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Technical Working Group on Erosion

Task Group 2 on

Nature and Extent of Soil Erosion in Europe

Final Report

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by

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Objectives WP2:

To appraise the current situation with respect to soil erosion using existing data, information systems and models; To establish harmonised criteria and guidelines for the development and use of indicators assessing the present soil erosion risk or state as well as trends in soil erosion over time.

Description of the work:

2.1 Identify different forms of soil erosion processes or mechanisms causing mass movements and consequent soil loss, as well as their relevance in different Member States (MS) and their inclusion in current soil erosion methodologies

- Water erosion
  - Rills and inter-rill erosion
  - Gully erosion
  - Snowmelt erosion
  - Bank erosion in rivers and lakes
- Disturbance or translocation erosion
  - Tillage erosion
  - Land levelling
  - Erosion due to harvesting of root crops
  - Erosion by trampling and burrowing animals
- Wind erosion
- Coastal erosion
- Landslides and debris flows
- Internal erosion provoked by groundwater flows

2.2 Review and analyse existing soil erosion assessment methodologies at European and national scales (including soil erosion indicators)

Analyse the results obtained in terms of erosion rates, potential and actual erosion risk, vulnerability areas. Compare the result and check possible inconsistencies.

2.3 Synthesis report of extent of soil erosion in Europe

Based on the information derived from the task 2.2 and, after a critical review, a synthesis report on the nature and extent of soil erosion should be delivered by the workgroup. This report might include the weak points and uncertainties, which have been pointed out in task 2.2.

2.4 Definition of benchmarks and soil erosion indicators

Assessment of existing soil erosion indicator systems: applicability at European and national level. Establish harmonised criteria and guidelines to develop a European soil erosion indicator system.

2.5 Secondary Threats

- Compaction: report on likely geographical extent, particularly in subsoils, in Europe and the links with erosion.
- Salinisation: report on nature and extent in Europe.

Acknowledgements

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Summary

1. Soil erosion is a natural process, occurring over geological time, and indeed it is a process that is essential for soil formation in the first place.
2. With respect to soil degradation, most concerns about erosion are related to accelerated erosion, where the natural rate has been significantly increased by human activity.
3. Soil erosion by water is a widespread problem throughout Europe.
4. The processes of soil erosion involve detachment of material by two processes, raindrop impact and flow traction; and transported either by saltation through the air or by overland water flow.
5. Combinations of these detachment and transport processes give rise to the main processes of 'Rainsplash', 'Rainwash', 'Rillwash', and Sheet wash.
6. Runoff by rainfall and from snowmelt is the most important direct driver of severe soil erosion by water and therefore processes that influence runoff play an important role in any analysis of soil erosion intensity. Measures that reduce runoff are critical to effective soil conservation.
7. The most dominant effect is the loss of topsoil, which is often not conspicuous but nevertheless potentially very damaging.
8. Physical factors like climate, topography and soil characteristics are important in the process of soil erosion.
9. The Mediterranean region is particularly prone to erosion because it is subject to long dry periods, followed by heavy bursts of erosive rain, falling on steep slopes with fragile soils.
10. This contrasts with NW Europe where soil erosion is less, because rain falling on mainly gentle slopes is evenly distributed throughout the year and consequently, the area affected by erosion is less extensive than in southern Europe.
11. However, erosion is still a serious problem in NW and central Europe, and is on the increase.
12. In parts of the Mediterranean region, erosion has reached a stage of irreversibility and in some places erosion has practically ceased because there is no more soil left.
13. With a very slow rate of soil formation, any soil loss of more than 1 t $ha^{-1}yr^{-1}$ can be considered as irreversible within a time span of 50-100 years.
14. Losses of 20 to 40 t ha^{-1} in individual storms, that may happen once every two or three years, are measured regularly in Europe with losses of more than 100 t ha^{-1} in extreme events.
15. The main causes of soil erosion are still inappropriate agricultural practices, deforestation, overgrazing, forest fires and construction activities.
16. The identification of areas that are vulnerable to soil erosion can be helpful for improving our knowledge about the extent of the areas affected and, ultimately, for developing measures to control the problem.
17. For assessing soil erosion risk, various approaches can be adopted that distinguish between *expert*-based and *model*-based methods.
18. The CORINE programme, an example of an expert-based approach, assessed the risk of soil erosion in Mediterranean Europe by overlaying soil, climate and topography using GIS technology.
19. Another example of an expert-based approach is GLASOD – Global Assessment of Soil Degradation. The GLASOD map identifies areas with a subjectively similar severity of erosion risk, irrespective of the conditions that would produce this erosion.
20. The Hot Spots Map, commissioned by the EEA, is a third example of the expert-approach. The spatial representation of areas at risk from erosion is too general to be of use to policy makers, but the study that produced it did extract data from the literature on actual sediment losses for a number of locations in Europe.
21. The availability of digital data sets in recent years has facilitated application of the model-based approach.
22. The USLE is a simple empirical model, based on regression analyses of rates of soil loss from erosion plots in the USA. It is designed to estimate long-term annual erosion rates on agricultural fields.

23. The map of erosion risk in Europe produced using the USLE model was a first attempt, using a standardised approach, to quantify soil erosion by rill and interrill erosion for the whole continent.
24. The Pan-European Soil Erosion Risk Assessment - PESERA - project has developed and is currently calibrating a process-based, spatially distributed model to quantify soil erosion by water and assess its risk across Europe.
25. However, other modelling approaches are needed in areas where other forms of erosion are dominant, e.g. by wind, snowmelt, etc.
26. The most extensive and most severe wind erosion is mapped in southeastern Europe with moderate wind erosion observed in the Czech Republic and parts of France, the UK and Hungary.
27. The EU-projects WEELS and WELSONS suggest that the area affected by wind erosion is probably much larger than previously thought. The estimated losses by wind of 21 t ha^{-1} yr^{-1}, over a 30-year period in southeast England, compare closely with estimated rates of water erosion in other parts of northwest Europe.
28. It is clear that erosion by water and wind is irreversibly degrading the soils in many parts of Europe, sometimes in a dramatic way in southern Europe and also in a less obvious but still damaging way in northern areas. In both cases off-site impacts are damaging as on-site effects.
29. The existing European Soil Database provides a harmonised basis for broadly identifying the areas most at risk and for examining the processes responsible. This coupled with CORINE land cover, a suitable DEM and climate data, provides a good basis for modelling erosion.
30. However, at present, reliable point data on actual soil loss and its trend in future are very scarce, particularly in southern Europe.
31. Process-based models, such as PESERA, offer some hope for obtaining better predictions of soil erosion by water than estimates made in the past.
32. Of the models reviewed here PESERA is the most conceptually appropriate because it takes into account: (i) runoff and eroded sediments separately; (ii) daily rainfall accumulated by month; (iii) dynamic crusting and vegetation cover by month; (iv) other climatic information such as freezing days.
33. The results of national studies from Austria, Belgium, Bulgaria, Czech Republic, France, Germany, Hungary, Italy, Spain, Slovakia, Switzerland and UK are briefly reported here. Though these provide valuable data for checking model estimates, such as those from PESERA, they cannot be a substitute for a standard European approach.
34. For precise environmental auditing, model estimates must be validated at sites where actual sediment losses are measured and, to quantify trends, erosion measurements should be added to the list of those that are needed for the whole of Europe.
35. Nothing less than a continent-wide soil monitoring network will be needed to provide such data. Refining erosion models and improving the resolution and accuracy of spatial data should go ‘hand in hand’ with real measurements, albeit at selected benchmark sites.
36. However in the immediate future, the area identified as being at high risk from erosion should be used as an overall ‘indicator of state’, and thereafter monitoring land cover can provide a valuable insight into whether or not the amount of erosion is likely to be increasing.
37. The status and distribution of the secondary threats of compaction and salinisation are also described in this report.
38. The overall deterioration in soil structure caused by compaction can (i) increase the risk of soil erosion on sloping land, through the concentration of excess water above compacted layers; and (ii) accelerate effective runoff from and within catchments.
39. Soil salinisation affects an estimated 1 to 3 million hectares in the enlarged EU, mainly in the Mediterranean countries. It is regarded as a major cause of desertification and therefore is a serious form of soil degradation. With recent increases in temperature and decreases in precipitation, characteristic of climate in recent years, the problem of salinisation in Europe is getting worse.

2.1 Soil erosion processes or mechanisms causing soil loss

Soil erosion is a natural process, occurring over geological time, but most concerns are related to accelerated erosion, whereby the natural rate has been significantly increased by human action. These actions have generally been through stripping of natural vegetation for cultivation, indirect changes in land cover through grazing and controlled burning or wildfires, through re-grading of the land surface and/or a change in the intensity of land management, for example through poor maintenance of terrace structures.

Resulting changes to the soil cover allow natural forces of erosion to remove the soil much more rapidly than soil-forming processes can replace it. Any soil loss > 1 t $ha^{-1}yr^{-1}$ can be considered irreversible within a span of 50-100 years

Erosion literature commonly identifies 'tolerable' rates of soil erosion, but these rates usually exceed the rates that can be balanced by weathering of parent materials to form new soil particles. Erosion is a normal process of soil formation and may be considered acceptable from an economic viewpoint. It is clear that on most productive land there is an overall loss of soil material that is becoming increasingly unacceptable.

Soil erosion is regarded as the major and most widespread form of soil degradation, and as such, poses severe limitations to sustainable agricultural land use. Soil can be eroded away by wind and water. Strong winds can blow away loose soils from flat or hilly terrain. Erosion by water occurs due to the energy of water when it falls to the earth and flows over its surface.

2.1.1 Background

Agriculture, forestry and urbanisation strongly affects the rate and types of hillslope processes, and the way in which land is managed can dramatically influence whether soil erosion remains at an acceptable level, or is increased to a rate leading to long-term and perhaps irreversible degradation of the soil.

Slope sediment transport processes are of two very broad types, first the weathering and second the transport of the regolith, with a number of separate processes within each type (Table 2.1); many of these processes occur in combination. Most slope processes are greatly assisted by the presence of water, which helps chemical reactions, makes masses slide more easily and carries debris as it flows. For both weathering and transport, the processes can conveniently be categorised as chemical, physical and biological (Gobin *et al.*, 2002).

2.1.2 Soil erosion by water

Although a small amount of material is washed through the soil, the most important erosion processes take place at the surface. Material may be detached by two processes, 'raindrop impact' and 'flow traction', and transported either by saltation through the air or by overland water flow (surface runoff). Combinations of these detachment and transport processes give rise to the main processes, 'Rainsplash', 'Rainwash', 'Rillwash', and 'Sheet wash' as indicated in Table 2.2 (Gobin *et al*., 2002).

Raindrops detach material through the impact of drops on the surface. For the largest drops, the terminal velocity is 10 m s^{-1}, but they only attain this after falling through the air for about 10 metres. If rainfall is intercepted by vegetation (throughfall), the raindrops hit the ground at a much lower speed, and have much less effect on impact. As raindrops hit the surface, their impact creates a shock wave, which dislodges grains of soil, or small aggregates and ejects them into the air in all directions.

The total rate of detachment increases rapidly with rainfall intensity. Where the raindrops fall into a layer of surface water that is more than about 5 mm thick, the impact of the drop on the soil surface is largely lost. Raindrop impact is also effective in breaking down soil aggregates into constituent soil particles. These particles are re-deposited between aggregates on and close to the surface, forming 'soil crusts', which seal the surface, and limit infiltration by filling the macropores between the aggregates.

These crusts may make the surface more resistant to erosion, but their greatest importance is in increasing runoff from storm rainfall. Susceptibility to water erosion is closely associated with the formation of soil crusts by rain falling on unprotected surfaces. In the immediate vicinity of crusted surfaces, erosion is less than on soil with no crust, but nearby downslope the increased volume of water flowing over the surface results in more erosion. Thus the destruction of crusts by tillage, freeze-thaw and drying can increase erosion risk locally.

If water is flowing with sufficient velocity, it exerts a force on the soil that is sufficient to overcome the resistance of soil particles. Resistance is due to friction, which increases with particle size, and cohesion between grains, which increases with the specific surface area of contact, and hence decreases with increasing particle size. There is virtually no cohesion between grains larger than 2mm (Birot, 1968). Resistance is lowest for small non-cohesive grains, particularly silt and fine sand sized particles with low clay content.

For ‘rainsplash’, grains are detached by drop impact and jump through the air. Transportation through the air, in a series of hops (saltation), is able to move material both up- and down-slope, but there is a very strong downslope bias on slopes of a gradient of more than 5%. The net rate of downhill transportation, therefore, increases with slope gradient, and decreases with the grain size transported. The rates of material transport by rainsplash are generally low.

For ‘rainflow’, grains are detached by raindrop impact, and carried farther than by rainsplash within a thin layer of flowing water. Both rainsplash and rainflow are most significant in areas between small channels, or rills, which form on a rapidly eroding surface, and are commonly grouped together as inter-rill erosion processes.

2.1.2.1 Rills and runoff

Runoff is the total amount of water reaching a point in the landscape, which may be a stream or river, and it is the most important direct driver of severe soil erosion. Processes, which influence runoff, must therefore play an important role in any analysis of soil erosion intensity, and measures, which reduce runoff, are critical to effective soil conservation.

Perhaps the most important control on runoff is the degree of crusting of the soil surface. This has a very strong influence on infiltration and therefore affects runoff rates. Of secondary, but still major importance, is the micro-topography of the soil surface and the sub-surface soil structure, particularly the presence or absence of macro-pores in the form of cracks and/or voids between soil aggregates. Micro-topography consists of random roughness on the surface, together with cultivation features such as plough ridges and terracing.

Figure 2.1 Rill erosion in Hungary (Photograph by Erika Micheli)

Where flow is sufficiently intense to entrain soil particles directly, small channels or rills (Figure 2.1) are formed on the surface, and material is eroded by ‘rillflow’, which is concentrated along these drainage lines (Figure 2.2a & b)

In cultivated land, resistance to erosion is commonly low within the cultivated layer, but increases considerably at the plough pan, which may be a layer of increased resistance, forming a transition to the undisturbed and more consolidated un-ploughed soil beneath. Rills therefore rarely penetrate beneath the plough layer, and are generally obliterated by later cultivation, as farmers seek to prevent further erosion.

Figure 2.2 Rill erosion in Severn Valley, UK
(Photographs by P.N. Owens)

2.1.2.2 Gully erosion

During storms with very heavy rainfall, and where gradients are at least locally steep, erosion may lead to greater incision, forming gullies, which are too large to be obliterated by normal tillage. The development of gullies can fragment farmland, and by steep gradients to adjacent fields, lead to rapid extension of a gully network, which then makes cultivation impracticable (Figure 2.3).

In steep mountainous terrain, soil masses from landslides can accumulate in existing gullies on slopes. During intensive rainfall, these gullies are often transformed to rapidly flowing streams. When the water flow becomes strong enough, the accumulated soil masses begin to flow. Together the water charged soil material (mud) forms a debris flow that builds up a high kinetic energy capable of causing severe erosion and damage along the gully. Where such gullies continue into urban areas, debris flows can cause severe damage to property and loss of human life.

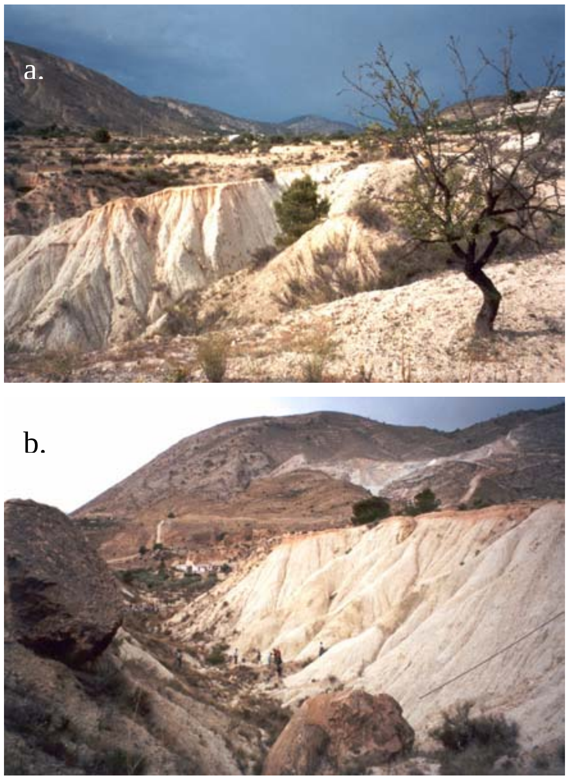

Figure 2.3 Gully erosion of former olive groves in Pedrera, Alicante Spain
(Photographs by R J A Jones)

Remediation of gully systems requires radical measures, including the possible re-grading of entire landscapes (land-levelling).

2.1.2.3 Snowmelt erosion

In northern parts of Europe, e.g. Norway, Sweden and Finland, erosion is often caused by snowmelt during winter and early spring – see Figure 2.4a. – (Lundekvam 1998, 2002). In these areas soils may be frozen during winter, restricting infiltration resulting in high surface runoff and subsequent erosion.

Topsoil conditions can vary from an ice- and snow-covered surface to a thawed surface with frozen subsoil. Saturated soil has low shear strength and high erodibility such that high losses may occur when snowmelt moves over or rain falls on partly frozen ground with an unfrozen topsoil overlying frozen subsoil (Figure 2.4b).

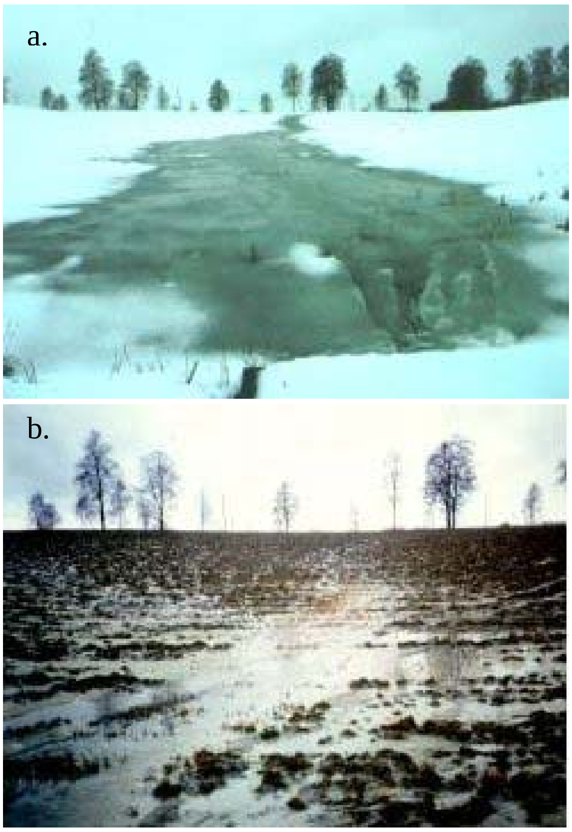

Figure 2.4 Snowmelt erosion Norway (Photographs by L. Øygarden.)

In Norway, the risk of erosion is high in areas under cereal production because autumn ploughing leaves the soil unprotected when rainfall can be heaviest, and in winter when snow melts on frozen ground (Lundekvam *et al.*, 2003). In some years, winter is the most important period for erosion. The combination of intense rainfall, frozen subsoil and saturated surface soil with low bearing strength during snowmelt, leads to both rill and gully development (Øygarden, 2003).

Annual soil losses during snowmelt are regularly measured to be in the range of 1-9 t ha^{-1}, but rates of >100 t ha^{-1} have been measured in gullies that have developed down to the depth of land drain pipes. If climate change leads to mild and unstable winter conditions, with several freezing and thawing cycles, more extreme erosion events might be expected.

In northern Sweden also combinations of intense snowmelt and heavy rainfall are reported. Heavy thunderstorms, which occur after warm spring days in May and June causing intensive snowmelt, triggering landslides in glacial till slopes that are often followed by debris flows.

Snowmelt erosion has also been reported in Germany, Poland, Slovakia, Austria, Italy and Switzerland (Kværnø and Øygarden 2002).

Most erosion models in use in Europe are designed to estimate erosion caused by rainfall-induced runoff. Such models cannot predict erosion from snowmelt and, consequently Lundekvam (2002) has developed an erosion model – ERONOR – for Norwegian conditions, and for Finland the ICECREAMS- model is being used. The development of these models illustrates the need for process-based models appropriate for the dominant erosion process.

2.1.2.4 Bank erosion in rivers and lakes

This is another kind of extreme form of erosion by water occurring only in specific locations in river valleys and along lake shores. Bank erosion can be exacerbated by rapid runoff after heavy rainfall. The increased volume of water in the drainage channel raises the water level and increases the speed of flow. This can quickly under cut banks and cause the river or stream to change its course.

Many processes of soil loss and sources of sediment are responsible for the sediment load in rivers and streams but Owens *et al.* (2000) found that bank erosion contributed 40% of the sediment load in the River Tweed in Scotland. In addition to soil loss caused by surface runoff on tilled fields, particles might be lost through preferential flow to a drainage system. If tillage has been performed on the bank side without leaving a buffer zone, erosion occurs as 'slides' along the stream banks (Figure 2.5).

Figure 2.5 Bank erosion in close proximity to cultivation (Photograph by L. Øygarden.)

In periods with high runoff there can also be erosion and scouring along the bank sides of the streams (Figure 2.6a). There is a link between bank erosion and landslides, as both are examples of mass movement of soil material, and can be associated with grassland (Figure 2.6b). Freeze-thaw is another cause of bank erosion.

Measures to control excess runoff should result in less water reaching the streams and rivers and hence reducing their ability to erode the banks. Such measures could also reduce the risk of flooding.

2.1.3 Disturbance or translocation erosion

Soil erosion can be initiated and/or excerbated by disturbance through tillage, excavation and animal activity. The following sections describe these processes.

2.1.3.1 Tillage Erosion

An important anthropogenic process is 'Tillage Erosion', which is the result of ploughing, either up and down slope or along the contour. Each time the soil is turned over, there is a substantial movement of soil. Up- and downhill ploughing produces a direct downhill component of movement as the turned soil settles back. Increasing use of mechanised cultivation has also led to a substantial increase in rates of tillage erosion.

Figure 2.6 Bank erosion (a, b) R Swale, northern England UK (Photographs by P N Owens)

Contour ploughing can move material either up or down, according to the direction in which the plough turns the soil. Contour ploughing, in which the soil is turned downhill, moves approximately 1000 times as much material as soil creep. Contour ploughing in both directions (soil turned uphill and then downhill or vice-versa), or ploughing up- or down-hill produces a smaller net movement, but the overall rate is still about 100 times greater than natural soil creep.

The spatial distribution of tillage erosion in Europe has not been systematically mapped, but research has shown that the intensity of tillage erosion depends on:

1. Slope variation or curvature: tillage erosion is most severe in areas of 'rolling topography', *i.e.* with a lot of convexities

(where erosion occurs) and concavities (where deposition occurs);
2. Management parameters: tillage depth, tillage speed, plough direction; and
3. Type of tillage implement.

Although the effect of soil type has not been investigated in depth, this parameter seems to be less important compared to the former ones (Van Muysen, pers. comm.). In Belgium, tillage erosion intensity has been mapped for Flanders (see section 2.2.2.2).

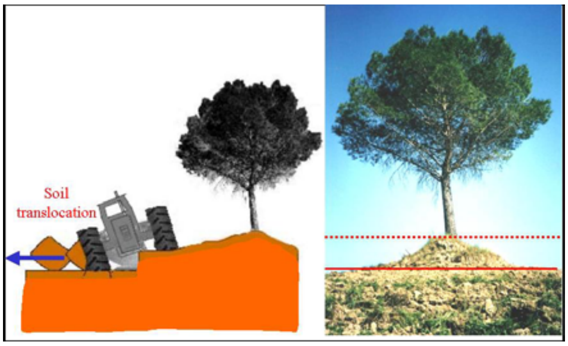

Figure 2.7 Tillage erosion caused by ploughing (P. Bazzoffi, pers. comm.)

Table 2.1. Classification of the most important Hillslope Processes.

	WEATHERING PROCESSES	*TRANSPORT PROCESSES*	*Type(S/T)*
CHEMICAL	Mineral Weathering/decomposition	Leaching	S
	(oxidation solution carbonation chelation,	Diffusion (ionic, molecular)	T
	hydrolysis, hydration, base-exchange,)		
PHYSICAL/	Freeze-Thaw	Mass Movements	
MECHANICAL	Salt Weathering (growth of salt crystals)	Landslides	S
	Thermal Shattering (through expansion &	Debris Avalanches	S
	contraction	Debris Flows & Slides	S
		Soil Creep	T
		Gelifluction & solifluction	T
		Tillage Erosion	T
		Rockfall	S
		Particle Movements	T
		Through-fall	T
		Rainsplash	T
		Rainflow	T
		Rillwash	
BIOLOGICAL/	Faunal Digestion (earthworms)	Biological Mixing (often	T
ORGANIC	Removal by mammals (rabbits, moles,	included within Soil Creep)	
	ground squirrels etc.);		
	Root Growth		

Types: T = Transport Limited: **S** = Supply Limited removal (Gobin *et al.*, 2002)

Table 2.2. Types of soil erosion by water.

Detachment by:	*Transportation*	*Mode*
Rainsplash (through the air)		N/A
Overland Flow Traction	Rainflow	Rillwash
	Snowmelt	Gully Erosion
		Sheet wash/slope wash
		Mud flows/earth flows
		Bank erosion

Soil translocation due to tillage is particularly intense in Mediterranean countries, e.g. Italy, Greece and Spain, because of the dominant morphology (Figure 2.7), and since mouldboard ploughing is often performed at a depth of 40 cm or more (Bazzoffi, 2003). Whilst the long-term effect of tillage is that of smoothing and sculpting the landscape, at field borders, steps and discontinuities are produced that often resemble grassed terraces. This soil removal on hillslope convexities leads to significant and possibly adverse changes in soil properties.

Such changes will affect soil quality and productivity and may also influence water and wind erosion rates by exposing more erodible subsoil (as it often the case in Italy and Greece). Values from extensive surveys in Tuscany (Borselli *et al*., 2002) indicate that tillage erosion is often close to 2 cm yr^{-1} with peaks in convex spots up to 4 cm yr^{-1}.

Sediment transport is more rapid using modern heavy machinery than with primitive ploughs, and it is clear that tillage erosion may have been responsible for more soil movement in the last few centuries than natural soil creep during the whole of the Holocene. The accumulated effect is often seen in the build-up of soil behind old-field boundaries.

2.1.3.2 Land levelling

Land-levelling, the mechanical translocation of soil by bulldozers to adapt the slope surfaces to mechanised agriculture, is common in many parts of Europe, especially in Italy, where it is extremely widespread in the Apennines and hilly pre-alpine regions. This operation is performed to clear shrubs in view of the cultivation of marginal lands and before the plantation of modern specialized orchards, vineyards and olive groves. Land levelling is generally followed by deep ploughing to about 1m depth to ensure a sufficient depth of rootable soil. Recently P. Bazzoffi (pers.com.) estimated that in Italy the area highly prone to risk of land levelling is about 10% of the area under permanent crops. After levelling, land is in a vulnerable condition and a few storms can easily cause severe soil losses. Bazzoffi *et al*. (1989) measured 454 t $ha^{-1}yr^{-1}$ of water erosion with the formation of a gully after six rainfall events of medium intensity.

During the late 1970s in Norway, extensive land levelling was stimulated by subsidies. This led to a two- to three-fold increase in soil erosion. The increase was especially high when former ravine landscapes used for pasture were levelled and turned into arable land that was ploughed in autumn. The clearly visible erosion and increasing negative offsite effects on water quality, together with overproduction, put an end to the subsidies for land levelling, but not before 13% of the agricultural area had been levelled with the support of these subsidies. The most visible effect was erosion caused by concentrated flow, including severe 'gullying' resulting from reduced infiltration, longer slopes and inadequate measures to handle concentrated flow. Now, land levelling is not allowed without special permission.

2.1.3.3 Soil loss by harvesting root crops

It is well known that soil particles attached to the surface of root crops, for example potatoes, carrots, beet root etc., can result in significant removal of soil from cultivated fields. In particular this is a problem in areas growing early potatoes because harvesting normally takes place when the topsoil is moist or very moist and soil readily adheres to the surface of the potatoes. However, preparation of the crop for marketing usually involves cleaning (washing) and removing the soil but returning it to the fields from where it came is not always advised, because of the possibility of spreading disease.

2.1.3.4 Erosion by trampling and burrowing animals

The surface pressure exerted by the hooves of grazing animals can destroy vegetation leaving a bare soil surface vulnerable to erosion by water. High stocking densities cause destruction of vegetation cover and cause erosion of the type reported by Evans (1977, 1997) in England and Wales and E. Bruneau (pers comm.) in Scotland. It is also a problem elsewhere in Europe where livestock dominate the agricultural sector.

Burrowing animals, such as rabbits, moles and ground squirrels, can also initiate or exacerbate soil erosion. Surface water entering burrows then erodes the unprotected sidewalls and floor of the tunnel, in extreme cases causing collapse. The resulting indentations on the surface then act as drainage channels for the removal of surface runoff and normal fluvial processes continue further erosion of the land.

2.1.4 Soil erosion by wind

Wind erosion tends to be less well researched in Europe, probably because it is less extensive than soil erosion by water. In northern Europe, the problem is only severe on light sandy soils when they are in a dry condition (Figure 2.8). Wind erosion also occurs on silty and clayey soils in the drier parts of southern Europe (Figure 2.9).

Figure 2.8 Wind-blown soil in N Germany (Schäfer et al., 2003)

Erosion of soils by wind has been recognised for millennia. Archaeological evidence reveals that wind erosion, exacerbated by cultivation and over-grazing, has occurred since Neolithic times. Serious wind erosion was experienced in the Veluwe in the Netherlands in the 17th century and the middle of the 18th century. Von Linnaeus described wind erosion in Scania at a time when deforestation and cultivation of new land by an expanding population had put the agricultural system in crisis (Warren, 2002).

Gross (2002) summarises the occurrence of wind erosion in Europe and cites Oldeman *et al* (1991) as the main source of reference. The most extensive and most severe wind erosion is mapped in southeastern Europe - in Romania, the Ukraine and Russia. Moderate wind erosion has also been reported from the Czech Republic and parts of France, the UK and Hungary. Wind erosion is also an important problem in Iceland and the Quaternary deposits of the north European plain, which extends from Belgium to beyond Poland (see Figure 2.22).

Figure 2.9 Dust rising during tillage in Aragon NE Spain (Riksen et al., 2002)

Recent investigations by the EU-projects WEELS and WELSONS suggest that the area affected is probably much larger than previously thought (Gross, 2002). The WEELS project has estimated rates of 21 t ha^{-1} yr^{-1} over a 30-year period in part of East Anglia, a rate that compares closely with estimated rates of water erosion in other parts of England.

Gross (2002) describes methods for estimating the distribution and severity of wind erosion but there are major difficulties in applying current models at European level.

2.1.5 Coastal erosion

In many areas, coastal erosion causes severe damage and high costs for society and individuals. Commonly, there is no problem until structures are built within the impact zone of storm surges or close to soft rock cliffs. The combined effect of infrastructure development and the erection of defences to protect them have created, in many areas, a narrow coastal zone. This is especially true in low-lying areas where a wide intertidal area, which adjusts to the

changes in sea level, storms and tides, is replaced by an inflexible barrier that does not.
As sea levels rise and storms increase in response to climate change, problems of coastal erosion and the risk of flooding increase. This may be critical in areas where seafront development, enclosure by dykes, embankment of tidal areas and seaward coastal defences has taken place. The difficulties of protecting this narrow inflexible barrier are increased where the natural resilience of the coast is lost as sedimentary systems and eroding cliffs are destroyed or stabilised.

Another important factor affecting natural coasts is the capacity of rivers to supply new sediments to the shoreline. In the past an important source of material for habitat creation in estuaries and deltas was provided by erosion in the catchments and the transport of sediment to the coast along rivers. Today river canalisation, dams, irrigation works and activities in the river catchments themselves have resulted in a dramatic reduction in sediment availability on the coast. In extreme cases, this can result in micro-tidal river deltas and macro/meso-tidal estuaries moving from accreting systems into eroding ones.

Relative sea level change is another key issue. Nordic countries benefit from post-glacial isostatic uplift, which helps to counteract the general trend of rising global sea level, and in many areas the land is actually rising faster than sea levels. In other parts of Europe, where the land is sinking, relative sea level rise is made worse.

Scientific studies – including those of the UN Intergovernmental Panel on Climate Change (IPCC) – indicate that the current rise of sea level will accelerate over the next decades, leading to considerably higher sea levels overall. In combination with an increasing frequency of exceptional storms and storm surges, the risks and the impacts of erosion and flooding are expected to increase considerably during the 21st century.

The combined impact of all these factors has been described as effecting a ‘coastal squeeze’. This is the process whereby intertidal land is continually removed from the influence of the sea through enclosure, which causes the direct loss of habitat. In areas where relative sea level is rising or where sediment availability is reduced, there is a further squeeze resulting from a steepening beach profile and foreshortening of the seaward zones.

Coastal erosion is well documented by civil authorities in the Member States and is not generally affected by land use or management. Furthermore, coastal erosion is normally taking place on such a large scale that it is hard to formulate any component of a Directive on Soil Protection that would alleviate or change it.

However, a programme EUROSION (www.eurosion.org) is compiling a database on erosion phenomena at local level, on the nature of coasts – sandy, rocky, with or without cliffs, etc. There are also other European projects such as ROCC (Risk of cliff collapse) 1998-2001, INTERREG II, and PROTECT (Prediction of the erosion of cliffs) 2001-2004 - 5 PCRD.

2.1.5.1 National coastal erosion

In Sweden, coastal erosion occurs mostly in the S and SW of the country in areas where sand, silt and till form the coast. In some places 300m of land has been lost in the past 150 years. However, the length of coastline subject to erosion is very small in comparison with the coastline of Sweden that totals 7000 km. Much of the coastline in Poland is considered eroded, with losses of up to 1m per year. Records, started in Roman times, reveal that the North Sea coast of Holderness in Eastern England has been severely eroded, with losses of land several km wide in places.

However, even accelerated erosion of coastlines results in deposition of the eroded material elsewhere. In the case of Eastern England, a large spit has formed across the Humber estuary comprising material from the eroded coast further north. Thus the erosive process does not always result in a negative effect.

2.1.6 Floods and Landslides

Floods and landslides are mainly natural hazards intimately related to soil and land management. In Europe, landslides form an increasing threat due to population growth, increasing summer and winter tourism, and to intensive land use and climatic change.

Floods and landslides are not a threat to soils in the same manner as soil erosion, but they can result in part from soil not performing its role of controlling the water cycle due to compaction or sealing. The result of development increases the incidence of floods and landslides by changing their topographic, soil, and vegetation controls.

Consequently, there is an increasing concern because the spread of roads, development of leisure and recreational areas, changes in agricultural practices and forest management, are having an adverse effect. Additionally, climate change can similarly increase the incidence of floods and landslides. Landslide hazard has clearly a European dimension, and concerns mountain as well as coastal environments (Maquaire and Malet, pers. comm.).

2.1.6.1 Floods and mudflows

Local flash flooding caused by intensive short duration rainfall (Figure 2.10), is often exacerbated by changing soil characteristics. Land management practices can lead to soil surface sealing and compaction, which are reducing infiltration capacity and hydraulic conductivity, leading to increased surface runoff. Furthermore, soil erosion itself leads to a thinner soil layer, which in the long term reduces the soil water storage capacity and thus causes increased surface and subsurface runoff.

However, many of the floods occurring cannot be reduced by changing land management practices. Long duration rainfalls or short periods of heavy rainfall will most likely always produce extreme discharges. Adaptation strategies should be further developed to improve forecasting and warning techniques, as well as spatial planning to move vulnerable land use types out of flood prone areas. Also, increased retention capacity could be created by enlargement of floodplains, building retention polders or water reservoirs.

These adaptation strategies should be evaluated at the scale of an entire river basin, as is done with the LISFLOOD model developed by the Joint Research Centre, Ispra (http://natural-hazards.jrc.it/floods/Prevention/). During the development of these adaptation strategies, it should be taken into account that extreme flood magnitudes and frequencies are likely to increase as a consequence of climate change.

Figure 2.10 Flooding in the Po, October 2000 (Photograph by Ad de Roo)

Several initiatives exist on floods in Europe. The Dartmouth Flood Observatory (http://www.dartmouth.edu/~floods/) has created overview maps of floods mapped using satellite data, including European floods. The European Commission's Concerted Actions RIBAMOD (River Basin Modelling), MITCH (MITigation of Climate induced natural Hazards) and ACTIF (Achieving Technological Innovation in Flood Forecasting) are trying to translate advances in knowledge into practical benefits across Europe. A DG RTD funded research project such as EFFS (European Flood Forecasting System) have paved the way for the development of a European Flood Alert System at the Joint Research Centre (http://natural-hazards.jrc.it/floods/Preparedness/), which aims at providing medium-range flood alerts 3-10 days in advance. The FLOODGEN project (King, 2001) was another research project that studied flooding at European level.

In France, a national mapping programme has resulted in an inventory of mudflows based on insurance claims filed for natural catastrophes between 1985 and 1995 (Figure 2.11).

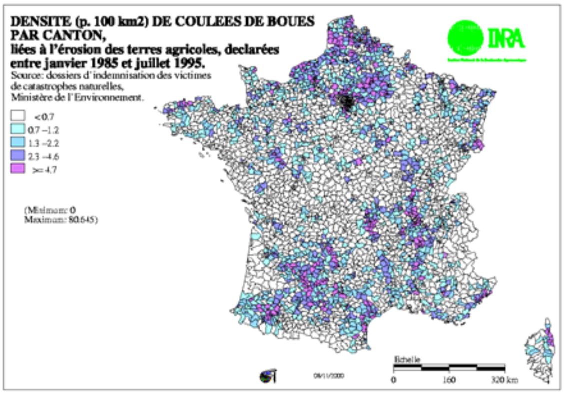

Figure 2.11 Map of mudflows in France (1985-1995)

2.1.6.2 Landslides

Landslide is a generic term for all forms of slope movement. The form and scope of slides, falls and debris flows are very diverse because of the multiplicity of initiating mechanisms. These mechanisms include erosion, deformation, dissolution and rupture under static or dynamic load, combined with topography (height and gradient of the slope etc.); lithology (characteristic and susceptibility of material – solid, plastic, viscous, liquid); structure (overhang, fracturing, superimposed layers); characteristics of the water table; and relative proportion of water to solid material (Maquaire and Ph Malet, 2003).

On the basis of the velocity of movement, which indirectly expresses risk level because it determines the possibility of avoidance at the onset of the event, two types of landslides can be distinguished:

- slow-moving landslides *(rotational, translational*) corresponding to mass displacements of more or less coherent soil, with limited internal deformation.;
- fast-moving landslides that may accelerate suddenly. They can be subdivided into two groups, depending on whether the material is propagated as more or less individual particles (*rockfall, rock avalanche*) or as reworked mass (*mudslides, earthflows, debris flows)* – see Figure 2.12.

Landslides are associated with a gravitational displacement of mass of destabilized earth and/or rock under the effect of natural processes (snowmelt, heavy rainfall, earthquake, action of the sea, etc.) or to human activity (terracing, mining, deforestation, exploitation of materials or water tables). Causes are generally multiple, a combination or superimposition of several factors, including predisposition and triggering factors such as rainfall or earthquake.

It is now increasingly clear that landslide hazard assessment forms an important part of land use planning in mountain and coastal environments. Authorities with the responsibility for protecting livelihood and infrastructure from the threat of landslides are particularly concerned with four critical aspects: (1) spatial distribution of landslides, (2) understanding of their mechanisms, (3) predicting (short- and long-term) occurrence and impact, and (4) mitigating impacts.

There is not much accurate data on landslides in Europe at a sufficient spatial and temporal scale, mainly because of the variety of landslides types with drastically different behaviour. Landslide management relies heavily on using the information available and on previous experience. Current knowledge must be extended by analysis and interpretation of well-documented case histories, preferably those from instrumented sites and catchments.

In areas with highly erodible soils, steep slopes and intense precipitation, such as the Alpine, Scandinavian and the Mediterranean regions, landslides are an increasing problem. They pose an increasing threat caused by population growth, increasing tourism, intensive land utilisation and climatic change (Maquaire and Ph Malet, 2003, Unpub.).

Figure 2.12 Debris flow, Cairngorms, Scotland UK following intense rain, 30 July 2002 (Lilley et al.) (Photograph by P. Moore)

Recent events have shown that landslides can be very destructive, e.g. Sarno, Italy, May 1998, 160 people killed; Gondo, Switzerland, October 2000, 13 died. In several European countries, this problem is being increasingly recognised and landslides are one of the primary hazards being mapped by the different civil authorities.

In Italy for example, more than 50% of the territory has been classified as having a high or very high hydro-geological risk, affecting 60% of the population or 34 million inhabitants. It has been estimated that more than 15% of the territory and 26% of the population are subjected to a high risk.

In Scandinavia, the post-glacial isostatic readjustment of the land during the past 10,000 years has raised some areas of the sea floor above the current sea level. The result is that today areas covered by marine clays suffer from landslides because of these clays are often unstable and easily eroded by rivers and streams.

Landslides associated with levelling of land for mechanised agriculture are quite common due to a general destabilisation of the levelled areas with contiguous surfaces upslope. Losses >500 t $ha^{-1}yr^{-1}$ due to all the known forms of soil erosion acting simultaneously, e.g. rills, gullies, piping and landslides have been estimated (Bazzoffi *et al.*, 1989; Chisci, 1986).

2.1.7 Subsurface erosion by groundwater

Subsurface runoff is generally slower than its erosive counterpart over the land surface, and can lead to water saturation of the upper part of the soil profile. It can cause gravity-induced mass movement on hill slopes (e.g. landslides) and is also responsible for the translocation (migration) of dissolved products of chemical weathering down a hill slope.

Calcareous rocks, such as chalk and limestone are subject to a distinct type of chemical weathering (Holmes, 1965; Monkhouse, 1968). Rainwater containing carbon dioxide slowly dissolves calcium carbonate, the principle mineral of chalk and limestone, which is removed as calcium bicarbonate. In addition, water passing through soil may also pick up additional carbon dioxide, generated by plant roots, bacteria, and other soil-dwelling organisms.

Because of the great permeability of these calcareous rocks, due to their jointing, underground water has played a major part in subsurface chemical weathering and erosion, producing intricate cave systems, distinct surface features, such as ‘swallow holes’ or ‘sinkholes’, depressions caused by the coalescence of several of these holes, dry valleys and gorges. The extent of porous calcareous rocks, e.g. limestone and chalk, can be identified from the European Soil Map highlighting areas where problems at the surface could occur.

Table 2.3. Types of erosion: occurrence at national level.

Country	Rill & Interrill	Gully	Snow melt	Bank	Tillage	Animals	Wind	Land-slides	Ground water	Coastal
Albania	XX	XX	X	XX	X	XX	?	XX	X	X
Austria	XX	X	XX	XX	X	N	?	XX	N	N
Belgium	XX	X	N	X	X	N	X	X	N	X
Bosnia Herzegovina	XX	XX	X	XX	X	X	X	X	X	N
Bulgaria	XX	XX	XX	X	X	X	X	X	?	N
Croatia	XX	XX	X	XX	XX	X	X	XX	X	X
Cyprus	XX	XX	X	X	XX	?	?	X	X	X
Czech Rep.	XXX	X	X	X	X	?	?	X	?	N
Denmark	XXX	X	N	X	X	N	XX	?	N	X
Estonia	XX	N	N	?	?	X	X	N	N	?
Finland	X	N	XX	X	?	X	N	N	N	N
France	XXX	XX	XX	XX		X	X	XX	X	X
Germany	XX	X	X	X	X	?	XX	XX	X	N
Greece	X	XXX	X	XX	X	XX	X	X	X	X
Hungary	XX	XX	X	X	XX	X	X	X	N	N
Iceland	X	XX	XXX	XX	N	N	X	XX	N	X
Ireland	X	N	N	XX	X	XX	N	N	N	X
Italy	XXX	XX	X	X	XX	?	X	XX	X	X
Latvia	XX	N	N	?	?	X	?	N	N	X
Lithuania	XX	N	N	?	?	X	?	N	N	?
Luxembourg	X	N	N	X	N	N	N	?	?	N
Macedonia FYROM	XX	XX	X	XX	X	X	?	X	X	N
Malta	X	XX	N	N	N	X	N	X	X	X
Montenegro	XX	XX	X	XX	X	XX	?	X	X	X
Norway	X	X	XXX	X	N	X	X	XX	N	X
Poland	XX	X	X	X	?	?	XX	XX	N	N
Portugal	XX	XXX	N	X	X	?	?	X	?	?
Romania	XX	XX	X	XX	X	X	?	X	?	N
Serbia	XX	XX	X	XX	X	X	X	X	X	N
Slovakia	XX	X	?	X	?	?	?	X	?	N
Slovenia	XX	XX	X	X	XX	?	?	XX	X	N
Spain	XX	XXX	X	X	X	X	X	XX	X	X
Sweden	X	XX	X	XX	N	X	X	XXX	X	XX
Switzerland	X	X	XXX	XX	?	X	?	XX	N	N
The Netherlands	X	N	N	?	N	?	X	N	N	?
United Kingdom	XX	X	X	XX	X	XX	X	X	X	X

Legend	XXX	Predominant
	XX	Important
	X	Minor
	?	Not know
	N	Not found

2.2 Soil erosion assessment methodologies

For assessing soil erosion risk, various approaches can be adopted. A distinction can be made between *expert*-based and *model*-based methods. Van der Knijff *et al.* (1999, 2002) describe in detail the main aspects of these two approaches. In addition, there have been many recently implemented erosion risk assessment programmes/projects to assess erosion at European and national scales. The following sections briefly review the most relevant examples.

2.2.1 European Scale

Gobin *et al.* (2002) have described in detail recent attempts to assess soil erosion at European level in a spatial context. Drawing on Gobin *et al.*'s work, the following sections briefly review these assessments highlighting their strengths and weaknesses.

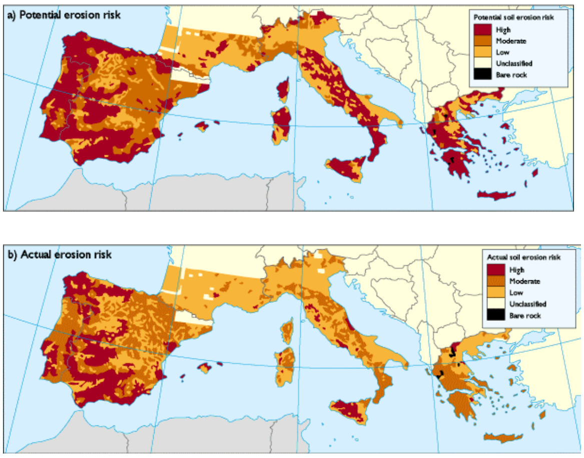

Figure 2.13 Potential versus actual erosion risk as estimated by the CORINE methodology (CORINE, 1992).

2.2.1.1 CORINE Approach

The CORINE methodology is based on the Universal Soil Loss Equation (USLE), a well-established technology (Wischmeier and Smith, 1978) that has been very widely used, both in North America and elsewhere in the world. It is an expert-based approach using a factorial method applied on a 1km x 1km grid.

Conventional wisdom suggests that the method correctly identifies areas of the Mediterranean that have the highest risk of erosion (Figure 2.13).

As a product of its time, it has considerable merit, and could be improved with the more detailed land cover classification now available. The CORINE report (CORINE, 1992) concedes that 'future development of this work would allow more sophisticated models of soil erosion to be used and improving the factors used in the procedure, notably in the calculation of erosivity and soil erodibility, and in the classification of land cover.'

However, the CORINE approach has the limitation that it is restricted to southern Europe, whereas present needs for erosion data apply to the whole of the European area. Furthermore, CORINE assessments are not validated and show significant differences from risks assessed by other methods.

2.2.1.2 RIVM Approach

As part of a major report on strategies for the European Environment (RIVM, 1992), a baseline assessment of water erosion was prepared in 1990. This assessment of current risk (Figure 2.14) was combined with climate and economic projections within the framework of the IMAGE 2 model to generate scenario projections for 2010 and 2050. This approach, also expert-based, has the advantage of making explicit scenario projections, a feature lacking in other approaches. However, it is currently only available at 50km resolution, so that it cannot readily be interpreted at sub-national scales.

The main advantage of the RIVM approach lies in its potential for integration with other environmental factors within an integrated model of the physical and economic environments. Nevertheless, these advantages cannot be fully realised unless the underlying modules are themselves of an acceptable standard.

The RIVM soil erosion model is a factor model, like CORINE, but in many ways has similarities to the Universal Soil Loss Equation (USLE) model. The RIVM method exploits the potential, inherent in any physically based or factor based assessment, of providing scenario analysis, through the inclusion of two dynamic components, the monthly rainfall totals (affecting erosivity) and land cover (affecting the assessed actual erosion) for Europe.

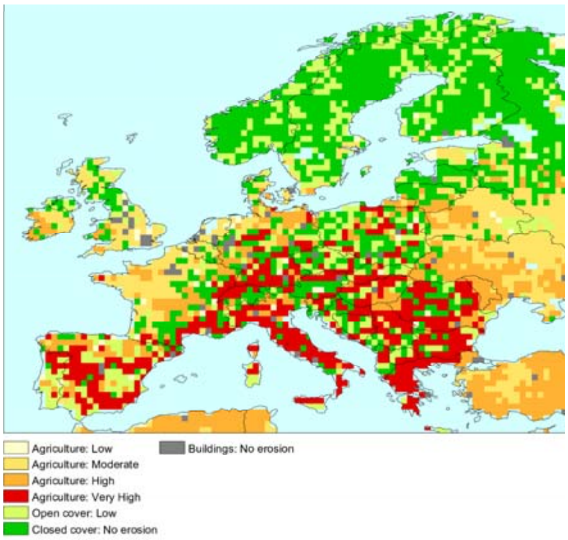

Figure 2.14 Water erosion vulnerability for 2050, according to the baseline scenario by RIVM (RIVM, 1992).

However, neither the 50km resolution nor the implementation of the factors contributing to erosion is now seen as providing a 'state-of-the-art' assessment. In simple terms, it is too crude for supporting the current policy making process.

2.2.1.3 GLASOD approach

The main objective of the GLASOD project – Global Assessment of Soil Degradation - was to bring to the attention of decision makers the risks resulting from inappropriate land and soil management to the global well being. Although its aims were limited, GLASOD is the only approach that to date has been applied world–wide.

It is based on responses to a questionnaire sent to recognised experts in all countries (Oldeman *et al.*, 1991) and thus depends on a set of expert judgements. Its weakness is that there was very little control or objectivity in comparing the standards applied by the different experts in the different areas. The information and data on soil erosion and physical degradation in the Dobris assessment (EEA, 1995) are based on an updated version of the European part of the GLASOD map.

For this update, questionnaires (van Lynden, 1994) were sent to scientific teams in each European country for comments and additions to the original GLASOD assessment. Not all countries completed and returned the questionnaires and the degree of detail of the information received varies greatly. It must also be noted that the scale of the maps (1:10,000,000) limits the detail that can be shown, providing a minimum resolution of approximately 10 km.

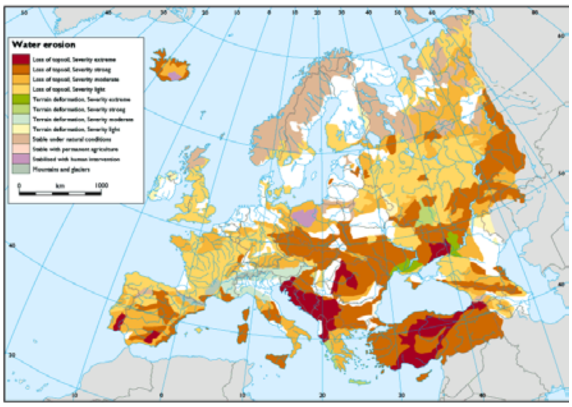

Figure 2.15 Water erosion of soils in Europe according to the GLASOD approach (Van Lynden, 1994).

The GLASOD map (Figure 2.15) identifies areas with a subjectively similar severity of erosion risk, irrespective of the conditions that would produce this erosion. Thus it too is an example of the expert-based approach. For water erosion, areas are grouped together primarily on the basis of the severity of topsoil loss. It is clear from comparison with other maps that there are substantial differences between the objective standards applied in different regions, although parts of southern Spain, Sicily and Sardinia are described as areas of high erosion risk in all assessments.

The results indicate that water erosion is the dominant degradation process in Europe, and that overall less than 10% is considered to be strongly or severely degraded. However, in specific regions the proportion of degraded land is much larger.

The GLASOD map is still widely used and quoted, although its authors and critics alike recognise the need for a more detailed and more quantitative assessment. A major drawback is that it is not possible to make truly objective comparisons between and within areas.

Regarding other assessment programmes at European scale, a study was carried out in order to assess the reliability of the GLASOD map to characterise the soil erosion process in Spain (Sánchez *et al*., 2001). Two maps were used to perform the comparative analysis. On the one hand, the 1:5,000,000 scale erosion map from the CORINE project (CORINE, 1992). On the other hand, the erosion map at the scale of 1:2,000,000 compiled by ICONA (MOPT, 1991). The latter synthesises information from studies dealing with soil erosion of watersheds at the scale of 1:400,000.

The comparison between the GLASOD map and the erosion risk map of the CORINE project revealed differences in spatially assessing water erosion in Spain. Such differences were accentuated when comparing the GLASOD map with information synthesised from maps prepared at a more detailed scale (ICONA map). It was concluded that for most of Spain the GLASOD map did not correctly assess water erosion.

Given that there are now improved methodologies, based on more quantitative analysis of particular problems, such as soil erosion, it is unquestionably timely to abandon the GLASOD approach, whilst not rejecting the data from local erosion sites to calibrate more quantitative models.

2.2.1.4 'Hot-Spot approach of EEA

An analysis and mapping of soil problem areas (Hot Spots) in Europe was published in the EEA-UNEP joint message on soil (EEA, 2000). The map (Figure 2.16) produced has been developed from earlier maps (Favis-Mortlock and Boardman, 1999; de Ploey, 1989), based on local empirical data, using expert knowledge to identify broad zones for which the erosion processes are broadly similar. Hot Spots are then highlighted within each zone, and associated with the best estimates, from the literature, of rates of erosion.

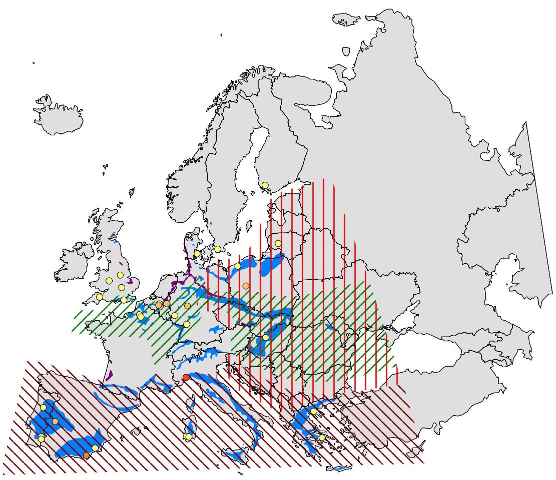

Figure 2.16 Hot Spots Map for water and wind erosion (EEA, 2000).

The intention is to identify areas of current erosion risk, under present land use and climate, as opposed to either evidence of past erosion, or of the potential for erosion under some hypothetical conditions. The data provide general or particular information about water erosion for approximately 60 sites or small regions across Europe, with measured erosion rates, which could be placed on the map at 35 sites. Measurements are taken from erosion plots, fields and small catchments.

Three groups are identified: Eastern Europe, the loess belt and southern Europe. This primarily represents different land use history, parent materials and climate respectively (Figure 2.16). Although there are advantages in concentrating on measured empirical data where this is abundant, and interpolation can be meaningful, the sporadic distribution and episodic occurrence of soil erosion makes this approach ill-suited. The most important information contained in the Hot Spots map probably lies in the considerable experience of its compilers, which it is hard to document or to quantify.

Within the area of overlap with the CORINE map in southern Europe, the Hot Spots map inherits from the De Ploey map a greater concentration on parent material as a key factor in localising significant erosion. It is also clear that sites of high erosion risk identified on this map are definitely areas of high impact, but that there is no reliable way to extrapolate these local results, even to surrounding areas. The main limitation here is that the spatial representation is much too coarse to be of practical use to policy makers.

2.2.1.5 USLE approach

The well-known Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) has been used for many research studies on soil erosion. The USLE is a simple empirical model, based on regression analyses of rates of soil loss from erosion plots in the USA. The model is designed to estimate long-term annual erosion rates on agricultural fields.

Although the equation has many shortcomings and limitations, it is widely used because of its relative simplicity and robustness (Desmet and Govers, 1996). It also represents a standardised approach and a revised version is now available (Renard *et al.*, 1997).

The application of the USLE in Europe by Van der Knijff *et al.* (2000) is a first attempt to quantify soil erosion by rill and inter-rill erosion, based on a 1km x 1km data set for all-Europe (Figure 2.17). The estimates of sediment loss, based on the European Soil Map (CEC, 1985), are not validated in most cases but relative differences are thought to be real in broad terms, e.g. between northern and southern Europe. It is a classic example of the model-based approach.

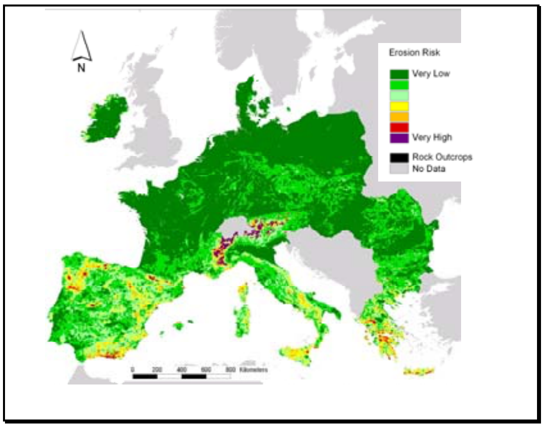

Figure 2.17 Actual soil erosion risk in Europe.

Potential erosion risk was also estimated by re-running the USLE assuming a total absence of vegetative cover. The resulting potential erosion risk map is shown in Figure 2.18 and represents the most extreme case for any area. One of the main advantages of the USLE model is that it is well-known and has been applied widely at different scales.

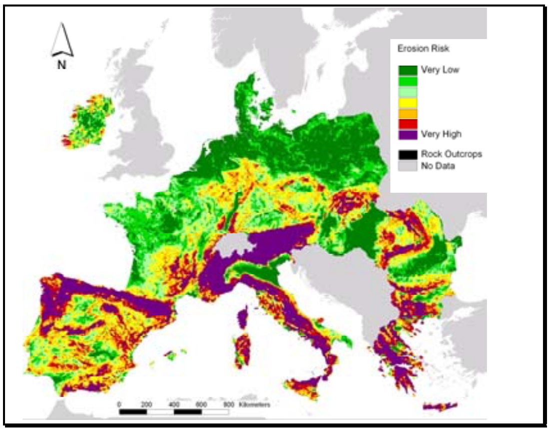

Figure 2.18 Potential soil erosion risk in Europe.

Compared with the expert-based methods described above, it probably gives the most objective information about the European-wide distribution of soil erosion risk. Its value lies in the fact that the estimates of erosion risk are based on standardised, harmonised data sets for the whole of Europe and the model produces quantitative output as actual sediment loss, for example t $ha^{-1}yr^{-1}$, which is important for policy-making.

However, in this study for Europe, a quantitative assessment may not be considered appropriate in view of the quality and resolution of the available data. Furthermore, it is not appropriate to use the maps to predict soil losses on any individual agricultural parcel, nor to predict soil loss for any individual year. Only rill- and inter-rill soil erosion by water flow is taken into account and deposition is not included. Thus, the maps should not be used to predict the occurrence of mass movements like landslides.

The effect of management practice is nearly impossible to assess at the small scale used here. Compared with other models, the USLE is one of the least data demanding erosion models that has been developed. However, there are still some uncertainties associated with the various data and it should be appreciated that, in many cases, management practice may be one of the most important factors affecting erosion. In conclusion, the results of this study may be considered as a further step towards a harmonised soil erosion risk map of Europe, though some major improvements could be achieved by using a more precise elevation, rainfall, soil and vegetation cover data sets.

2.2.1.6 INRA approach

This approach, elaborated by INRA (Institut National de la Recherche Agronomique, France), is an intermediate step towards 'state-of-the-art' erosion modelling at the European scale, subsequent to the USLE approach (Van der Knijff *et al.*, 2000) and prior to the initiation of the PESERA project.

Figure 2.19 shows the annual soil erosion risk for Europe, based on empirical rules that combine data on land use from the CORINE Land Cover database, soil crusting susceptibility, soil erodibility (determined by pedotransfer rules from the European Soil Database at scale 1:1,000,000), relief (1km x 1km resolution) and meteorological data (Le Bissonnais and Daroussin, 2001).

The INRA approach is based on modelling using an hierarchical multi–factorial classification designed to assess average seasonal erosion risk at regional scale.

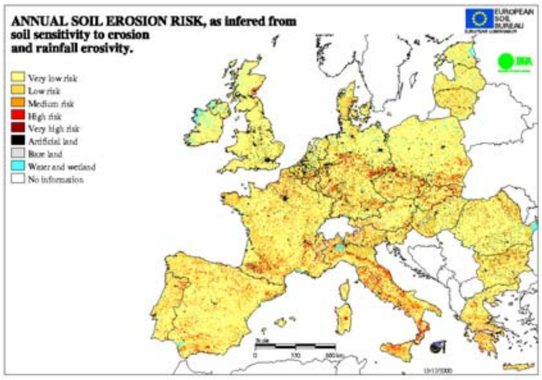

Figure 2.19 Annual Soil Erosion risk in Europe

The model is based on the premise that soil erosion occurs when water, that cannot infiltrate the soil, becomes surface runoff and moves soil downslope. A soil becomes unable to absorb more water either when the rainfall intensity exceeds surface infiltration capacity (Hortonian runoff), or when the rain falls onto a saturated surface because of antecedent wet conditions or an underlying water table (saturation runoff).

The INRA approach is simple and versatile and, as with the USLE, it does not require parameters that are not available at national scale. It probably gives more precise and accurate results than the CORINE erosion model but the disadvantage in the INRA model is that it is essentially qualitative and the final information is provided on a 5-class scale of risk, not linked to quantitative values of erosion, nor is it possible to assess the errors associated with the results.

2.2.1.7 PESERA approach

The Pan-European Soil Erosion Risk Assessment - PESERA - approach (Gobin *et al.*, 1999) uses a process-based and spatially distributed model to quantify soil erosion by water and assess its risk across Europe. The conceptual basis of the PESERA model can also be extended to include estimates of tillage and wind erosion. Preliminary results for PESERA (Figure 2.20) are currently being validated using erosion measurements from several European countries (Van Rompaey *et al.*, 2003).

Thus PESERA, being a quantitative model, has the potential for dealing with Pan-European applications, more easily than an expert-based approach, and forms a basis for replacing estimates from CORINE, without making excessive data demands. However, further development of the model and a substantial amount of calibration and validation work are essential if PESERA is to become operational. Preliminary results suggest that, although the model can be applied at regional, national and European levels, low resolution and poor quality input data cause errors and uncertainties (Kirkby *et al.*, 2004).

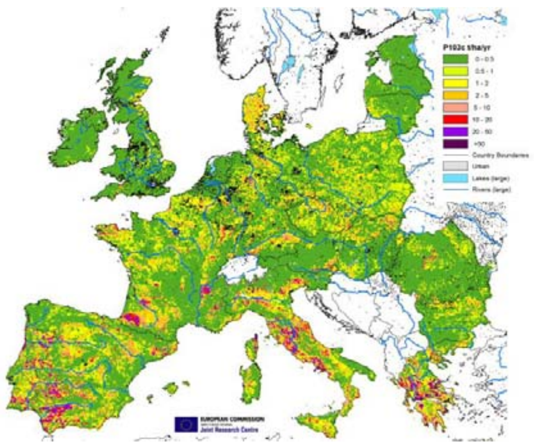

Figure 2.20 PESERA: Estimated annual soil loss by water erosion in Europe.(S.P.I.04.73).

Soil erosion indicators developed from a physically based model will not only provide information on the state of soil erosion at any given time, but also assist in understanding the links between different factors causing erosion. Another advantage for policy-making is that scenario analysis for different land use and climate changes is possible using PESERA. This will enable the impacts of agricultural policy, and land use and climate changes to be assessed and monitored across Europe.

At the European scale, the initial need is seen to be the development of an effective tool for erosion risk assessment, and to offer it as a component of decision support systems that can explore the implications of policy options. The PESERA model itself incorporates as many of the physical parameters as can be quantified, but it is important for policy making to assess the impact of the physical soil loss.

2.2.2 National Scale

Soil erosion estimates have been made in several EU and Candidate Countries, but these are based mostly on national systems and the results are not yet harmonised. Therefore, combining them at a European level will not provide a basis for policy making. However, the results of national erosion studies can be invaluable for assessing the performance of a model such as PESERA designed for application at European level.

Thus, some examples from Austria, Belgium, Bulgaria, France, Germany, Hungary, Italy, Spain and Switzerland are briefly described in the following sections.

2.2.2.1 Austria

Figure 2.21 shows an evaluation of soil erosion risk for Austrian communities, based on a classification using the USLE approach. Slope information was collected from a DEM with a grid resolution of 250 m. Information on land use was obtained by merging the CORINE data set with exact land use data on a community level.

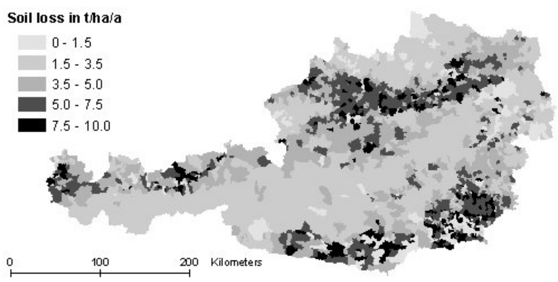

Figure 2.21 Soil erosion by water from arable and pasture land in Austria, based on USLE approach.

Soil information was obtained from the Austrian mapping system at the scale of 1:50,000. Rainfall was obtained from mean annual rainfall data on community level using a transfer function to erosivity (Strauss *et al.*, 1994).

As a result, Figure 2.21 does not quantify total soil losses within a community as these depend not only on the extent of agricultural land but also on the proportion of forests and paved areas. Protected areas, such as the terraced landscape of the Wachau region in the Danube valley are not included in the analysis and problems with data quality in Alpine regions are even more important.

2.2.2.2 Belgium

Soil erosion in Belgium mainly occurs in the loess belt, which stretches from east to west across the central part of the country, i.e. in the south of Flanders, and in the north of Wallonia. Verstraeten and Poesen (1999) questioned 123 municipalities in southern Flanders about the occurrence of muddy floods and 53 indicated there are serious soil erosion problems on the agricultural fields in these municipalities.

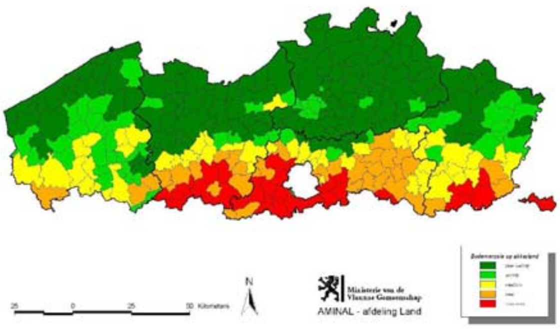

Figure 2.22 Actual Soil erosion risk (from water and tillage erosion) on arable land at municipality level in Belgium (Vandekerckhove et al., 2003)

The Flemish administration based its erosion policy on a map with mean annual soil erosion values (t ha^{-1} yr^{-1}) for pixels of 20m x 20m, which can be aggregated at the field parcel level or at the municipality level (Van Rompaey *et al.*, 2000). Both soil erosion by water and by tillage are considered. For each pixel, the net soil loss rate by water erosion, and the net soil loss or deposition rate by tillage translocation are calculated. Soil loss by water erosion is predicted using the RUSLE, adapted to a two-dimensional landscape by the procedure proposed by Desmet and Govers (1996). The calculation of tillage erosion was based on the work of Govers *et al.* (1994) and Van Muysen *et al.* (2000).

Vanderkerckhove *et al.*, (2003) show soil erosion risk on the basis of municipality (see Figure 2.22).

2.2.2.3 Bulgaria

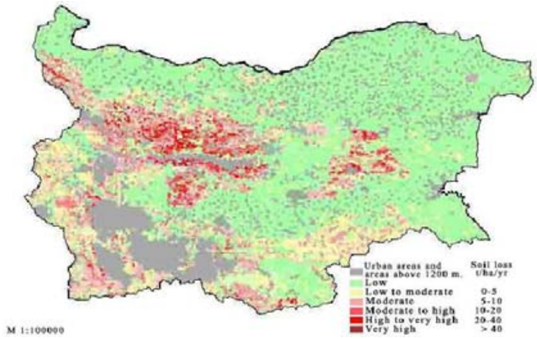

Figure 2.23. Soil erosion risk in Bulgaria, based on the USLE approach (Yordanov, pers. comm.)

The Executive Environment Agency in Bulgaria has produced potential and actual soil erosion risk maps on the basis of the USLE equation, which was adapted for Bulgarian conditions. An example is shown in Figure 2.23.

2.2.2.4 Czech Republic

The map of soil erosion risks in the Czech Republic (Figure 2.24) was drawn using the Universal Soil Loss Equation method (Wischmeier & Smith, 1978) in combination with GIS tools (Dostal *et al.*, 2003).

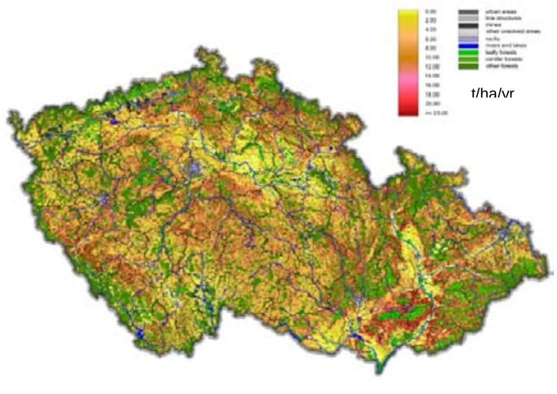

Figure 2.24. Soil loss by erosion in Czech Republic estimated using USLE (Dostal et al., 2003, unpubl.)

The soil categories examined comprise agricultural soils and so-called mixed areas, including mostly agriculturally cultivated soil. The resulting map at 1:200,000 gives numerical estimates of soil loss and sediment transport. The input data are listed in Table 2.4.

2.2.2.5 France

An early version of the PESERA model was applied to appropriate data for France, and a map showing erosion risk (Kirkby and King, 1998) demonstrated the feasibility of this new approach (Figure 2.25a).

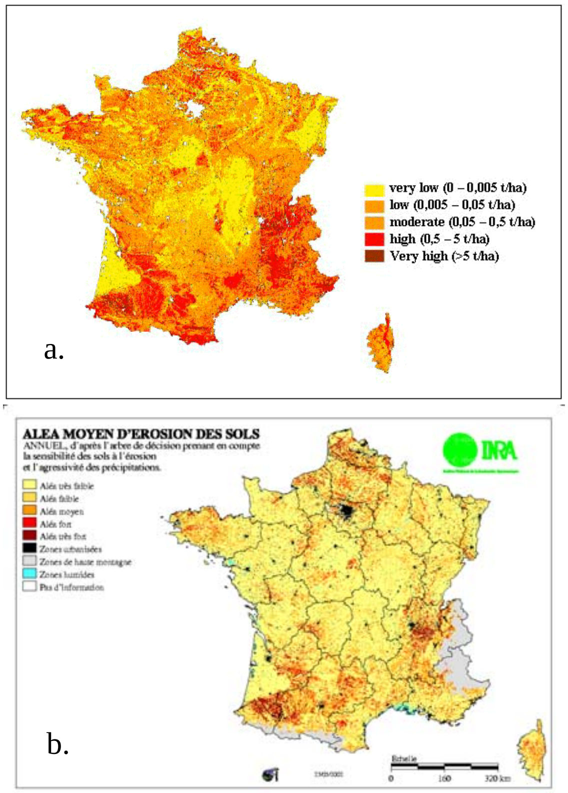

Figure 2.25 Soil erosion risk in France (a) using PESERA and (b) using the INRA approach

INRA Orleans have also produced a map of erosion risk in France (Figure 2.25b) using the methodology described by Le Bissonnais and Daroussin (2001).

2.2.2.6 Germany

Under a programme for soil conservation conducted by Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover, Hennings (2003) has produced the first draft of a nationwide erosion risk map (Figure 2.26) showing the vulnerability to soil erosion by water as a function of topsoil texture class, rainfall erosivity and slope class. The map is based on the 1:1,000,000 scale soil map of Germany (BÜK 1000) and high-resolution digital elevation data.

Assessments are restricted to arable land and semi–quantitative vulnerability classes range from 'negligible' to 'very high'. The long-term objective is to produce a map showing classes of mean annual soil loss.

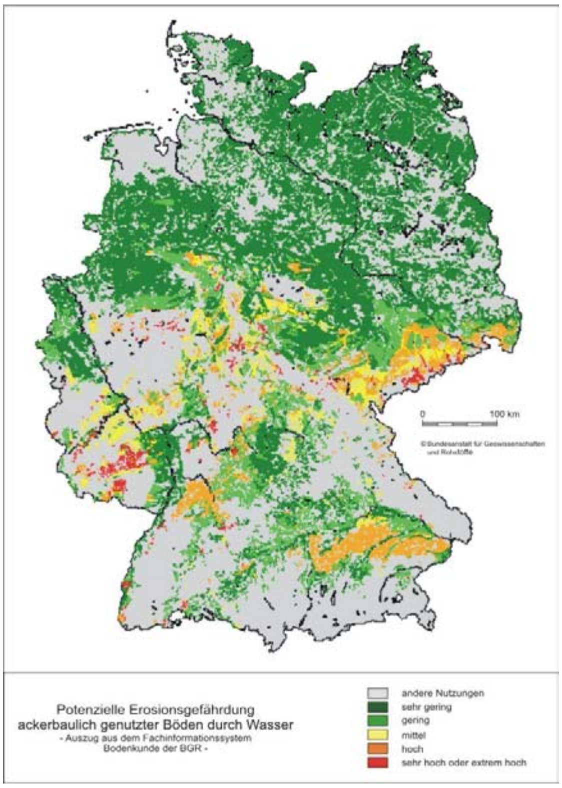

Figure 2.26 Vulnerability to soil erosion by water in Germany (Hennings, 2003)

With respect to soil erosion by wind the German Institute for Standardisation (DIN) is currently preparing a standard in order to determine the soil exposure risk from wind erosion (DIN 1976, Draft standard). Based on this standard, the Geological Survey of Lower Saxony (NLfB) has produced a map of potential wind erosion risk (Figure 2.27).

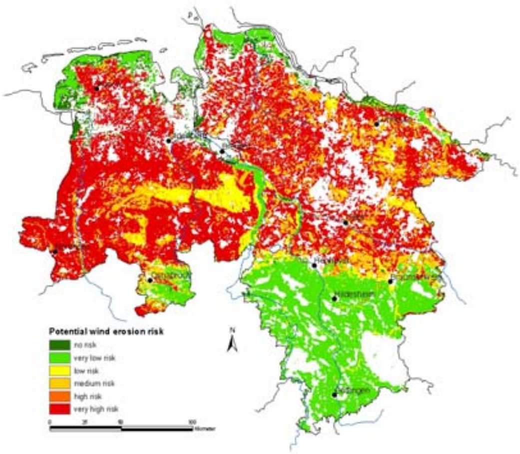

Figure 2.27 Potential soil erosion risk by wind in Lower Saxony, N Germany

2.2.2.7 Hungary

Figure 2.28 shows predicted soil erosion in Hungary, which has been produced using the USLE approach. The data used for this map include erosivity at 1:100,000 scale prepared by Szilárd Thyll (1992); erodibility estimated from an Agrotopography map of Hungary at 1:100,000 scale (1985); a DEM at 1:100,000 (1981); and CORINE Land Cover 100 (1997).

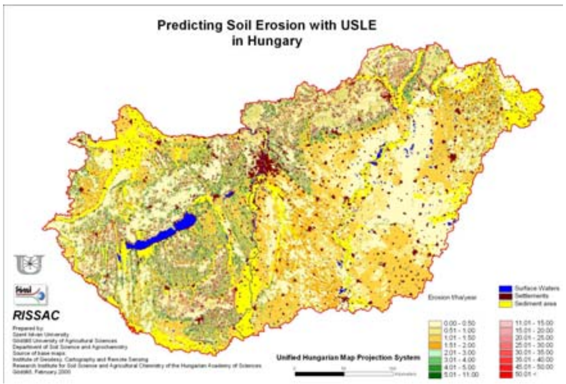

Figure 2.28 Actual Soil erosion risk in Hungary, based on the USLE approach.

The map shows arable lands with a crop cover factor of 0.5, equivalent to continuous cultivation of corn. About 14% of the land belongs to the 2-11 t $ha^{-1}yr^{-1}$ class and 6% suffers severe erosion (>11 t $ha^{-1}yr^{-1}$).

Changing corn to winter wheat, changes the C factor from 0.5 to 0.25 and this increases the areas estimated to suffer <2 t $ha^{-1}yr^{-1}$ by 6 %. It is thought that, in general, this study underestimates erosion in Hungary (Berenyi Uveges, pers. comm.).

2.2.2.8 Italy

Running the USLE model for Italy (Van der Knijff *et al.*, 1999, 2002; Grimm *et al.*, 2003), on the basis of 250-m resolution elevation data instead of the 1km data used for the European scale, gives the distribution of estimated annual erosion risk in Italy shown in Figure 2.29.

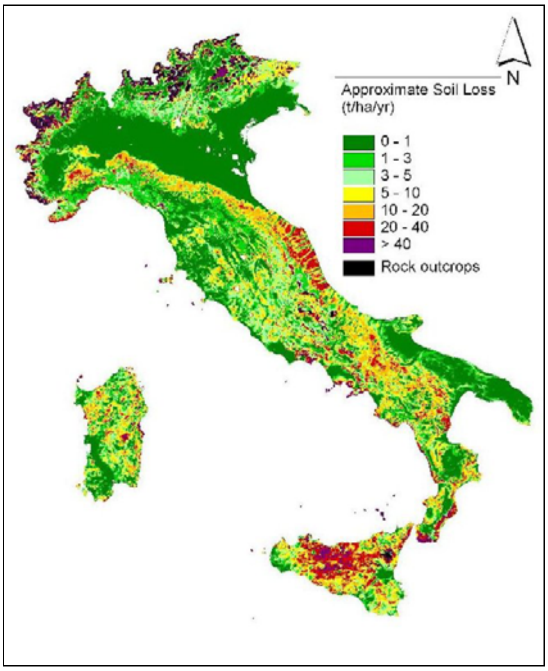

Figure 2.29 Actual Soil erosion risk in Italy, based on the USLE approach.

2.2.2.9 Netherlands

Approximately 4% of the surface of the Netherlands is affected by wind and/or water erosion. Wind erosion involves some 97,000 ha (2.6%) in the Netherlands. The areas mainly occur in:

1. the coastal dunes;
2. sandy arable soils in South-Brabant and the North of Limburg;
3. central sections of the Netherlands (Veluwe)

4. the arable raised peat bog soils in the North (Groningen and Drenthe).

Quantitative data on rates of soil loss are lacking, mainly due to the nature of wind erosion. Economic costs are therefore difficult to estimate. There are no policy instruments to combat wind erosion.

About 61,000 ha. (1.6%) of the country is affected by water erosion, which occurs mainly in the southern part of the province of Limburg.

2.2.2.10 Norway

The Norwegian Institute of Land Inventory (NIJOS) has used its soil information system to produce a potential soil erosion risk map (Nyborg and Klakegg, 1998), assuming conventional autumn ploughing. This map is based on an adjusted version of the USLE approach.

2.2.2.11 Slovakia

Potential soil erosion maps at 1:1,000,000 scale and actual soil erosion at 1:500,000 scale for Slovakia have been produced by Suri *et al.*, and published in the Landscape Atlas of the Slovak Republic (2002, p.286-8). Potential erosion has been estimated using the USLE and actual erosion by a national methodology. The estimated actual soil erosion by water is shown in Figure 2.30.

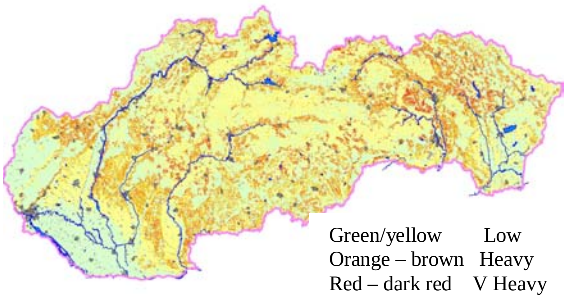

Figure 2.30 Actual Soil erosion losses in the Slovak Republic (M. Suri,T. Cebecauer, E. Fulajtar jun, J. Hofierka, Landscape Atlas Slovak Republic (2002.).

2.2.2.12 Spain

The Spanish National Action Programme on Desertification – PAND (MMA, 2001) has generated a Map of Erosive States at scale 1:1,000,000 for the whole country (Figure 2.31). This map is based on previous work done by the National Institute for the Conservation of Nature-ICONA (1987-1994), which applied a methodology based on the Universal Soil Loss Equation (USLE) to generate maps of the erosive state in each of the main catchments in the country (Ibanez *et al.*, 1999).

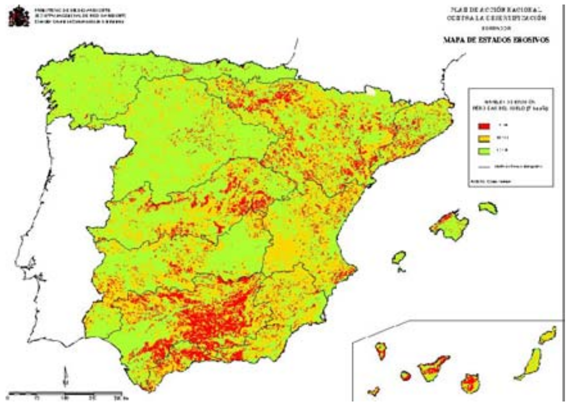

Figure 2.31 Actual Soil erosion risk in Spain based on the USLE approach.

The methodology applied by ICONA consisted of defining homogeneous land units, based on existing information (land use, topographic and geology maps, and aerial photographs), and designing a sampling scheme for gathering information about the USLE factors in each unit. Soil loss estimates for each unit were classified into 7 classes reflecting different erosive states.

A map at scale 1:400,000 was generated by the PAND for each of the main catchments within the Spanish territory. The maps were digitised, joined and adjusted, and the erosive states were aggregated at national level and assigned to one of the following 3 classes: 1 (green) 0–12(t ha^{-1} yr^{-1}), 2 (yellow) 12–50 (t ha^{-1} yr^{-1}), 3 (red) >50 (t ha^{-1} yr^{-1}), as shown in Figure 2.31.

2.2.2.13 Sweden

Field measurements of soil erosion by water are very few and for wind erosion measurements are even fewer. Locally the problem is considerable for arable land but there is no general quantification. No simple or direct relationship between average slope angle and transport of suspended concentrations has been found from fields observed. However, in most fields with soils >35% clay concentrations of suspended solids can be quite high.

An inventory of 29 selected fields with erosion problems in the county of Scania revealed large and varied amounts of eroded material between 0.5-300 t $ha^{-1}yr^{-1}$. Problems of erosion also occur around Lake Mälaren on agricultural land with heavy clay soils. In addition, erosion of silty soils occurs along the coast in the north and west of Sweden.

A national survey of landslide stability conditions is carried out regularly in the different provinces of Sweden. A similar survey of the debris flow risks is planned.

2.2.2.14 Switzerland

A map showing erosion risk on arable land, based on a simplified USLE-model, has been produced in Switzerland, with a spatial resolution of about 6 km^2. More recently, erosion risk maps, based on different models or mapping methodologies, have been prepared at regional or local level.

During the period between winter 1997/98 and summer 2001 a total of 770 erosion damages was assessed and analysed. The results show that every year about 20% of the arable land was affected by soil erosion. Mean soil loss from all fields during this period was 0.67 t ha^{-1}, but losses amounted to 20 t $ha^{-1}yr^{-1}$ from single fields in some places. With mean soil losses of less than 1 t $ha^{-1}yr^{-1}$ overall, soil erosion on arable land in Switzerland is generally a less serious problem than in other countries.

2.2.2.15 United Kingdom

Soil erosion has been observed intensively in England and Wales for the past 4-5 decades (Evans, 1996, 2002). Previous reviews of erosion in Britain include those by Morgan (1980) and Boardman & Evans (1994). The erosion risk for associations of soils delineated on the National Soil Map of England and Wales has been described in detail by Evans (1990).

In addition, a map at a scale of 1:250,000 has been prepared by the National Soil Resources Institute showing erosion risk for land under winter cereals (R. Palmer, pers. comm.). Both classifications are based on observation and expert judgement.

More recently, Boardman and Evans (In press) have produced a map showing the distribution of water, wind and upland erosion in Great Britain as a whole (Figure 2.32).

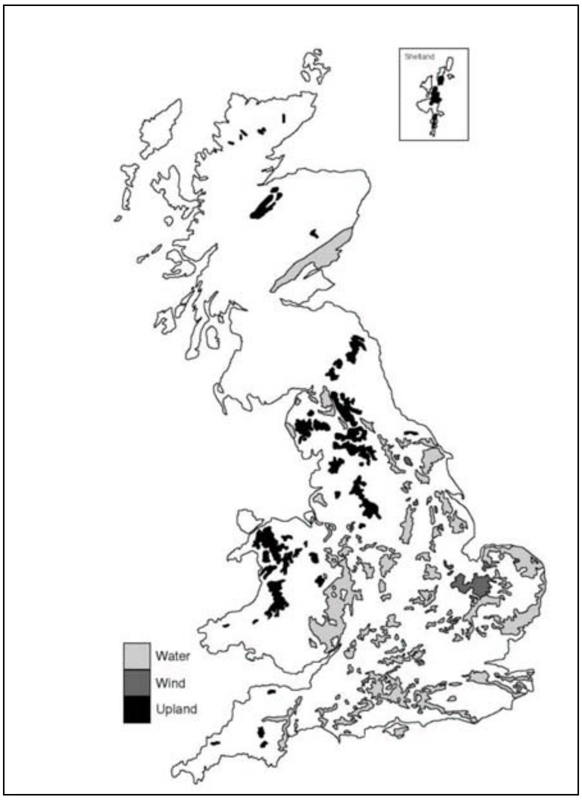

Figure 2.32 Actual soil erosion in Great Britain.

Birnie (1993) has described peat erosion due to overgrazing in the uplands (Figure 2.33) and Lilly et al. (2002) have defined the inherent geomorphological risk of soil erosion by overland flow in Scotland (Figure 2.34).

Thus, although no erosion model has been applied nationally in the UK, there is a very large number of records of observed erosion events from all over the country.

Figure 2.33 *Peat erosion, south of Glenartney, Perthshire. Scotland UK. (Photograph MLURI)*

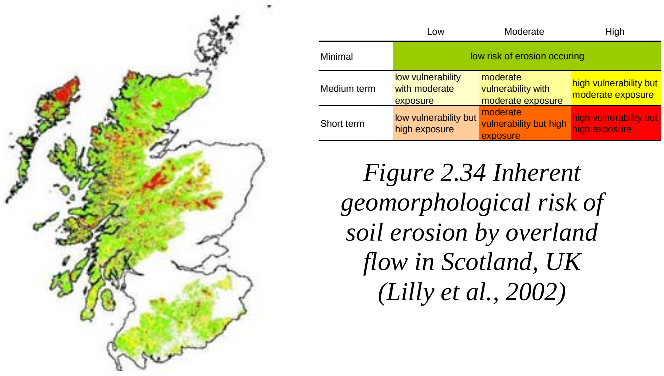

Figure 2.34 Inherent geomorphological risk of soil erosion by overland flow in Scotland, UK (Lilly et al., 2002)

2.3 Current extent of soil erosion in Europe

Soil erosion by water is a widespread problem throughout Europe. A report for the Council of Europe, using revised GLASOD data (Oldeman *et al.*, 1991; Van Lynden, 1995), estimates that 12 million ha of land, in Europe (including part of the former Soviet Union), or approximately 10% of the area considered, is strongly or extremely degraded by water erosion.

The most dominant effect is the loss of topsoil, which is often not conspicuous, but nevertheless potentially very damaging. Physical factors like climate, topography and soil characteristics are important in the process of soil erosion. In part, this explains the difference between the severe water erosion problem in Iceland, and the much less severe erosion in Scandinavia, where the climate is less harsh and the soils are less erodible.

The Mediterranean region is particularly prone to erosion. This is because it is subject to long dry periods, followed by heavy bursts of erosive rain, falling on steep slopes with fragile soils, resulting in considerable amounts of erosion.

This contrasts with NW Europe where soil erosion is slight, because rain falling on mainly gentle slopes is evenly distributed throughout the year. Consequently, the area affected by erosion in northern Europe is much more restricted in its extent than in southern Europe.

In parts of the Mediterranean region, erosion has reached a stage of irreversibility and has practically ceased in some places, because there is no more soil left! With a very slow rate of soil formation, any soil loss of more than 1 t $ha^{-1}yr^{-1}$ can be considered as irreversible within a time span of 50-100 years. Losses of 20 to 40 t ha^{-1} in individual storms, that may happen once every two or three years, are measured regularly in Europe, with losses of more than 100 t ha^{-1} in extreme events (Morgan, 1995).

Figure 2.35 *Intensive Olive (5–80 years old) cultivation near Sevilla, Spain*

It may take some time before the effects of such erosion become noticeable, especially in areas with the deepest and most fertile soils or on heavily fertilised land.

Table 2.4. Assessment of erosion: use of models and observation at national level.

Country	Model	Observat.	Other	Soil	Land use	Topography	Climate
Albania	?						
Austria	USLE			1:50,000	250m	250m	commune
Belgium	RUSLE	Regional		1:25,000	250m	20m	
Bosnia Herz.	?						
Bulgaria	USLE			?	?	?	?
Croatia	?						
Cyprus	?						
Czech Rep.	USLE	Regional		1:200,000	100m	1:25,000	1:50,000
Denmark	?						
Estonia	?						
Finland	USLE	Regional					
France	National	Regional		1:1,000,000			
Germany	National	Regional	wind	1:1,000,000		High resol.	?
Greece	?						
Hungary	USLE			1:100,000	100m	1:100,000	?
Iceland	?						
Ireland	N						
Italy	USLE			1:250,000	100m	250m	366 stns
Latvia	?						
Lithuania	?						
Luxembourg	?						
Mace-FYROM	?						
Malta	?						
Montenegro	?						
Norway	USLE	National		?	?	?	?
Poland	?						
Portugal	?						
Romania	USLE						
Serbia	?						
Slovakia	USLE	National		1:500,000	250m	High resol.	1:5,000
Slovenia	?						
Spain	USLE	National		1:1,000,000	?	?	?
Sweden	?						
Switzerland	USLE			?	?	?	?
The Netherlands	?						
United Kingdom	N	National		1:250,000	1:250,000	?	5km

Legend		
	USLE	Universal Soil Loss Equation
	National	National models
	Observation	Survey by experts, regional and national
	?	Not Known
	N	Not used

However, this is all the more dangerous because, once the effects have become obvious, it is usually too late to do anything about it. The main causes of soil erosion are still inappropriate agricultural practices (e.g. Figure 2.35 shows the effect of intensive olive cultivation in Andalucia), deforestation (including forest fires), overgrazing and construction activities (Yassoglou *et al.*, 1998).

Of the models reviewed in Section 2.2, PESERA is the most conceptually appropriate because it takes into account:

1. Runoff and erosion sediments separately, which are the 2 components of the global erosion process;
2. Daily frequency distribution of rainfall month by month, which includes both regular and exceptional events;
3. Dynamic crusting and vegetation cover, month by month (Le Bissonnais *et al.* 2003);
4. Other climatic information such as freezing days that in part cater for the effect of snow.

The other models – USLE, INRA etc. – do not take these aspects into account. However, a comparison of the results obtained from the three models PESERA, USLE and INRA identifies with more confidence areas that are eroding from those that are not. Figure 2.36 presents such a comparison on the data currently available at European level.

In conclusion, no model can give good estimates of erosion if the input data are poor. At European level, the aim should only be to provide a tool for decision making at European level. No modelling approach at this level can produce results relevant at local level (Y. Le Bissonnais, pers comm.).

The following data, at European level, are needed if models such as PESERA are to give satisfactory results:

1. Soil parameter data derived from 1:250,000 scale surveys;
2. Digital elevation model (DEM) at 250m minimum resolution;
3. Climatic data (e.g. precipitation) at 10km x 10km resolution;
4. Land/crop cover data at 250m resolution that are up to date;

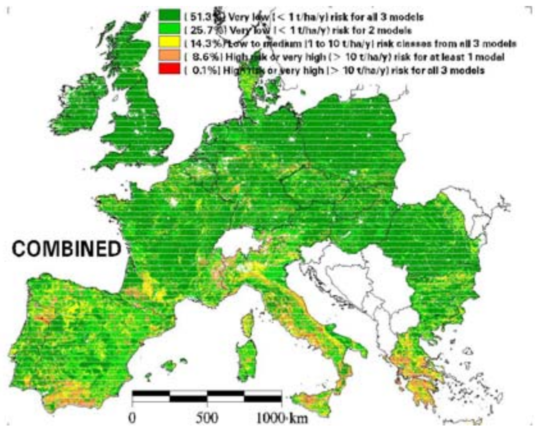

Figure 2.36 Soil erosion (by rill and inter-rill) estimates for Europe by combination of 3 models (Le Bissonnais and Daroussin, pers. comm.)

Finally, it must be accepted that any model selected for application throughout Europe will not give satisfactory results in areas where the main process taking place is not included in the model. In the case of PESERA, the results will not be appropriate for areas where snowmelt erosion or erosion from land-levelling is the dominant process. This limitation is not so important, since such processes are dominant only locally.

2.4 Indicators of state

The OECD has defined a core set of indicators for environmental performance reviews (OECD, 1993). These indicators were translated by Gentile (1999) to relate to soil erosion. A number of them have been critically reviewed by Gobin *et al.* (2004) who conclude that the area actually affected by erosion is the best indicator of state and this area should be directly related to the area at risk from erosion. The area at risk can be estimated using an appropriate model of soil erosion, together with the necessary spatial data sets to define the boundaries of these areas.

Soil erosion takes place at the field scale, and the main problem is that the digital data sets used to quantify the factors causing erosion are usually too coarse (in terms of spatial resolution) to provide accurate estimation of soil losses at this scale. These conclusions are in accordance with the earlier findings of Düwel and Utermann (1999), who proposed the approach outlined in Figure 2.37.

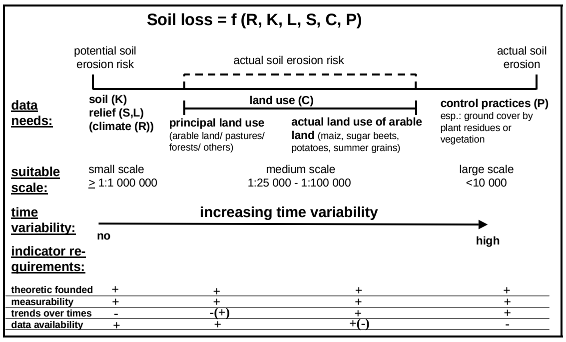

Figure 2.37 An approach to assessing soil erosion

Especially with regard to agricultural land this approach means: the higher the proportion of crops which increase the risk of soil erosion (‘row crops’, e.g. corn, sugar beet, potatoes) of total arable land in areas with a high potential soil erosion risk, the higher the actual soil losses due to soil erosion, unless accompanying protection measures are applied. Soil, climatic and relief conditions cannot be changed by human activities, at least not in the short-term. Consequently ground cover measures should be used to combat soil erosion in other forms of land use as well.

An important surrogate indicator of actual erosion is its risk. A *risk* is the chance that some undesirable event may occur. *Risk assessment* involves the identification of the *risk*, and the measurement of the exposure to that risk. The response to risk assessment may be to initiate categorisation of the risk and/or to introduce measures to manage the risk. In some cases, the risk may simply be accepted. In other cases, the priority will be to adopt a mitigation strategy. Various approaches that can be adopted to assess soil erosion risk are presented in section 2.2.

The area affected by erosion is the key indicator for soil erosion. Trends in soil erosion could be established from periodic estimates. A number of national databases are available for making estimates at national level.

One of the major negative aspects is that national databases are not available for all EU countries. Estimates of the area actually affected by soil erosion at regional and national levels are not readily available. This is because measurements of actual erosion are difficult and usually expensive to make. Soil erosion often takes place surreptitiously and over long periods before the true extent is observed and appreciated. Accurate data are, therefore, scarce. Estimates from European countries, based on national data sets, could be compared with estimates derived from European data sets (e.g. the European Soil Database, CORINE land use and climate data).

Although, there are difficulties in making measurements, existing data should be compiled and stored centrally for comparison with model estimates. Erosion models offer the main mechanism whereby the area affected by erosion can be estimated. An appropriate model should be identified and used in conjunction with standard data sets to provide standardised estimates of the areas at risk from soil. The result would be to provide an appropriate state indicator including time series for use by policy-makers. The currently implemented PESERA project should provide such a model within the next two years (Gobin *et al.* 2004).

2.5 Secondary threats

The Soil Communication (CEC, 2002) identifies compaction and salinisation as threats to soil. The current policy initiative places a higher priority on erosion, loss of organic matter and contamination. Nevertheless, all threats to soil are important and thus the Technical Working Group on Erosion was given the remit to report on the extent of compaction and salinisation in Europe.

2.5.1 Compaction

Soil compaction occurs when soil is subject to mechanical pressure through the use of heavy machinery or dense stocking with grazing animals, especially in wet soil conditions (Figure 2.38). Compaction reduces the pore space between soil particles and the soil partially or fully loses its absorptive capacity.

Figure 2.38 Compacted soil. (Photograph by Erika. Micheli)

Consequently, intensification of agriculture is now recognised as often having a detrimental effect on soils, not least the widespread development of compaction. Compaction can occur at the surface or below in subsurface soil horizons. Compaction of deeper soil layers is very difficult to reverse.

2.5.2 Effects of compaction

The worst effects of surface compaction can be rectified relatively easily by cultivation and, hence, it is perceived to be a less serious problem in the medium to long-term. On the contrary, once subsoil compaction occurs, it can be extremely difficult and expensive to alleviate. Furthermore, remedial treatments usually need to be repeated. The risk of subsoil compaction increases with the growth in farm size, increased mechanisation and equipment size, and the drive for greater productivity.

The response of the engineering industry to the demands of agriculture has been impressive over the past 30 years. Larger and larger machines have been developed but, from the soil standpoint, the result has been a significant increase in axle loads not always matched by reductions in ground contact pressures to prevent or minimise compaction. (Renius, 1994; Tijink *et al.*, 1995; Chamen *et al.*, 2001).

Research into the causes and effects of compaction in topsoils and subsoils in Europe has demonstrated the detrimental effects on the farming system (Hakansson, 1994). It is now clear, however, that the detrimental effects go far beyond agricultural concerns of a decrease in yield and increase in management costs. The overall deterioration in soil structure that may result from compaction can: (i) increase the risk of soil erosion on sloping land, through the concentration of excess water above compacted layers; and (ii) accelerate effective runoff from and within catchments. Other effects impact mainly on contamination trough transfer of pollutants. These effects are illustrated in Figure 2.39.

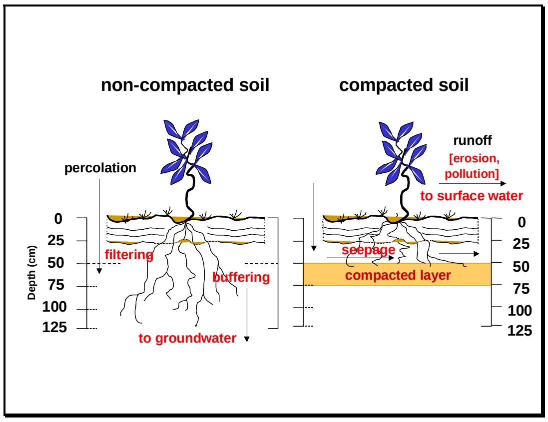

Figure 2.39 The Impacts of subsoil compaction

Subsoil compaction is the manifestation of increased bulk density, and therefore, can be related directly to soil properties. External aspects, such as land use and the use of machinery, also play an important part in the occurrence and distribution of compacted subsoils.

2.5.3 Extent of compaction in Europe

Knowledge concerning the vulnerability of subsoils to compaction in Europe is now an increasingly important requirement within agriculture and for planning environmental protection measures. Fortunately, subsoil compaction has been the subject of two recent Concerted Actions (Van den Akker, 1999; Van den Akker and Canarache, 2001) funded by the EU.

Under these projects, a database of experimental results on subsoil compaction has been compiled, and Jones *et al.* (2003) have produced a preliminary map (Figure 2.40) showing the susceptibility of subsoils to compaction by applying a structured model to the European Soil Database (Heineke *et al.*, 1998).

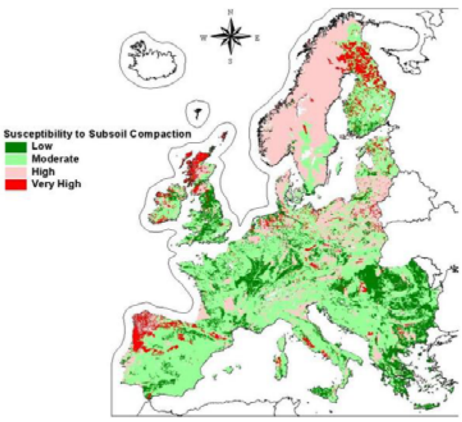

Figure 2.40 Extent of susceptibility to subsoil compaction in Europe.

The following proportions of land in the four susceptibility classes are as follows: low 20%; moderate 44%; high 28%; very high 9%. Thus more than a third of European subsoils are classified as having high or very high susceptibility to subsoil compaction.

A study of compaction in Italy by R. Barberis (pers comm.) provides information for comparison with the susceptibility map for Europe (Figure 2.40). Ilavaska, Houskova and Granec have published a map of the susceptibility of agricultural soils to compaction in the Landscape Atlas of the Slovak Republic (2002, p.281).

2.6 Salinisation

Salinisation is the accumulation in soils of soluble salts of sodium, magnesium, and calcium to the extent that soil fertility is severely reduced. This process is often associated with irrigation as irrigation water always contains variable amounts of salts, especially in regions where rainfall is low, evapotranspiration is high, or soil textural characteristics impede the washing out of the salts, which subsequently build-up in the surface soil layers.

Irrigation with water of high salt content dramatically worsens the problem. In coastal areas, salinisation can also be associated with over-exploitation of groundwater (caused by the demands of growing urbanisation, industry and agriculture) leading to a lowering of the groundwater table, and triggering the intrusion of salt water from the sea. In Nordic countries, the winter maintenance of roads with salts can lead to local salinisation.

2.6.1 Extent of salinisation in Europe

The precise evaluation of salt-affected soils is difficult (ISRIC-UNEP 1990), because the problem of salinisation develops progressively and it is difficult to detect the problem in its early stages. There have been several attempts to assess the extent of salt-affected soils in Europe. In the world as a whole, this area exceeds 10% of the total land surface (Szabolcs 1996).

In Europe, the problem of salinisation is restricted to Austria, Bulgaria, Slovakia, France, Greece, Hungary, Italy, Portugal, Rumania, Spain, Russia, Bosnia, Ukraine, Serbia and Croatia. The largest area of salt affected soils in Europe can be found in the semi-arid steppe and forest steppe regions of Russia, Ukraine, on the lowlands of the Danube in Slovakia, Romania, Hungary, Croatia and Serbia, and in Spain. The main climatic conditions favouring salinisation are arid, semi-arid and semi-humid.

Figure 2.41 shows the distribution map of salt affected soils in Europe (Szabolics, 1974, 1996). It is possible to distinguish three scenarios depending on the type of salinisation processes taking place.

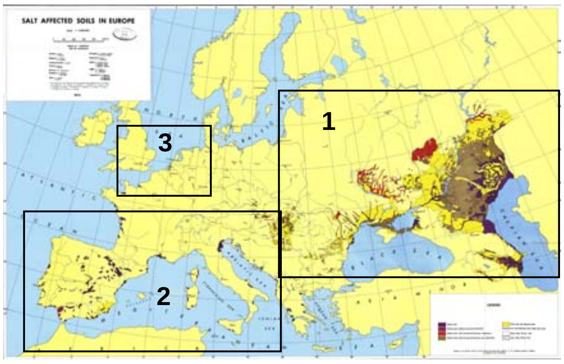

Figure 2.41 Salt affected soils in Europe (Szabolcs, 1974)

Scenario 1: Soil salinity caused by the extension of irrigated agriculture. More than half of European irrigated areas can be found in this category. The climate of these areas is continental to semi-arid. They are located mainly in Russia and Ukraine, and occupy 22 million ha, but considering the potential risk they can be extended to 41 million ha.

Scenario 2: Soil salinity caused by climatic changes. The Mediterranean is the region most likely to be affected by increased salinisation if temperature increases and precipitation decreases. These salt affected soils occupy approximately 2.8 million ha, mainly in the dry areas of the Iberian peninsula (Ebro Valley, Castilla, Mediterranean coast see Figure 2.42), with small areas in south-western France, Italy, Sicily (Dazzi & Fierotti, 1996) Sardinia, Corsica, and the Dalmatian coast of the Balkans.

Scenario 3: Soil salinity caused by sea-level rise. This territory occupies about 1 million ha, mainly in coastal areas of north-western Europe (western Netherlands, Belgium, north-eastern France, and south-eastern England).

Estimates of the area of EU and Candidate Countries affected by salinisation vary from 1 to 3 million ha. In Spain about 3% of the 3.5 million hectares irrigated land is severely affected, significantly reducing its agricultural potential, and another 15 % is at serious risk. In Greece about 30% of the approximately 0.5 million hectares of irrigated land is affected by soil salinisation (Katakouzinos, 1968).

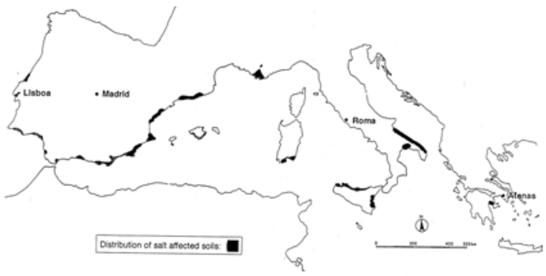

Figure 2.42 Map of Salt affected soil in Europe elaborated by Gisbert (1991).

In the GLASOD study about soil degradation at global scale, Bridges and Oldeman (1999) assessed that 4 million ha of soils of Europe have a moderate to high level of degradation by salinisation. The GLASOD methodology was based on expert judgement (type, extent, degree, rate and cause) on a national/sub-national level and the resulting map at 1:10,000,000 scale is, therefore, only approximate and not appropriate for supporting soil protection and conservation policies at European level.

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