine worked in the Guadalentin basin (south-eastern Spain), where a direct erosion displacement was given per pass, with the use of metal tracers. De Alba (1998), in Central Spain, with similar tracers, determined that tillage erosion was one order of magnitude larger than water erosion on plots with 15–30% slopes (54.7 and 7.3 t ha^{-1}, respectively) (Table 1.26.7).

However, more authors have studied the effects of different tillage methods on water erosion, such as De Alba *et al.* (2001) and De Alba (2003) in Central Spain and Valcárcel *et al*. (2002) in Galicia with the use of GIS to model the effect of agricultural factors such as the rotation scheme and the characteristics of the tillage system on surface water runoff and erosion. Also, Martínez-Raya *et al*. (2002) in Granada have evaluated different tillage methods on steep slopes. López *et al*. (2003) have studied in dryland systems the impact of soil management on soil resilience and erosion.

1.26.5 MAJOR ON- AND OFF-SITE PROBLEMS AND COSTS

1.26.5.1 On-site Effects

According to data of the Directorate General for Nature Conservation (DGCONA), 48% of Spanish territory (220 000 km^2) shows a soil loss higher than soil tolerance (12 t ha^{-1} yr^{-1}) and 90 000 km^2 (18% of the total) is affected by very intense erosion rates higher than 50 t ha^{-1} yr^{-1}. The soil erosion affected areas are predominantly located in the Mediterranean basin.

Major consequences of soil erosion is reservoir siltation and this is reviewed in Section 1.26.4.1.3.

The abandonment of traditional land-use systems results in a loss of pastoral quality, soil erosion, fire risk and a decrease in biodiversity and threatens vulnerable species (González Bernáldez, 1991).

The protective role of forests on soils includes the maintenance of biological functions, the regulation of nutrients and the storage of carbon.. Martinez-Mena *et al*. (2002) have shown on experimental plots in

TABLE 1.26.7 Soil loss by tillage erosion in Spain

Reference	Location	Plot size (m)	Period	Slope	Soil type	Annual precipitation (mm)	Land use	Treatment	Soil loss ($t\,ha^{-1}\,yr^{-1}$)
Poesen *et al.*, 1997	SE Spin	50 (length)		20%	Eutric Regosol	274	Almonds	Up-and-down tillage	54–88
Poesen *et al.*, 1997	SE Spin	50 (length)		20%	Eutric Regosol	274	Almonds	Countour tillage	22–39
De Alba, 1998	Toledo	4.5 × 2.75	1995–96	9%	Calcic Luvisol	n.a.	Experimental	Tillage along slope	57.4
De Alba, 1998	Toledo	4.5 × 2.75	1995–96	9%	Calcic Luvisol	n.a.	Experimental	Contour tillage	5.9
Quine *et al.*, 1999	SE Spin	n.a.	Pass	24°	[a]	275	Almonds	Conventional tillage	$200\,kg\,m^{-1}$ per pass
Quine *et al.*, 1999	SE Spin	n.a.	Pass	<14°	[a]	275	Almonds	Duckfoot chisel	$657\,kg\,m^{-1}$ per pass
Martinez Raya *et al.*, 2002	Granada	n.a	1 event	>30 %	n.a.	17.2	Olives, almonds	Conventional tillage	0.17
Martinez Raya *et al.*, 2002	Granada	n.a	1 event	>30 %	n.a.	17.2	Olives, almonds	No tillage	0.068
Martinez Raya *et al.*, 2002	Granada	n.a	19 events	>30 %	n.a.	56.9	Olives, almonds	Legum as cover crop	5.0613
Martinez Raya *et al.*, 2002	Granada	n.a	19 events	>30 %	n.a.	56.9	Olives, almonds	Cereal as cover crop	3.6304

[a] Eutric Regosols and Calcaric Cambisols.

Sierra de Orihuela that organic carbon decreased from 4 to 2.8% in the 9 years after vegetation removal. The carbon decrease is equivalent to an estimated loss of 46.8 t ha^{-1} of organic carbon, which is attributed to enhanced mineralization and oxidation of organic matter due to an increase in radiation and the temperature of surface soil layers (Martínez-Mena *et al*., 2002).

Soil erosion by water causes not only the loss of mineral components but also the loss of the organic fraction (organic matter, litter, etc.) and seeds, which are very important for the evolution of soils and landscapes (Cerdà and García-Fayos, 2002). In studies of the process of erosion of seeds, it was found that the interaction between vegetation and erosion that occurs at hillslope scale (e.g. and Puigdefábregas and Sanches, 1996) also occurs on a millimetric scale with seeds. Shapes, sizes, appendages and mucillage of seeds interfere in the erosion process determining the removal and deposit of seeds.

1.26.5.2 Off-site Effects

One of the most dramatic off-site effects of water erosion is that related to floods: morphological impacts and their relation to magnitude and frequency of floods in ephemeral streams of Mediterranean Spain (Lopez-Bermúdez *et al*., 2002). Such impacts include bank erosion, modifications of the channel where banks were overtopped, and floodplain sedimentation. In the 1973 flood on the Nogalte rambla in south-eastern Spain, sediment loads of 40 % of the volume of flow (which reached over 2000 m^3 s^{-1}) were recorded (Heras, 1973, in Lopez-Bermúdez *et al*., 2002), resulting in many casualties and damage to buildings and civil works. However, this is only one case of 2400 recorded flood events in Mediterranean Spain since 1450 (Lopez-Bermúdez *et al*., 2002). Peak flow discharges over 1000 m^3 s^{-1} have been estimated for six Southern Spanish ephemeral rivers for a return period of 25 years (Heras, 1973, in López-Bermúdez *et al*., 2002).

Atlantic rivers, such as the Tagus, also produce important floods, estimated from historical documents or evaluated by means of paleohydrological methods (Benito, 2002; Benito *et al*., 2003).

Another consequence of soil erosion is reservoir silting. The mean sediment deposition rate over a period of 5–101 years (Avendaño Salas *et al*., 1997) in Spanish reservoirs with corresponding catchments ranging between 31 and 16 952 km^2 equals 4.4 t ha^{-1} yr^{-1} and can even go up to 10 t ha^{-1} yr^{-1} or more (Avendaño Salas *et al*., 1997; Lopez Bermúdez, 1990; Romero-Diaz *et al*., 1992).

According to Olcina (1994), between 1983 and 1993, the economic losses caused by natural disasters in Spain, including earthquakes, never exceeded 1% of the gross national product, i.e. €3000 million at that time. Taking into account that natural disasters include droughts, floods, mass movements, earthquakes, forest fires and soil erosion, is not easy to assign a given percentage to losses related to soil erosion. However, Ayala *et al*. (1988), estimated the potential losses for soil erosion during the period 1986–2016 at €5200 million (assessed in 1986), i.e. about €173 million per year, while landslides would cost between €5350 and 4500 million (assessed in 1986).

1.26.6 SOIL CONSERVATION AND POLICIES TO COMBAT EROSION AND OFF-SITE PROBLEMS

Chapter 2.23 by Fullen *et al*. deals with the same topic, so only complementary information is provided here.

Since the end of the 18th century, a few authors have shown their concern about erosion in Spain, and even considered it as one of the most important problems (Mallada, 1890). Specific research into the problem, however, did not start until the second half of the 20th century. At that stage, erosion was approached as a technical problem, and research was focused on the development of measures to avoid both sedimentation in reservoirs and damage to civil works. In 1955, the *Servicio Central de Conservación de Suelos* was created, but the first quantification of erosion was not available until the 1970s. At present, erosion is considered by different institutions within the Ministry of Environment (Dirección General de Conservación de la Naturaleza, formerly ICONA, and the 10 *Confederaciones Hidrográficas* or Basin Authorities).

According to an official report (Presidencia del Gobierno, 1977), most of the country was affected by severe water erosion, and only the north-western and northern-central regions were affected to a moderate degree. In 1987, ICONA, CSIC and some Universities, established the ongoing project LUCDEME (*Lucha contra la Desertificación en el Mediterráneo*) to combat desertification in Mediterranean drainage basins. Since then, a series of maps of actual and potential soil erosion have been produced.

The Spanish Forest Administration has long experience in protecting soil against water erosion and restoring degraded vegetable cover. Since 1901, when the Hydrology and Forest Divisions were created to revegetate thousands of hectares, several reforestation plans have been launched. From 1940 to 1980, more than 2.5×10^6 ha were afforested and complementary programmes for soil conservation and soil agricultural productivity maintenance were implemented. In the last decade, most responsibility for forest resources and nature conservation has been transferred to the Autonomous Communities from the Environment Ministry, although Central Government continues to coordinate plans and programmes related to soil protection and desertification control through DGCN (formerly ICONA, General Directorate for Nature Conservation).

However, the negative impact of some political measures on soil erosion, at regional, national and European scales, have been raised by Faulkner (1995), García Pérez *et al*. (1995) and García Pérez (1999), who mentioned very damaging soil preparation methods and the almost exclusive use of coniferous trees, among others. However, recent studies (Rojo Serrano *et al*., 2002) prove that mechanized afforestation techniques in the Guadalentin basin (south-eastern Spain), such as terracing and subsoiling, have been more effective than manual methods (holes, bench terraces and strips) in cutting hillslope runoff and retaining and storing as much water as possible.

Moreover, the rate of implementation of recent revegetation plans has been too slow to reverse erosion trends, and efforts to push back desertification should be stepped up (OECD conclusions and recommendations, 1997).

IN 1995, a network of experimental stations for monitoring and assessing erosion and desertification (RESEL) was established consisting of 47 representative field sites in problematic environments where erosion is being monitored at small scales on plots, hillslopes and/or in small catchments (Rojo Serrano and Sanchez Fuster, 1996). The RESEL network was formed by experimental stations from CSIC and some Universities. However, the scarcity of funding is a threat to its continuity.

In 2002, DGCN started a new national inventory of soil erosion (INES) with a 10-year periodicity with objectives to locate, quantify and analyse the evolution of erosion processes in Spain, with a final aim of giving priority to areas in which to fight erosion, and also to define and evaluate actions to carry out within the different national plans (reforestation, plant cover improvement and management of biodiversity in forests). For every province the following erosion types are inventoried and mapped (at a scale of 1:50 000): rill erosion, gully erosion, river bank erosion, mass movements and wind erosion. So far three provinces (Madrid, Murcia and Lugo) have been completed, five more are fairly advanced and the other five are under way.

In addition to the national involvement in the assessment of soil erosion, local, regional and international concerns have been addressed by several organizations, but the results do not always agree. Sanchez Diaz *et al*. (2001) showed the discrepancies in some cartographic documents from ICONA (national), CORINE (European) and GLASOD (international), which might be due to different methodologies, input data and scales used.

1.26.7 CONCLUSIONS

In Spain, erosion is produced as a result of a set of processes over a variety of landscapes (forming a finer mosaic than in more humid areas). Centuries of anthropogenic action, especially in the Mediterranean region, have resulted in large areas of highly erodible, shallow soils with low organic matter content. Land-use changes and disturbances (urbanization, road construction, forest fires, abandonment of land, especially terraces) have been reported as the main causes of severe erosion. Even reforestation of sensitive deforested areas has also been described as causing significant erosion.

Many of the reviewed documents indicate that accelerated erosion is a widespread and important concern in Spain and most emphasize the role of extreme events in long-term soil loss, especially in semi-arid regions.

What was stated by Wise *et al*. (1982) for south-eastern Spain regarding '. . .the difficulty of establishing contemporary rates of erosion: events are not only of high magnitude and infrequent occurrence, but also spatially discontinuous and greatly influenced by human activities' applies to most of Spain: erosion is more a collection of individual, local problems than a general one, as is commonly considered. Moreover, as most present erosion rates have been obtained from measurements on single gullies, small plots or small catchments, quantitative assessments of large areas should not be made by extrapolation. This effect of scale in erosion rates is extremely important: runoff is generated discontinuously on slopes so that fluxes of water transporting sediment from the top to the bottom rarely exist except in badlands, artificial taluses, roads, highways and urban zones. Sediments undergo a constant redistribution process in which plants play a fundamental role. Therefore, erosion is a slow process, although it can be accelerated under extreme events.

In spite of the initial alarm because of the high erosion rates estimated by the USLE, after 20 years of studies in Spain, it has been confirmed that, although there are erosion problems, severe erosion is restricted in space (specific areas of the country such as badlands, highway earthworks and restored zones) and in time (after fires, after agricultural abandonment, after ploughing). However, this does not mean that a broader perspective should not be considered in addressing soil erosion over the whole of Spain: erosion should be considered for a broad range of landscapes (steep and flat land) and relationships established for different land uses and management practices.

Erosion from rills and ephemeral gullies is more important than inter-rill erosion. At the agricultural plot scale, erosion along plot discontinuities (drainage paths, pathways, plot boundaries) and natural drainage pathways are much more important than erosion within plots, where most sediments remain. At the catchment scale, effective areas of sediment production are only a small percentage of the total catchment area.

Zones with intense natural erosion represent only a small loss of the overall soil resource, and may produce forms of high aesthetic value (especially in humid or sub-humid mountain regions), although they represent an important sediment source, which is its main nuisance from an environmental point of view (degradation of water quality, silting of reservoirs).

Soil conservation and protection measures should be applied following specific criteria for every region, taking into account physical and socio-economic factors, and considering spatial and temporal scales (recurrent torrential storms and droughts). The magnitude of soil loss tolerance for different environments and the capacity of such environments to withstand different soil losses should also be considered (a loss of 20 cm of soil over hard limestone is not comparable to the loss of a similar soil thickness over a soft parent material which is several metres thick).

In the years to come, soil erosion should be approached by modelling in which temporal and spatial scales are taken into account.

Finally, the study of soil erosion should not be dissociated from the essential study of Spanish soils (precise characterisation, formation processes and behaviour under different land uses and managements) or from the present and potential uses of the best soils, especially those from coastal areas which are being sealed by urbanization and roads. Regional characterization allowing soil conservation and a sustainable soil use should be a priority.

List of Abbreviations

CSIC	Spanish Research Council
CEAM	Centre for Environmental Mediterranean Studies
ICTJA	Earth Science Institute 'Jaume Almera'

EEZA	Experimental Station for Arid Zone Studies
EEZ	Experimental Station 'El Zaidin'
EEAD	Experimental Station 'Aula Dei'
IPE	Institute of Pyrenean Ecology
CIDE	Centre for Desertification Studies
CEBAS	Centre of Soil Science and Applied Biology of the Segura Basin
CCMA	Centre for Environmental Studies
UPC	Polytechnic University of Catalonia
UPM	Polytechnic University of Madrid
CEDEX	Centre for Experimental Studies on Civil Engineering
DGCN	Directorate General of Nature Conservation

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