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COVER PICTURE

LANDSCAPE DOMINATED BY EROSION PROCESSES NEAR VOLTERRA, TUSCANY, ITALY

Validation Soil Erosion Risk Assessments in Italy

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1 Summary

In 1999, the Universal Soil Loss Equation (USLE) was applied by the European Soil Bureau to produce a soil erosion risk map of Italy. For each pixel of 6.25 ha (250m x 250 m) a mean annual erosion rate (in t ha^{-1} yr^{-1}) was assessed using the most accurate data available at the national scale. Nevertheless, the authors warn in their report that the regional erosion estimates should be used with caution as the uncertainty involved in the model predictions is not known. A comparison of the predicted erosion rates with direct field observations was not made but could have given an idea about the accuracy of the estimates but this was not possible because it is practically and financially not feasible to acquire long-term soil erosion data at a regional or national scale.

An alternative solution is the use of sedimentation records in lakes and reservoirs. The mean annual sediment volume that is trapped in reservoirs can be measured. This provides sediment flux data (1) at a regional spatial scale (the size of the contributing area) and (2) at a long timescale (since the year of construction or last cleaning of the reservoir). It should, however, be kept in mind that not all of the eroded sediment reaches the outlet of the drainage basin. An important fraction of the sediment is deposited at intermediate locations depending on the drainage density and the spatial configuration of both land cover and topography.

In this paper, sedimentation records from lakes and reservoirs, made available by the ISSDS, have been used to validate the soil erosion risk map of Italy. More than 20 reservoirs were geo-referenced via the Corine Land Cover map. Next, the contributing area of each drainage basin was delineated using a 75m resolution digital elevation model. For each delineated drainage basin, sediment delivery ratios were assessed with WaTEM/SEDEM, a spatially distributed sediment delivery model. Finally, observed and predicted exported sediment volumes were compared.

The results show that:

1) The variation accounted for in the predicted values by validation with the observed values is 62%
2) Soil erosion and sediment export are overpredicted by the model in alpine mountain basins under forest. This can be explained partly by the the fact that the protective role of rock fragments in sparsely vegetated areas is not taken into account because of a lack of input data.
3) If the data from the alpine drainage basins are left out of the data set the variation accounted for in predicted values is 70%.

Future work will incorporate sedimentation data from 25 additional reservoirs, which should allow development of better model procedures for soil erosion risk assessment in mountain areas. The same validation procedure will be applied to evaluate the performance of the PESERA soil erosion model at European scale.

2 Introduction

Human-induced environmental change at a global scale is causing a spectacular increase of geomorphic process activity and sediment fluxes in many parts of the world (e.g. Turner *et al.*, 1990; IGBP-BAHC, 1997; COST Action 623, 1999). The Mediterranean region is particularly susceptible to erosion. This is because it is subject to long dry periods followed by heavy bursts of erosive rainfall, falling on steep slopes with fragile soils, resulting in considerable amounts of soil erosion.

The consequences of soil erosion and sediment deposition occur both on- and off-site. On-site effects are particularly important on agricultural land where the redistribution of soil within a field, the loss of soil from a field, the breakdown of soil structure and the decline in organic matter and nutrients result in a reduction of cultivable soil depth and a decline in soil fertility. The net effect is a loss of productivity, which at first, restricts what can be grown and results in increased expenditure on fertilizers but later might leads to land abandonment (Pimentel *et al.*, 1995).

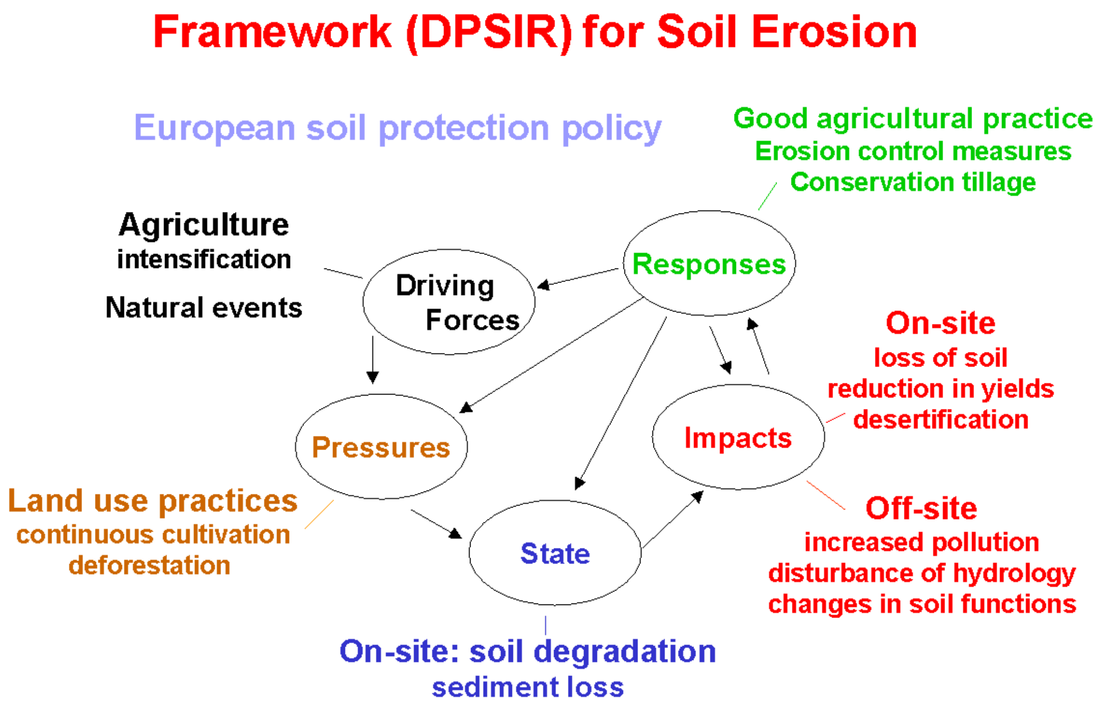

Figure 1: On -and off-site impacts of soil erosion

Off-site problems result from sedimentation downstream, which reduces the capacity of rivers and retention ponds, enhances the risk of flooding and muddy floods and shortens the design life of reservoirs (Clark, 1985; Boardman *et al.*, 1994; Verstraeten and Poesen, 1999). Sediment is also a pollutant in its own right and, through the agro-chemicals adsorbed to it, can increase the levels of nitrogen and phosphorus in water bodies and result in eutrophication (Sibbesen, 1995; Steegen *et al.*, 2001).

The on-site costs of soil erosion are necessarily born by the farmer although they may be passed on in part to the community in terms of higher food prices. The farmer, however, bears little of the off-site costs that fall on local authorities for road clearance and maintenance and all the landholders in the local community affected by sedimentation and flooding.

Not surprisingly soil erosion and sediment delivery have become important topics on the agenda of local, national and European policy makers. This has led to an increasing demand for reliable regional scale erosion models to delineate target zones in which conservation measures are likely to be the most effective. Secondly, regional scale erosion models were requested to predict the geomorphic response of possible conservation measures at the scale of drainage basins.

Until the beginning of the 1990's, the scientific community studying soil erosion was mainly focused on the development of physically-based soil erosion models, aiming at a better understanding of erosion processes at the level of plots or individual parcels. The first attempts to apply such models at a regional or national scale were rather disappointing as their application at such scales appeared to be very problematic because of a lack of high quality input data.

Therefore the regional scale soil erosion risk maps produced in the 1980's and early 1990's used expert-based approaches (e.g. De Ploey, 1989, Oldeman, 1990) or factorial scoring methods (e.g. CORINE, 1992). These kinds of methods allowed relative delineation of areas with a high soil erosion risk, but offered very limited possibilities to evaluate the effect of different land management scenarios.

The increasing availability of regional scale data layers on climate, topography and land use has recently led to the application of simplified quantitative soil erosion models at regional and national scales in Europe (Table 1).

Table 1: Overview of regional and national scale soil erosion risk assessments with quantitative models

Area	Model	References
Germany	USLE	Jäger *et al.*, 1994
France	SEMMED	De Jong *et al.*, 1999
Belgium	USLE2D	Van Rompaey *et al.*, 2000
Italy	RUSLE	van der Knijff *et al.*, 1999, 2002; Grimm *et al.*, 2003
England/Wales	WEPP/MIRSED	Brazier *et al.*, 2001
Czech Republic	RUSLE	Dostal *et al.*, 2001
France	RDI	Kirkby and King, 1999
Europe	RUSLE	van der Knijff *et al.*, 2000
Europe	PESERA	Gobin and Govers, 2001; Grimm *et al.* 2001

Although such soil erosion maps were produced with the most accurate data that were available at regional scale, many researchers warn about the uncertainties involved in this kind of model applications. Two types of errors can be identified (Van Rompaey *et al.*, 2002). In general regional scale modelling involves the application of very simple model structures that may not have the appropriate degree of complexity to describe all the processes involved. A second error source is the uncertainty associated with the various input layers, which propagate through the mathematical equations of the model.

Regional scale soil erosion maps must therefore be used with caution. In fact, it is almost impossible to come to well-founded policy-decisions based on regional scale soil erosion maps if there is no reliable assessment of the of the error on the predicted soil erosion rates.

A comparison with direct field observations could give an idea about the accuracy of the estimates but is rather problematic given the spatial and temporal variability of soil erosion processes. In principle there are 4 techniques to measure soil erosion rates at the scale of a drainage basin:

1) Direct measurement of rill and gully volumes on the fields (e.g. Steegen *et al.*, 2000).
2) Assessment of erosion volumes using remote sensing (e.g. Nachtergaele and Poesen, 1999).
3) Monitoring of the sediment load in rivers.
4) Measurement of sediment deposition rates in lakes and reservoirs.

The first option (direct measurement) is extremely labour-intensive and time-consuming which makes it unsuitable for the acquisition of reliable long-term erosion records for large spatial units. The potential of the second option (remote sensing) is still under investigation. Nachtergaele and Poesen (1999) pointed out that aerial photographs can be used to assess soil losses by gully erosion. The assessment of rill– and interrill erosion is still problematic. The potential of high-resolution space borne imagery (such as IKONOS and QUICKBIRD) with respect to erosion monitoring is still open for exploration.
The measurement of sediment load in rivers (option 3) is suitable for the validation of event-based predictions while the use of sediment deposition records in lakes and reservoirs (option 4) is in general more suited for the validation of long-term soil loss predictions. There are 3 main methods for acquiring lake and reservoir sedimentation rates:

1) Regular mapping of the elevation of the lake or reservoir floor with land survey techniques (e.g. Verstraeten *et al.* (2001),
2) Direct measurement of deposited sediment volumes with SONAR-profilers (e.g. Bazzoffi *et al.*, 1996, Dearing, 1992),
3) Assessment of excavation volumes (in the case of maintained reservoirs) (e.g. Avendano Salas *et al.*, 1997; Dostal *et al.*, 2001)

However, it should be kept in mind that the measurement of sediment deposition volumes in lakes and reservoirs is an indirect soil erosion monitoring technique because only a proportion of the eroded soil reaches a permanent river channel or the outlet of the drainage basin. This means that observed sediment export values can only be compared with predicted erosion values if the sediment delivery ratio (SDR) is taken into account. The sediment delivery ratio (SDR) is the ratio of the total volume of exported sediment over the total volume of eroded sediment. This ratio is different for each drainage basin depending on the topographic characteristics, the drainage density and the spatial configuration of soil types and soil cover.

A wide range of empirical regression equations has been developed to assess sediment delivery ratios. In general such models predict the sediment delivery ratio using 'lumped' or aggregated drainage basin parameters such as the average slope gradient, the percentage of forest, the drainage density etc.

Examples of these lumped approaches are given by Roehl 1962, Vanoni 1975, Walling 1983, Klaghofer *et al.*, 1992, Atkinson 1995, Verstraeten *et al.*, 2001, 2003. Such lumped models have however two major drawbacks:

1) They can not take into account the topological configuration of sediment sources and sinks within a drainage basins
2) They cannot be extrapolated out of the area for which they were calibrated.

Spatially explicit sediment delivery models on the other hand link each sediment source with the permanent river channels via unique flow paths. If at some point on the flow path, the sediment transport capacity is not sufficient, sediment deposition will occur. Such an approach has been proven to be more successful than the traditional lumped SDR modelling approaches if relatively accurate topographical and land cover data are available. Van Rompaey *et al.* (2001b) developed a spatially explicit sediment delivery model (WaTEM/SEDEM) that incorporates the spatially distributed principle described above. The model was applied relatively successful to model sediment fluxes in humid temperate lowlands (central Belgium), in humid temperate hilly areas (central Germany and Czech Republic), in Mediterranean mountain environments (South Africa) and in tropical mountain environments (Ecuador).

The main objective of this paper is a validation of soil erosion assessments in Italy made by the European Soil Bureau (ESB) in 1999 (van der Knijff *et al.*, 1999, 2002). The erosion map was made with the most accurate data available at a national scale. However, the accuracy of the predicted soil erosion rates was never evaluated because of a lack of validation data. Subsequently, through a collaboration with the Instituto Sperimentale per lo Studio e la Difesa dello Suolo (ISSDS Firenze, Ministero delle Politiche Agricole e Forestali) a data set with sedimentation records in 44 Italian lakes and reservoirs was made available. In this paper, the ISSDS database has been compared with the ESB soil erosion risk map of Italy. The WaTEM/SEDEM model was used to assess SDR-values and to convert soil erosion rates in sediment export rates.

3 ESB Soil erosion risk map of Italy

In 1998, the Italian Ministry of Agriculture commissioned the 'Soil map of Italy Project' that aimed at compiling a 1:250,000 scale soil map and associated database for Italy. In the framework of this project, a soil erosion risk map of Italy was compiled by the European Soil Bureau (van der Knijff *et al.*, 1999, 2002).

The map is based on a national scale application of the Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1978). The USLE is an empirical equation that computes the mean annual soil loss in t ha^{-1} yr^{-1} by multiplying 5 factors. The equation is as follows:

$$A = R\ K\ L\ S\ C$$

Where:

A	=	Mean annual soil loss (in t ha^{-1} yr^{-1})
R	=	Rainfall erosivity factor (in MJ mm ha^{-1} h^{-1} yr^{-1})
K	=	Soil erodibility factor (in t h MJ^{-1} mm^{-1})
L	=	Slope length factor (dimensionless)
S	=	Slope factor (dimensionless)
C	=	Cover management factor (dimensionless)

For each grid cell of 6.25 ha (250m x 250m) 5 parameters were assessed. Rainfall erosivity values were derived from monthly rainfall data made available through the MARS Meteorological Database (Rijks *et al.*, 1998). Pedotransfer functions taking into account soil texture and the parent material were applied to derive soil erodibility values from the European Soil Database at a scale of 1:1,000,000. Slope length and slope gradient were calculated using the equations of Moore *et al.* (1993) at a 250m resolution DEM.

Grimm *et al.* (2003) refined the USLE-application for Italy in two ways by:

1) Ameliorating the rainfall erosivity map by using data from more meteorological stations combined with more sophisticated interpolation procedures.
2) Assessing soil erodibility by taking into account the susceptibility of soil surface to form crust or become sealed using a methodology proposed by INRA, Orléans (Le Bissonnais and Darrousin, 1998).

The procedures and the data that were used to estimate the RUSLE factors are described in detail by van der Knijff et al. (1999, 2002) and Grimm et al. (2003). The end result of these studies is an assessment of the mean annual soil erosion rate for each 250m x 250m grid cell (Figure2). Although the map is based on the most accurate data available for the whole of Italy, the authors warn about possible errors involved in the model application resulting from both model simplification and input error.

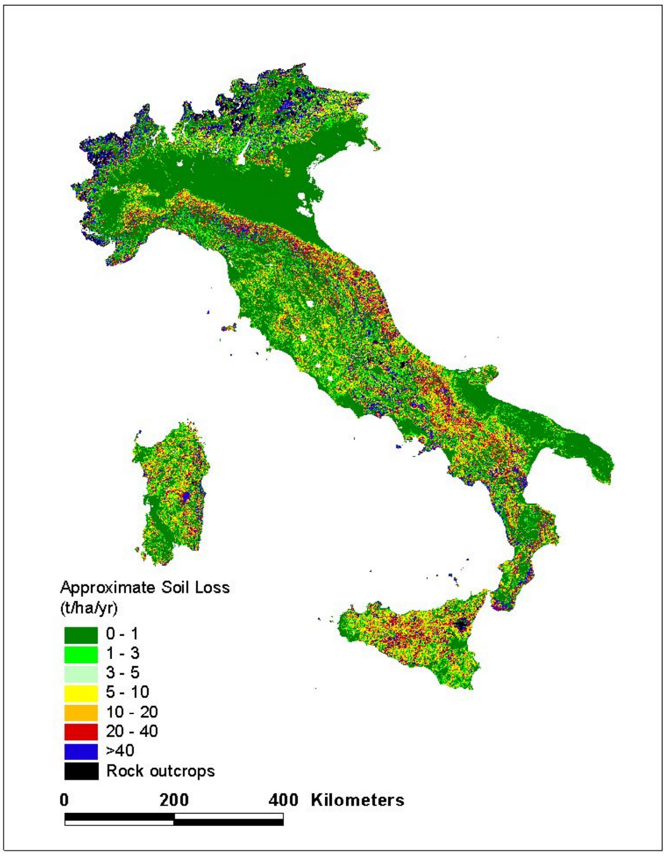

Figure 2 Predicted mean annual soil erosion rates for Italy (after Grimm et al., 2003)

4 ISSDS Sediment yield data set

Bazzoffi at the ISSDS has compiled a data set with sediment deposition rates for reservoirs constructed in the 1950's and 1960's throughout Italy.

Sediment deposition rates were assessed by direct sonar sub-bottom profiler measurements or derived from estimates and measures made by ENEL (Italian Electricity Power Company) during dredging or from direct surveys. Only lakes and reservoirs with a likely sediment trapping efficiency of 100% were considered. Nevertheless, there is never a 100% guarantee that that sediment trapped in a reservoir represents the total sediment yield from the watershed in the lapse of time from dam building to survey time. For this reason only 44 watershed-reservoir systems were selected from the database, retaining only the better-known ones respect to management history.

The sediment volumes where converted to mass volumes using a mean bulk density of 0.865 t m^{-3} derived from the direct analysis of sedimentary profiles of 4 reservoirs of the data set and from the application of equations of Lara and Pemberton (1963) and Lane and Koelzer (1943) for estimating sediment density from grain size distribution and regime of exposition to air of deposits.

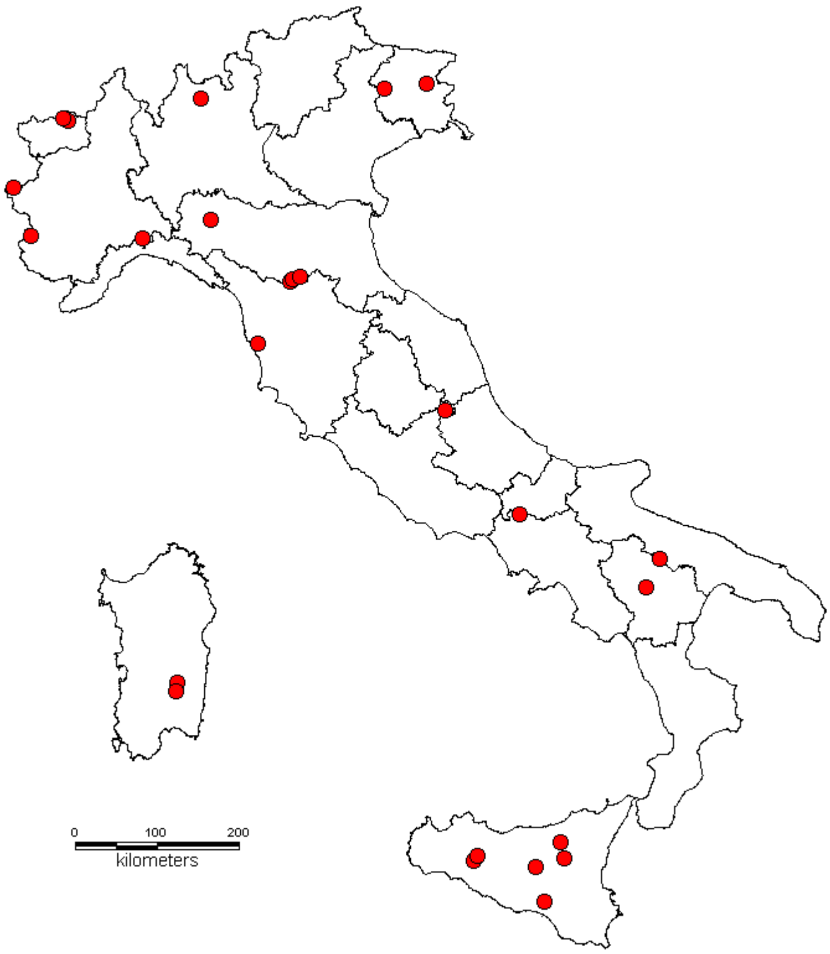

Figure 3 Location of the 22 drainage basins with measured sedimentation volumes in reservoirs at the outlet.

The lakes and reservoirs are located in a vector-point file. In order to delineate the contributing area of each measuring point the following procedure was applied:

1) An overlay of the lake-point map with Corine Land Cover map (CLC) was used to identify lakes and reservoirs with sediment deposition records.
2) The automatic watershed analysis of Idrisi32 ® was applied to delineate the drainage basin contributing to the lake or reservoir using a digital elevation model with a resolution of 75m.

The CLC-map is a generalized European scale landcover layer with a minimum size of 25 ha for each mapping unit. Only 22 lakes and reservoirs of the ISSDS-data set were large enough to be identified on the CLC-layer. Therefore the validation of the erosion rates was carried out, initially, using a sub-data set of 22 records. In some drainage basins there is a cascade system of reservoirs. In these cases the contributing area of the upslope reservoirs was subtracted from the total area contributing to the reservoir under investigation. Figure 3 shows the location of the 22 watershed-reservoir systems that are used in this study.

The ISSDS-data set includes data from semi-natural alpine basins in the north as well as agricultural and semi-natural basins in central and southern Italy (see Table 2).

Table 2 Characteristics of the drainage basins used in this study

Basin	Type	Size (km²)	Slope grad. (%)	Ann. Precip (mm)	Meas. SSY (ton/ha.y)
Ancipa	South	50	17.76	643	5.6
Barcis	Alps	390	59.92	1945	5.2
Castello	Alps	68	48.37	907	3.7
Cignana	Alps	12	51.03	913	0.0
Desueri	South	249	11.27	650	16.8
Flumendosa	South	697	26.28	950	0.9
Gammauta	South	91	24.33	792	1.6
Lavagnina	Alps	43	30.43	1592	4.1
Letino	South	13	24.3	1500	0.5
Mignano	Alps	87	20.48	993	12.8
Mulargia	South	171	11.86	711	10.3
Placemoulin	Alps	68	60.17	913	2.3
Ponte Fontanelle	South	352	19.55	823	6.7
Pozzillo	South	578	16.86	658	19.6
Prizzi	South	21	14.5	792	5.7
Rochemolles	Alps	24	49.81	901	0.1
Santa Luce	Central	40	9.91	684	9.2
Scalere	Central	14	25.05	1600	0.9
Scandarella	Central	39	15.24	881	4.9
Serra di Corvo	South	298	5.73	473	1.9
Suviana	Central	75	33.44	1631	3.8

The average size of the basins in the selected subset is 155 km², ranging from 12 to 697 km². The mean annual precipitation ranges from 473mm in the south to 1945mm in the Alps to the north. The measured area-specific sediment yield (Meas. SSY) varies between 0.1 t $ha^{-1}y^{-1}$ and 16.8 t $ha^{-1}y^{-1}$. Figure 4 shows a picture of a reservoir in the data set near Volterra in Tuscany.

5 Modelling sediment delivery

In order to compare predicted erosion rates with observed sediment export volumes, it is necessary to assess the fraction of the eroded sediment that reaches the outlet of the drainage basin. Therefore WaTEM/SEDEM, a spatially explicit sediment delivery model, was used to assess the sediment delivery ratio (SDR). For a detailed description of the model and its components, we refer to Van Rompaey *et al.* (2001b). In this report only the basic principles are described.

Figure 4 Reservoir near Volterra (Tuscany). The sediment volume in this reservoir was measured by sonar sub-bottom profiler (Bazzoffi et al., 1996)

Whether or not the eroded sediment is deposited within the basin depends on the travel distance and the characteristics of the travel path. Lumped sediment yield models use average basin characteristics, such as drainage density, mean slope gradient, percentage of forest, to predict the sediment delivery ratio. Recent research (Lenhart *et al.*, in press) pointed out that taking into account the spatial pattern of rivers, topography and soil cover results in much more accurate SDR-predictions.

WaTEM/SEDEM (Figure 5) requires a layer of mean annual erosion rates and a layer with the location of the permanent rivers in the basin as input. For each pixel of the drainage basin, the mean annual transport capacity (TC in t yr^{-1}) is calculated using the following equation:

$$TC = K_{TC} R K (L S - 5.3 S_g^{0.8})$$

Where:

R, K, L, S: USLE-parameters
S_g : the slope gradient
K_{TC}: the transport capacity coefficient

K_{TC}-values for different types of land use have to be assessed by means of calibration. Once the mean annual soil erosion rate and the mean annual transport capacity are known, a routing algorithm is used to transfer the eroded sediment from the source to the river network. All the sediment sources are connected with the rivers via topographically derived flow paths.

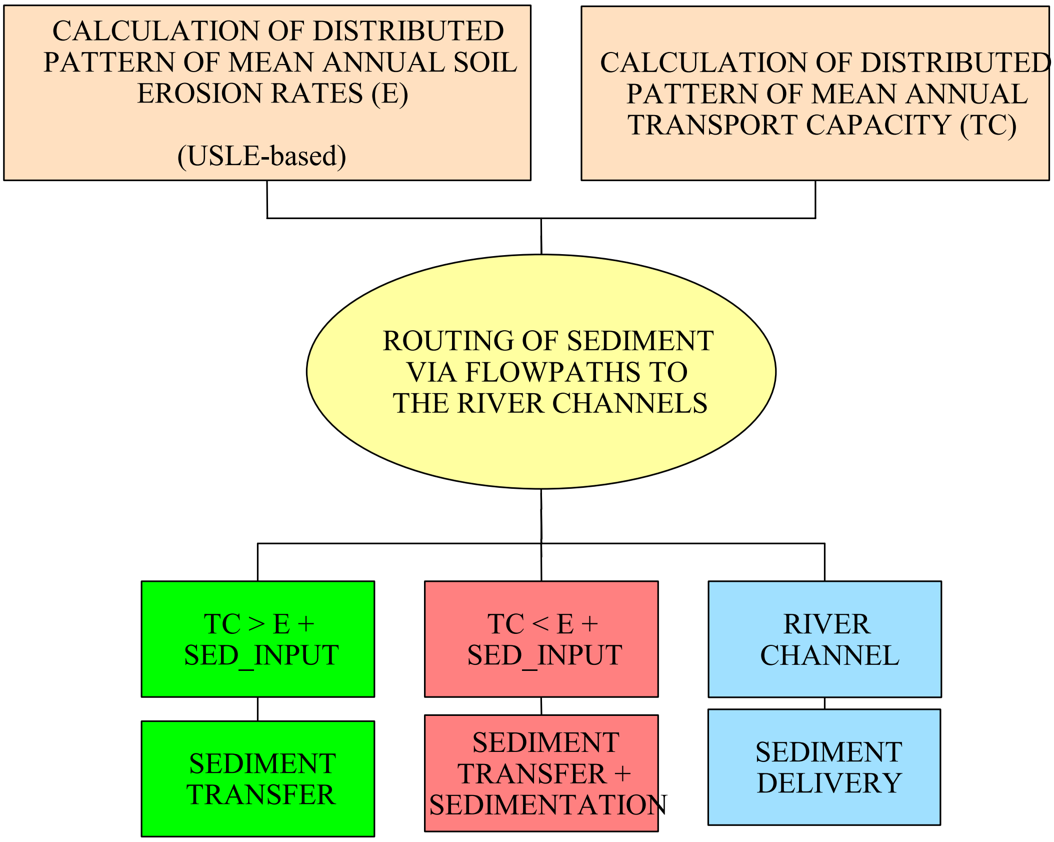

Figure 5 Main components of the WaTEM/SEDEM model

For each pixel the amount of sediment input is added to the amount of soil erosion in that cell. If the sum of the sediment input and the local sediment production is lower than the transport capacity then all the sediment is routed further down slope. If this sum exceeds the transport capacity then the sediment output from the pixel is limited to the transport capacity. In the latter case, limited net erosion will occur if the transport capacity exceeds the sediment input to the pixel. If the transport capacity is lower than the sediment input, there will be a net sediment deposition.

The output of the model consists of a pixel map representing the amount of net erosion and net sediment deposition at each pixel. Furthermore the amount of sediment that reaches the river channels is calculated. The sediment yield (SY in t yr^{-1}) can be expressed as an absolute value. An area-specific value (SSY in t ha^{-1} yr^{-1}) can be calculated when the absolute sediment yield value is divided by the size of the drainage basin.

6 Model calibration and application

The procedure described above was applied to all 22 drainage basins of the subset. For each drainage basin 3 raster maps with a resolution of 75m x 75m were prepared (see
Figure ***6***) :

1) A map with the mean annual sediment production (extracted from the ESB soil erosion risk map)
2) A map with the land cover and river channels (an overlay of the CLC-map and a river-vector file extracted from the Geographical Information System for the European Commission (GISCO-database)
3) A digital elevation model with a resolution of 75m derived from scanned contourline-maps at a scale of 1:100,000.

Soil erosion map (extract from ESB soil erosion risk map)	**Land use map** (extract from Corine Land Cover)	**Digital Elevation Model**

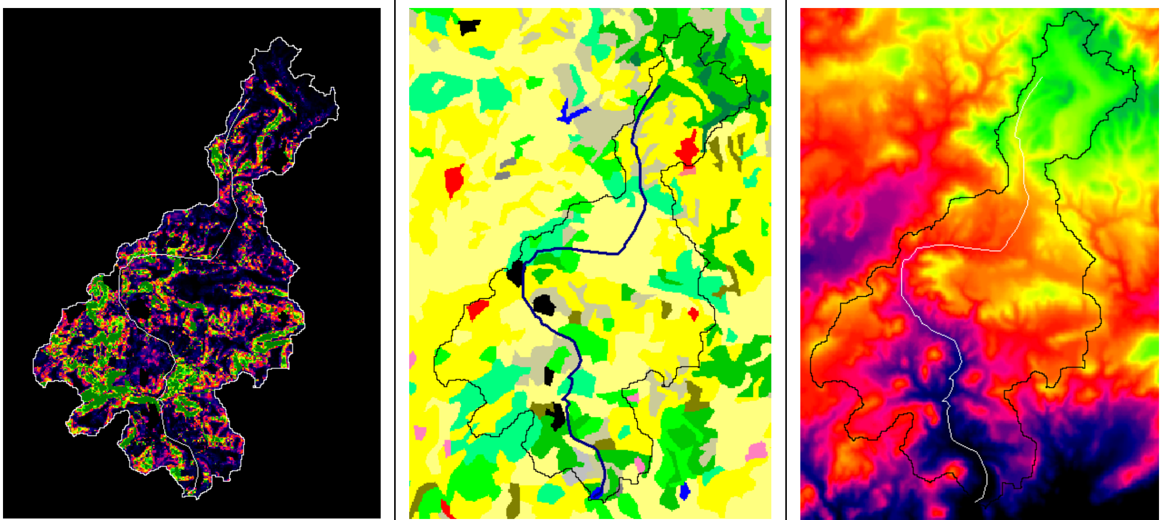

Figure 6 Input layers for WaTEM/SEDEM

Because of the limited number of observations in the data set, only the transport capacities for arable land (K_{TCA}) and for 'non-eroding' surfaces (K_{TCN}) such as forest, pasture and natural grassland were calibrated.

For each drainage basin of the data set, the model was run with for the K_{TCA}-parameter values ranging from 5 to 40 and for K_{TCN} from 20 to 100. For each combination of K_{TCA} and K_{TCN} a sediment yield value was calculated for the 22 drainage basins. This allowed a comparison of the measured and predicted sediment yield values for each parameter combination. The model efficiency coefficient as proposed by Nash and Sutcliffe (1970) was used as a measure of likelihood :

$$ME = 1 - \frac{\sum (Y_{obs} - Y_{pred})^2}{\sum (Y_{obs} - Y_{mean})^2}$$

Where: ME: the model efficiency, Y_{obs}: the observed value, Y_{pred}: the predicted value, Y_{mean}: the mean observed value. Values for ME range from -∞ to 1. The closer ME approximates to 1, the better the model will predict individual values.

The results of these simulations are plotted in Figure 7 and Figure 8. The results show an optimal value for K_{TCA} at 50 m and an optimal value for K_{TCN} at 30 m.

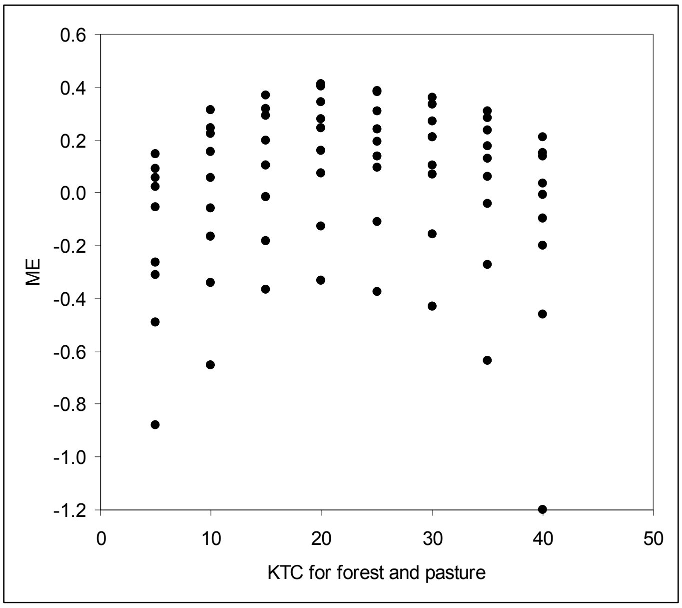

Figure 7 Calibration of the transport capacity for forest and pasture (K_{TCN} in m) (ME, model efficiency)

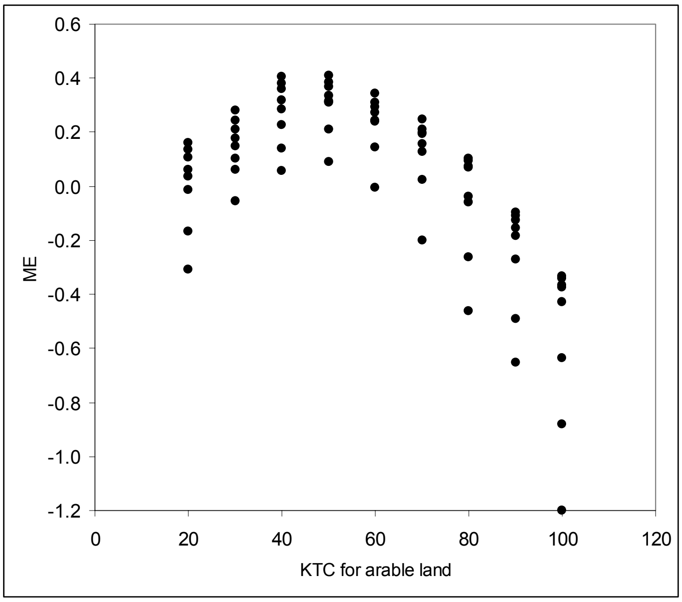

Figure 8 Calibration of the transport capacity for arable land (K_{TCA} in m) (ME, model efficiency)

7 Results and Discussion

After the calibration, the mean annual sediment yield was calculated using the calibrated K_{TC}-parameters. Predicted and observed values are shown in Table 3.

Table 3 Measured and predicted Area-specific sediment yield (SSY in t ha^{-1} yr^{-1}) for 22 Italian drainage basins.

Basin	Meas. SSY (t ha^{-1}yr^{-1})	Pred. SSY (t ha^{-1}yr^{-1})	Pred. Erosion (t ha^{-1}yr^{-1})	SDR
Ancipa	5.6	7.8	54.3	0.14
Barcis	5.2	5.2	55.0	0.09
Castello	3.7	6.5	18.4	0.35
Cignana	0.0	5.8	8.5	0.68
Desueri	16.8	9.8	37.2	0.26
Flumendosa	0.9	2.8	44.8	0.06
Gammauta	1.6	3.0	16.7	0.18
Lavagnina	4.1	9.6	111.1	0.09
Letino	0.5	4.3	38.2	0.11
Mignano	12.8	20.6	108.8	0.19
Mulargia	10.3	6.4	20.9	0.31
Placemoulin	2.3	4.8	12.1	0.40
Ponte Fontanelle	6.7	9.0	33.5	0.27
Pozzillo	19.6	19.2	144.5	0.13
Prizzi	5.7	4.7	32.6	0.14
Rochemolles	0.1	3.1	13.6	0.23
Santa Luce	9.2	10.7	44.1	0.24
Scalere	0.9	7.3	73.0	0.10
Scandarella	4.9	7.8	37.9	0.21
Serra di Corvo	1.9	4.0	15.4	0.26
Suviana	3.8	4.0	49.4	0.08
Torre Crosis	1.2	5.5	66.6	0.08

The results of the model runs are plotted in Figure 9. Although observed and predicted values are positively correlated, Figure 9 shows a significant scatter. The Pearson's R^2 between observed and predicted values is 62%. The optimal model efficiency after calibration is 0.41. This value is lower than those reported in other WaTEM/SEDEM applications (see Table 4). This may be because that Italian data set covers a wide range of landscape types ranging from Alpine mountain basins over agricultural areas in central Italy to semi-arid Mediterranean basins in Sicily and Sardinia. The data sets in the other studies are much more homogeneous, which facilitates a more accurate calibration.

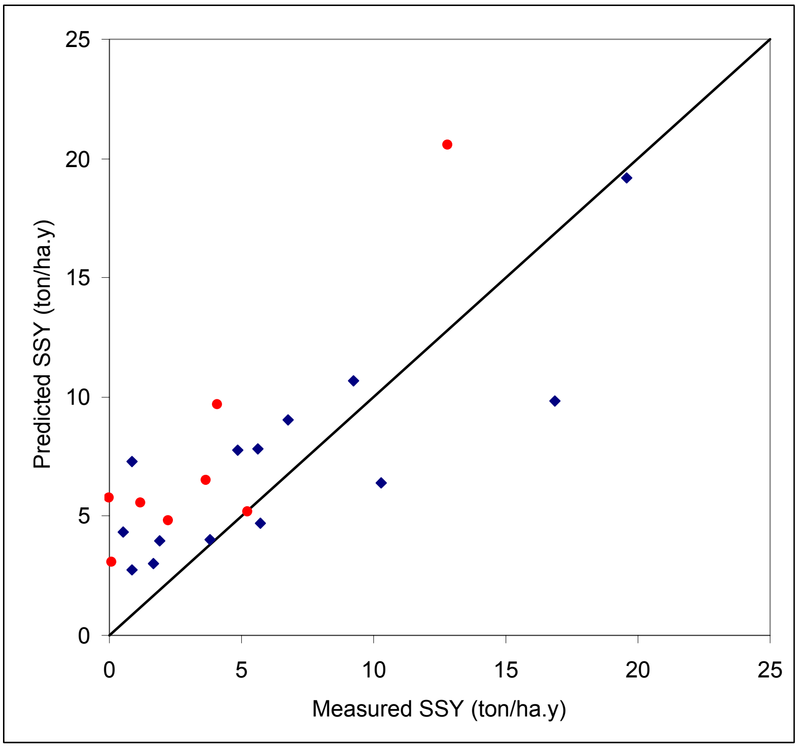

Figure 9 Observed versus predicted area-specific sediment yield (in t ha^{-1} yr^{-1}). Red dots are alpine mountain basins

The RRMSE (Relative Root Mean Square Error) on the model predictions in this study is 70%. This means that 33% of all sediment yield predictions have >70% error. If for a given drainage basin an average annual soil loss of 10 t/ha is predicted, there is a 34% chance that the actual soil loss will be than 17 t ha^{-1}. It should however be kept in mind that the followed validation procedure has three main sources of uncertainty:

1) Error on the measured values
2) Error on the predicted SDR ratio
3) Uncertainty on the predicted soil erosion rates

Table 4 ME-values in other WaTEM/SEDEM-applications

Region	**N basins**	**ME-value**	**Reported in :**
Italy	23	0.41	This paper
Central Belgium	24	0.77	Van Rompaey *et al.*, 2001b
Jonkershoek - South Africa	6	0.55	Van Rompaey *et al.*, 2001a
Czech Republic	6	0.59	Van Rompaey *et al.*, 2003

The first source of uncertainty is the error involved in the assessment of the sediment volumes deposited in the reservoirs. Verstraeten *et al.* (2001) reported that the error involved in measuring sediment volumes in retention ponds can go up to 20%. The error involved in advanced SONAR-measurements may be significantly lower. Although the data set was compiled with the greatest care, there is never a 100% guarantee that that sediment trapped in a reservoir represents the total sediment yield from the watershed in the lapse of time from dam building to survey time. Unreported excavation, fillings or modifications of the reservoir could be the cause of flawed sediment yield values.

The second source of uncertainty is the prediction of SDR-values with the WaTEM/SEDEM model. As mentioned before, the use of sediment yield data for the validation of an soil erosion map is only indirect because the measured sediment yield data must be converted into soil erosion data by means of SDR-values. It is therefore rather problematic to point out which part of the uncertainty must be contributing to an erroneous SDR-prediction and which part to an erroneous soil erosion prediction. Moreover the calibration procedure tends to camouflage systematic errors: if the soil erosion rates are systematically over predicted, this will be compensated to a certain extent by underestimated SDR-values derived via a calibration procedure. A systematic error in SDR-values however will never hide away the relative differences between the catchments.

Taking a closer look at Figure 9, it appears that the modelled sediment losses from drainage basins with low observed soil losses tend to be overpredicted. The alpine mountain catchments mainly belong to this group (red dots in Figure 9).

This may be explained by the fact that the USLE was not developed for this kind of environment and that parameter values such as the topographic factor (LS) may not be extrapolated to these kinds of systems. A second possible explanation for the biased results is the possible overestimation of the RUSLE soil cover factor (C). The procedure followed by van der Knijff *et al.* (1999, 2002) does not take into account the protective effect of rock fragments. Experimental research (Poesen *et al*., 1994, Poesen and Lavee, 1994) showed that.the mean decrease of relative interrill and rill sediment yield with rock fragment cover can be expressed by an exponential decay function. At present however, the 1:1,000,000 European Soil Database, which was used in this study, does not contain sufficiently detailed information on stone cover to apply this kind of correction function.

Field surveys in some of these catchments could be an appropriate method of validation. Eventually, when more data from more alpine drainage basins become available, a separate calibration and validation is recommended.

8 Conclusions

The original objective of this paper was to validate the soil erosion risk map of Italy. Because direct field surveys are technically and financially impossible, sedimentation records in reservoirs were used as a validation data set. Such a procedure however requires the assessment of sediment delivery ratios (SDR-values) as only a proportion of the eroded sediment eventually reaches the outlet of a drainage basin. SDR-values were assessed with the WaTEM/SEDEM model.

Observed values were compared with predicted values. The error on the predicted sediment yield values was 70%. This error is higher than those reported in other WaTEM/SEDEM applications but the accuracy of the available input data in those studies was much higher. Moreover the soil erosion map of Italy covers a range of completely different environments, which makes calibration procedures more complex. Nevertheless a relative error of 70% is acceptable given the simplified model structure that was applied and the quality of the input data that were used. A comparison with the accuracy of soil erosion risk maps, for which input data of a similar quality were used, is not possible as this study is the first attempt to validate soil erosion predictions at regional scale.

The results show that the soil loss is probably over predicted in the forested mountain catchments because of modelling concepts in these kinds of environments and erroneous parameterization procedures. Further research on the modelling of sediment fluxes in mountain areas is needed.

Although the present study comes up with some error estimation for the soil erosion risk map of Italy, the results should be interpreted with care as the validation is only indirect. The total error involved is caused by two model applications : the RUSLE model to predict the soil erosion rates and the WaTEM/SEDEM model to predict SDR-values. Although the WaTEM/SEDEM model has been proven to be rather reliable in a range of different landscapes, a significant part of the relative error of 70% may be contributed to the prediction of the SDR-value. Nevertheless, we believe that the validation procedure presented above is the only possible approach for a regional scale validation of soil erosion estimates.

The methodology proposed by van der Knijff *et al.* (1999, 2002) and Grimm *et al.* (2003) produces soil erosion assessments of acceptable accuracy in hilly areas under cropland. The soil erosion assessments in mountain environments are less reliable but, from land management point of view, it is much more important to predict accelerated soil erosion under cropland than in (semi-)natural soil erosion in forested mountain areas.

The soil erosion risk map of Italy produced by van der Knijff et al. (1999, 2002) can therefore be used for the regional delineation of areas susceptible to soil erosion in agricultural areas. For the implentation of soil conservation measures at field level, more detailed studies at large scales are necessary. The soil erosion risk map of Italy can be considered as the first step in an hierarchical assessment system. Further modelling studies or fieldwork should focus on drainage basins with a high soil erosion risk as predicted using the regional scale approach.

Future research at regional scale in Italy will focus on the incorporation of additional drainage basins in the ISSDS database. This will make the validation base much broader, and allow partitioning of the database into homogeneous groups that could make the calibration more accurate. Eventually, the same validation methodology will be applied to soil erosion estimates using the PESERA model.

References

Atkinson, E., 1995. Methods for assessing sediment delivery in river systems. Hydrological Sciences, 40(2) : 273-280.

Avendano Salas, C., Sanz Montero, E., Rayan, C., Gomez Montana, J.L., 1997. Sediment yield at Spanish reservoirs qnd its relationship with drainage basin area. Proceedings of the 19th Symposium of Large Dams, Florence. ICOLD (International Committee on Large Dams), Paris, 863-874.

Bazzoffi, P., Baldassarre G., Vacca S. 1996. Validation of PISA2 model for automatic assessment of reservoir sedimentation. Proceedings of the International Conference on Reservoir Sedimentation. M.Albertson Ed. Colorado State Univ. 519-528.

Boardman, J., Ligneau, L., De Roo, A., Vandaele, K., 1994. Flooding of property by runoff from agricultural land in north-western Europe. Geomorphology, 10: 183-196.

Brazier, R.E., Rowan, J.S., Quinn, P. and Anthony, S., 2001. Towards an MIR (Minimum Information Requirement) approach to modelling on-site soil loss at the National scale. Catena, 42: 59-79.

Clark, E.H., 1985. The off-site costs of soil erosion. Journal of soil and water conservation, 40(1): 19-22.

CORINE, 1992. CORINE - Soil erosion risk and important land resources in the southern regions of the European Community, final report EUR 13233-EN. Office for Official Publication of the European Communities.

COST Action 623 (European COorporation in the field of Scientific and Technical research), 1999, Soil erosion and global change. www.cost623.leeds.ac.uk.

de Jong, S.M., Paracchini, M.L., Bertolo, F., Folving, S., Megier, J., de Roo, A.P.J., 1999. Regional assessment of soil erosion using the distributed model SEMMED and remotely sensed data. Catena, 37(3-4): 291-308.

De Ploey, J., 1989. Erosional systems an perspectives for erosion control in European löss areas. Soil Technology Series, 1: 93-102.

Dearing, J.A., 1992. Sediment yields and sources in a Welsh upland lake-catchment during the past 800 years. Earth Surface Processes and Landforms, 17: 1-22.

Dostal, T., Krasa, J., Vaska, J., Vrana, K., 2001. Map of soil erosion risk and sediment transport in the Czech Republic.VUV TGM, 1-21.

Gobin, A., Govers, G., 2001. PESERA (Pan-European Soil Erosion Assessment). EC Contract no. QLK5-CT-1999-01323, First Interim Report, 69pp.

Grimm, M., Jones, R.J.A., Montanarella, L., 2001. Soil erosion risk in Europe. European Soil Bureau. EUR 19022 EN, 38pp.

Grimm, M., Jones, R.J.A., Rusco, E., Montanarella, L., 2003. Soil erosion risk in Italy: a revised USLE approach. European Soil Bureau Research Report No. 11, EUR xxxxx EN,

IGBP-BAHC (International Geosphere-Biosphere Programme), 1997. Modelling the transport and transformation of terrestrial materials to freshwater and coastal ecosystems, IGBP Report No. 39, IGBP, Stockholm, Sweden.

Jäger, S., 1994. Modelling regional soil erosion susceptibility using the USLE and GIS. In: Rickson (ed.): Conserving Soil resources: European Perspectives, CAB International, Wallingford: 161-177.

Kirkby, M., King, D., 1999. Summary report on provisional RDI erosion risk map for France. Report on contract to the European Soil Bureau (unpublished).

Klaghofer, E., Summer, W., Villeneuve, J.P., 1992. Some remarks on the determination of the sediment delivery ratio. IAHS Publ. No. 209: 113-118.

Lane, E.W., Koelzer, V.A., 1943. Density of sediments in reservoirs. In: A study of methods used in the measurements and analysis of sediments loads in streams. U.S. Corp of Engineers, Hydr.Lab. Iowa University.

Lara, J.M., Pemberton, E.L. 1963. Initial Unit Weight of deposit sediments. Proceedings of the Federal Inter-Agency Sedimentation Conference, Paper No. 82., USDA.

Le Bissonnais, Y., Darrousin, J., 2001. A pedotransfer rules database to interpret the Soil Geographical of Europe for environmental purposes. Proceedings of the workshop on the use of pedotransfer in soil hydrology research in Europe, Orléans, France, 10-12 October 1996.

Lenhart, T., Van Rompaey, A.., Steegen, A., Fohrer, N., Frede, H.G., Govers, G., 2003. A modification of the sediment routines in SWAT: A simple approach to consider spatial distribution and deposition, Hydrological Processes, in press.

Moore, I.D., Turner, A.K., Wilson, J.P., Jenson, S.K., Band, L.E., 1993. GIS and land-surface-subsurface modelling. In: Goodchild, M., Parks, B.O., Steyaert, L.T. (eds): Environmental modelling with GIS, pp. 196-230.

Nachtergaele, J., Poesen, J., 1999. Assessment of soil losses by ephemeral gully erosion using high-altitude (stereo) aerial photographs. Earth Surface Processes and Landforms. 24 (8): 693-706.

Nash, J.E. and Sutcliffe, J.V., 1970. River flow forecasting through conceptual models. Part I. A discussion of principles. Journal of Hydrology, 10: 282-290.

Oldeman, L.R., 1990. World map of the status of human-induced soil degradation (GLASOD): an explanatory note. ISRIC, Wageningen, The Netherlands.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R., Blair, R., 1995. Environmental and economic costs of soil erosion and conservation benefits. Science, 267(5201): 1117-1123.

Poesen, J., Torri, D., Bunte, K., 1994. Effects of rock fragments on soil erosion by water at different spatial scales: a review. Catena, 23: 141-166.

Poesen, J., Lavee, H., Rock fragments in top soils: signifcance and processes. Catena, 23: 1-28.

Rijks, D., Terres, J.M., Vossen, P., 1998. Agrometeorological applications for regional crop monitoring and productions assessment. EUR 17735 EN, 505pp.

Roehl, J.E., 1962. Sediment source areas, delivery ratios and influencing morphological factors., IAHS Publ. No. 59: 202-213.

Sibbesen, E., 1995. Phosphorus, nitrogen and carbon in particle-size fractions of soils and sediments. In: Correl, A. (ed.) Surface runoff, erosion and loss of phosphorus at two agricultural soils in Denmark, plot studies 1989-1992, SP-report No. 11: 135-148.

Steegen , A., Govers, G., Nachtergaele, J., Takken, I., Beuselinck, L., Poesen, J., 2000. Sediment export by water from an agricultural catchment in the Loam Belt of central Belgium. Geomorphology 33: 25-36.

Steegen, A., Govers, G., Takken, I., Nachtergaele, J., Poesen, J., Merckx, R., 2001. Factors controlling sediment and phosphorus export from two Belgian agricultural catchments. Journal of Environmental Quality, 30(4): 1249-1258.

Turner, B.L., Clark, W.C., Kates, R.W., Richards, J.F., Matthews, J.T., Meyer, W.B. 1990. The earth as transformed by human action. Cambridge University Press.

van der Knijff, J.M., Jones, R.J.A., Montanarella, L. 1999. Soil erosion risk assessment in Italy. European Soil Bureau. EUR 19022 EN, 52pp.

van der Knijff, J.M., Jones, R.J.A., Montanarella, L. 2000. Soil erosion risk assessment in Europe. European Soil Bureau. EUR 19044 EN, 36pp.

van der Knijff, J., Jones, R.J.A., Montanarella, L., 2002. Soil Erosion Risk Assessment in Italy. In: J.L. Rubio, R.P.C Morgan, S. Asins and V. Andreu (eds). Proceedings of the third International Congress Man and Soil at the Third Millennium. Geoforma Ediciones, Logrono. p.1903-1913.

Van Rompaey A.J.J., Govers, G., Waumans, T., Van Oost, K., Poesen, J., Desmet, J., 2000. Een regionale bodemerosierisicokaart voor Vlaanderen, @WEL, 3, pp. 1- 6.

Van Rompaey, A.J.J., Verstraeten, G., Van Oost, K., Rozanov, A., Govers, G., Poesen, J., 2001a. Modelling sediment fluxes in the Jonkershoek catchment. Part 1 : Model calibration and validation, Proceedings of the workshop : Cartographic Modelling of Land Degradation (Gent)

Van Rompaey, A.J.J., Verstraeten, Van Oost, K., G., Govers, G., Poesen, J., 2001b. Modelling mean annual sediment yield using a distributed approach. Earth Surface Processes and Landforms, 26(11): 1221-1236.

Van Rompaey, A.J.J., Govers, G. 2002. Data quality and model complexity for continental scale soil erosion modelling. International Journal of GIS, 16(7): 663-680.

Van Rompaey, A.J.J., Krasa, J., Dostal, T., Govers, G., 2003. Modelling the impact of decollectivization on soil erosion and sediment yield, Hydrobiologia, in press.

Vanoni, V.A., 1975. Sedimentation Engineering. ASCE Manuals and Reports on Engineering Practices, no. 54.

Verstraeten, G., Poesen, J. 1999. The nature of small-scale flooding, muddy floods and retention pond sedimentation in central Belgium. Geomorphology, 29(3-4): 275-292.

Verstraeten, G. Poesen, J., 2001. Factors controlling sediment yield from small intensively cultivated catchments in a temperate humid climate. Geomorphology, 40: 123-144.

Verstraeten, G., Poesen, J., de Vente, J., Koninckx, X., 2003. Sediment yield variability in Spain: a quantitative and semi-quantitative analysis using reservoir sedimentation rates. Geomorphology, 50: 327-348.

Walling, D.E., 1983. The sediment delivery problem. Journal of Hydrology, 65 : 209-237.

Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses – a guide for conservation planning. U.S. Department of Agriculture, Agriculture Handbook 537.

European Soil Bureau Research Reports:

No.1 European Land Information Systems for Agro-environmental Monitoring. D. King, R.J.A. Jones and A.J. Thomasson (eds). EUR 16232 EN, 284pp. (1995). Office for the Official Publications of the European Communities, Luxembourg.

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No.5 Georeferenced Soil Database for Europe: Manual of Procedures Version 1.0. European Soil Bureau, Scientific Committee. EUR 18092 EN 184pp. (1998). Office for Official Publications of the European Communities, Luxembourg.

No.6 Soil Resources of Europe. P. Bullock, R.J.A. Jones and L. Montanarella (eds). EUR 18991 EN 202pp. (1999). Office for Official Publications of the European Communities, Luxembourg.

No.7 Soil Classification 2001. Erika Micheli, Freddy O. Nachtergaele, Robert J.A. Jones & Luca Montanarella. (2002). EUR 20398 EN, 248pp. Office for Official Publications of the European Communities, Luxembourg.

No.8 Soil Geographical Database for Eurasia & The Mediterranean: Instructions Guide for Elaboration at scale 1:1,000,000. Version 4.0. J.J. Lambert, J. Daroussin, M. Eimberck, C. Le Bas, M. Jamagne, D. King & L. Montanarella. (2003). EUR 20422 EN, 64pp. Office for Official Publications of the European Communities, Luxembourg.

No.9 Soil Resources of Europe: incorporating EU Candidate Countries. P. Bullock, R.J.A. Jones & L. Montanarella (eds). (2003). EUR 20559 EN. Office for Official Publications of the European Communities, Luxembourg. [In press].

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No.12 Validation of soil erosion risk assessements in Italy. A.J.J. Van Rompaey, P. Bazzoffi, R.J.A. Jones, L. Montanarella & G. Govers. (2003). EUR 20676 EN. Office for Official Publications of the European Communities, Luxembourg.

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