REGIONAL DIFFERENCES AND SCALE DEPENDENCY OF SEDIMENT YIELD IN EUROPE

M. Vanmaercke, matthias.vanmaercke@ees.kuleuven.be, +32/16/32.64.20, J. Poesen, G. Verstraeten, W., Maetens, Physical and Regional Geography Research Group – K.U.Leuven, Celestijnenlaan 200^{E}, 3001 Heverlee, Belgium; J. de Vente, Estación Experimental de Zonas Áridas, EEZA-CSIC, Desertification and Geoecology Department, Almeria, Spain; F. Ocakoglu, Eskişehir Osmangazi University

Abstract Improved insight into the regional patterns of sediment yield (SY, t km^{-2} a^{-1}) and its scale dependency helps to better understand erosion and transport processes, factors controlling sediment export from river catchments, and to identify major erosion hotspots. Over the past decades, large efforts have been made to model sediment yield. Although this has led to a better understanding of the factors controlling sediment yield, most of the insights are either valid for a particular region and catchment or focus only on the largest rivers, at a global scale. However, little is known about regional differences of sediment yield at the continental scale, particularly in Europe.

Based on an extensive literature review (scientific publications and internal reports), a SY-database was developed which aims at bridging this gap. Only data on sediment yield measured at gauging stations or derived from reservoir siltation rates were considered. In total, sediment export data at 1 794 different locations throughout Europe were collected (507 reservoirs and 1 287 gauging stations), representing a minimum of 29 200 catchment-year data. The database comprises a large range of catchment areas (A, km²): i.e from small upland catchments (≥ 0.01 km²) to major European river basins (≤ 1 360 000 km²).

Here we provide an overview of the SY-data collected and a discussion of the spatial patterns of SY in Europe. A clear difference could be noted between temperate regions of Western Europe (low SY values, i.e. <50 t km^{-2} a^{-1}) and Mediterranean regions of Europe (generally higher SY-values, often more then 300 t km^{-2} a^{-1}). Mountainous regions could also be clearly distinguished with relatively high SY values. We further investigated the relationship between catchment area (A, km²) and SY for several regions in Europe. A negative relationship is normally expected due to a decrease in topsoil erosion rates on more gentle slopes and an increase in alluvial sediment deposition with an increase in catchment size. However, for several regions, including Mediterranean Europe, no clear decrease was found. A comparison of the SY-values with rates of sheet and rill erosion measured, using runoff plots also showed important differences between the Mediterranean region and other regions. These differences in scale dependency illustrate the importance of erosion processes, other than sheet and rill erosion (i.e. mass movements, riverbank erosion, and gullies) and stress the need for an integrated SY-modeling approach, considering various types of sediment sources and sinks.

INTRODUCTION

The risk of soil erosion by water has received considerable attention in Europe (e.g. Boardman & Poesen, 2006). Extensive research during the last decades has led to a better insight into the spatial patterns and intensity of water erosion processes at the hillslope scale in Europe (e.g. Cerdan et al., 2006; Kirkby et al., 2004). Regarding sediment export rates at the catchment scale

the insights are, however, much more limited. Nevertheless, a better insight is crucial to avoid the off site impacts of soil erosion, e.g. reservoir siltation (Verstraeten et al., 2006) and eutrophication (Rekolainen et al., 2006).

Several studies indicated that extrapolation of soil erosion rates from the hillslope to the catchment scale is not straightforward, as with increasing catchment area other erosion and sediment deposition processes become more important (Walling, 1983; de Vente & Poesen, 2005; de Vente et al., 2007). Attempts to model sediment yield (SY, t km^{-2} a^{-1}) at the catchment scale in a physical way often perform badly as they do not include all relevant erosion and sediment deposition processes or have too high data requirements (Merritt et al., 2003; de Vente & Poesen 2005). Empirical models are therefore a powerful alternative as they have smaller data requirements and often perform at least equally well (Jetten & Favis-Mortlock, 2006). However, their results are either only valid for large river systems at a global scale (e.g. Syvitski & Milliman, 2007) or for a specific region (e.g. Aalto et al., 2006; de Vente et al., 2006; de Vente et al., 2008; Verstraeten, 2006) and heavily depend on their calibration due to site-specific conditions. Hence, our insights in the regional differences in sediment yields, their controlling factors and their scale dependencies are limited for the European continent.

An important issue, hampering a better insight in the spatial variations of SY in Europe, is the lack of an overview of available sediment yield data. Whereas for the USA, an extensive gauging network exists, providing suspended sediment load data for more then 1400 catchments (USGS, 2009 in Gonzales-Hidalgo et al., 2009), such large dataset is not available for Europe. Nevertheless, many sediment yield data exist for European catchments, reported in various scattered sources. Although several authors have summarized available sediment yield data worldwide, they do not exploit the full potential of the currently available SY-data for Europe as they only consider larger river systems (i.e. > 100 km^2) and are based on only a limited number of catchments for Europe. (e.g. Jansson, 1988 : 445 entries for Europe; Meybeck & Ragu, 1995: 45 entries; Milliman et al., 1995: 112 entries). Furthermore, many new SY-data have been published recently.

Therefore the objectives of this study are: i) to present an overview of available SY-data in Europe, collected from different sources; ii) to discuss differences in SY for different regions in Europe; and iii) to explore regional differences in scale dependency of SY in Europe.

CONSTRUCTION OF THE DATASET

Based on an extensive literature review, data on sediment yield of European rivers were collected from scientific publications, MSc., PhD. theses and reports from hydrological institutes. Only sediment yields that were derived from measurements at a gauging station or from reservoir siltation rates, over a measuring period of at least one year and with a catchment area (A, km^2) of at least 0.01 km^2 were considered.

Each entry in the database corresponds to one catchment for which SY has been measured and contains at least the name of the river, the measurement method (observation at a gauging station ('GS') or derived from a reservoir siltation rate ('R')), the location of the GS or R, A (km^2), the total sediment yield (TSY, t a^{-1}), the area-specific sediment yield (SY, t km^{-2} a^{-1}), and the measuring period. For several entries, the actual measuring period was not reported but indicated

to be longer then one year. In these cases, a measuring period of one year was assumed. If available, additional information on the measuring method was also recorded. The coordinates of all entries were included, based on the originally reported coordinates. If original coordinates were unavailable, an estimation was made, based on the description of the measuring location, using Google Earth™. If the measuring location could not be determined sufficiently accurate (e.g. when no location name was reported), the entry was not included in the database. As many SY data are reported several times in different sources, the database was checked for duplicate entries. Two entries were considered as duplicates if they had the same measuring location and (therefore) the same drainage area. In such case, only the most reliable entry was used. In general, the source that reported the sediment yield for the longest measuring period was considered as most reliable. If the measuring period were equal or unknown, the source that provided the most detailed information on the measuring location and measuring technique was used.

The GS-entries in the database comprise SY-data, measured and calculated by a wide variety of techniques and procedures. It was assumed, however, that all reported sediment export rates, were calculated as accurate as possible and all sediment export values were incorporated in the database as reported in their original reference. For GS-entries, only the suspended sediment export was considered, as bedload data was unavailable for most gauging stations and dissolved loads fell out of the scope of this study. For R-entries, TSY was estimated as the product of the annual sedimentation rate in the reservoir or pond ($m^3\ a^{-1}$) and the dry sediment bulk density (dBD, $t\ m^{-3}$), divided by the sediment trap efficiency of the pond or reservoir (TE). In several cases, not all factor values for this calculation were known. Some sources did not report the dBD of the sediment. In these cases, a bulk density of 1.12 ton m^{-3} was assumed. This value was calculated as the average bulk density of a large dataset of reservoir siltation rates (Verstraeten et al., 2006). Also TE was unknown in most cases. Although TE can be measured, this is generally expensive and time-consuming. Several procedures exist to estimate TE (Verstraeten & Poesen, 2000). In our study, missing TE-values were estimated using an empirical equation, where TE is assessed, based on the reservoir capacity, the catchment area and a constant depending on specific characteristics of the reservoir (Brown, 1943 in Verstraeten & Poesen, 2000).

DESCRIPTION OF THE DATASET

The constructed dataset, currently consists of 507 R-entries and 1 287 GS-entries. The sum of the duration of the measuring periods of all the R-entries represent a minimum of 13 751 ‘catchment years’ of data (for 87 R-entries the measuring period was unknown and a period of 1 year was assumed). The GS-entries cover a minimum of 15 452 catchment years of data (for 120 GS-entries a period of 1 year was assigned as the measuring period was unknown). Figure 1 gives an overview of the number of entries and the number of catchment years for each country. Whereas several countries have many SY-data (e.g. Romania, Italy, Spain, Turkey), other countries have only a limited number of entries or no data at all (e.g. Ireland, Belarus, Lithuania). For several countries, more SY-data exists, but could not be obtained (e.g. Ukraine, Kovalchuk & Vishnevskiy, 2004). The overview presented here is therefore not a complete overview of all SY-data but covers the vast majority of available SY-data in Europe.

Figure 2 shows the distribution of all entries and number of catchment years according to their drainage area. From these histograms, it is clear that most entries have drainage areas between

100 and 10 000 km². Data from catchments, smaller than 10 km² and especially smaller than 1 km² are relatively rare. The distribution of the number of catchment years per A-class corresponds more or less with the distribution of the number of entries, except for entries with a catchment area of 1-10 km². This group has a relatively larger number of catchment years as it includes several old reservoirs in England from which long-term SY-values could be calculated. A more detailed description of the data and their references is provided in Vanmaercke et al. (submitted).

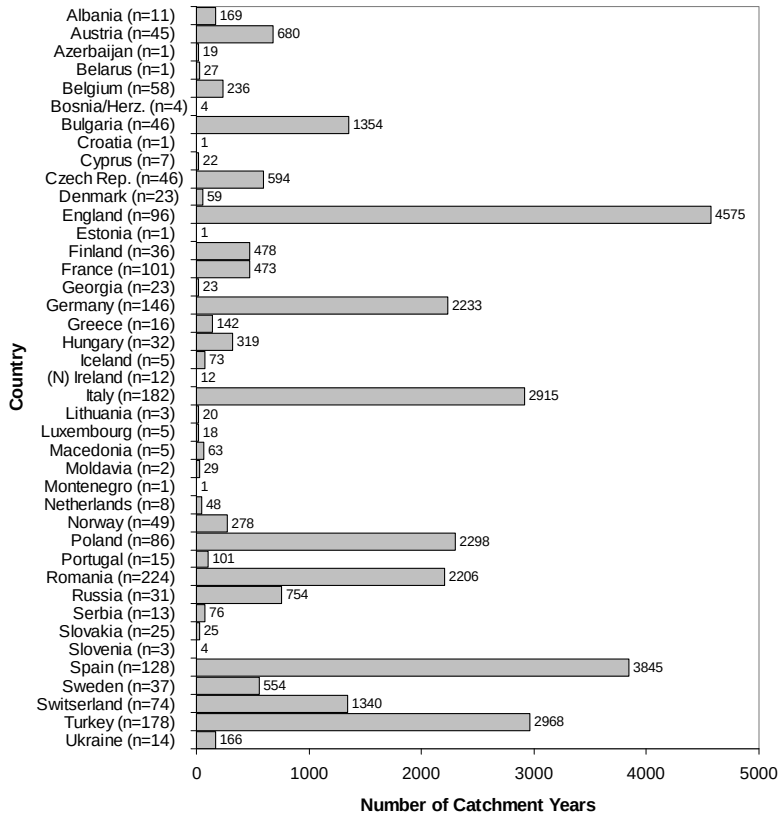

Figure 1 Overview of number of catchment-year data in the database for each country ('n' indicates the corresponding number of entries).

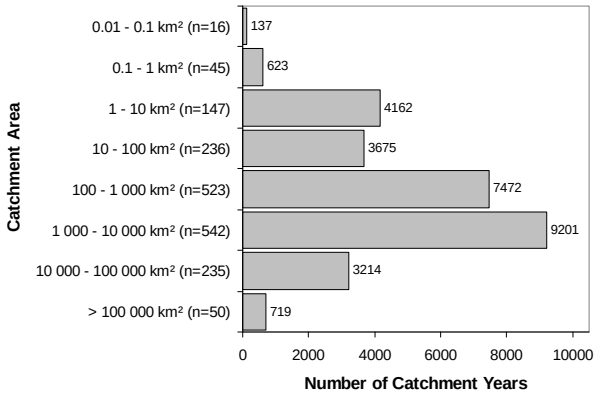

Figure 2 Overview of number of catchment-year data in the database for several catchment area classes ('n' indicates the corresponding number of entries).

SPATIAL PATTERNS AND SCALE DEPENDENCY OF SY IN EUROPE

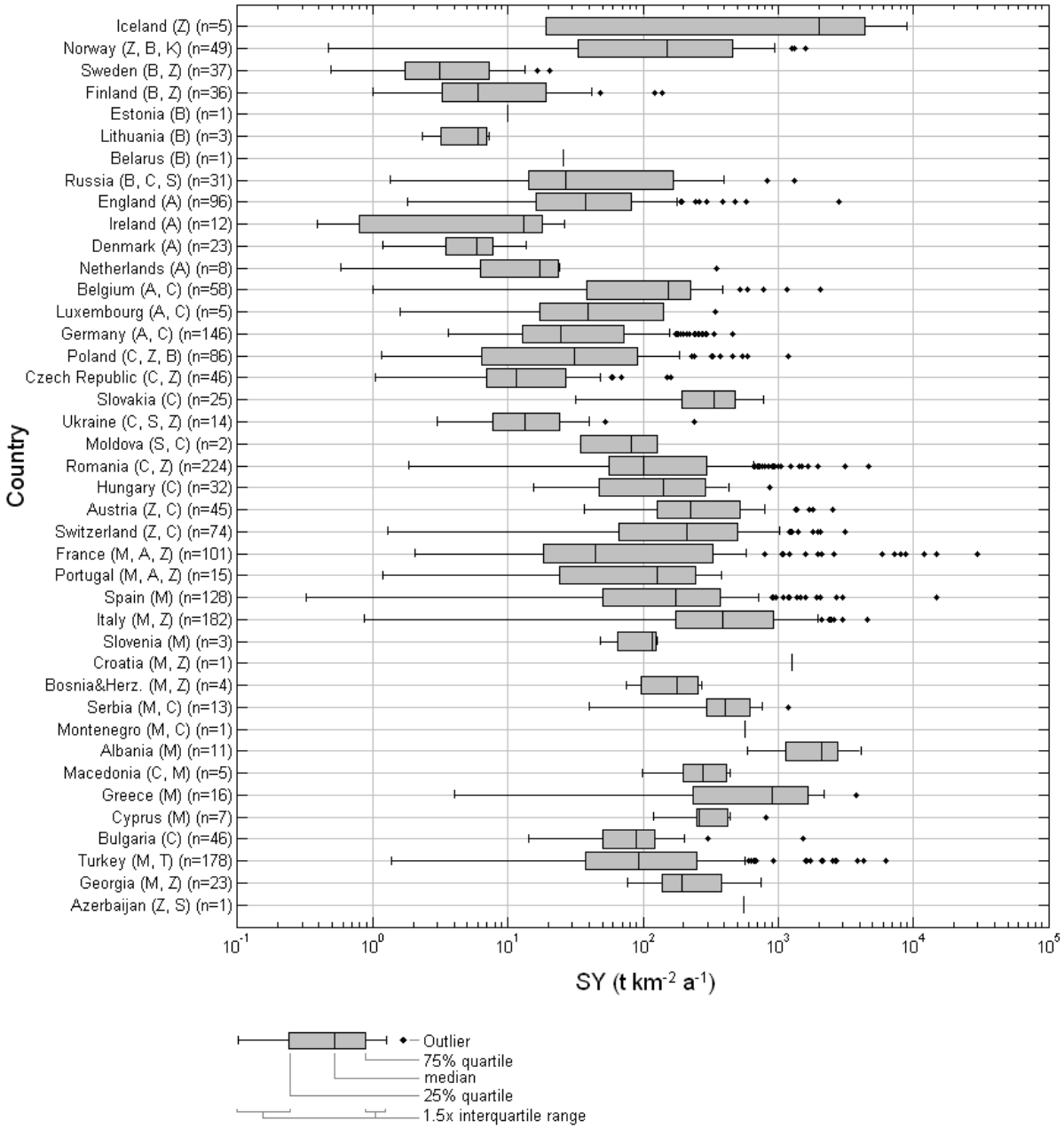

Figure 3 Boxplot of SY-values per country. The dominant climatic regions of the country (according to the LANMAP 2 classification; Mücher et al., 2006; Metzger et al., 2005) are indicated between brackets (A: Atlantic, B: Boreal, C: Continental, K: Arctic, M: Mediterranean, S: Steppic, T: Anatolian, Z: Alpine). 'n' is the number of entries.

The range of measured SY-values per country is displayed in figure 3. As can be seen from this figure, large differences in SY exist between as well as within countries. To allow better comparison, the dominant climatic zones of each country (according to the LANMAP 2 classification; Mücher et al., 2006; Metzger et al., 2005) are indicated. The climatic zone of each

entry was determined, based on the location of the GS or R. As some large catchment cover more than one climatic zone, their assignment to the climatic zone of the outlet may be disputable. However, the number of catchments in the database being in this situation is expected to be relatively small (i.e. < 25%). Although direct interpretation is difficult as country borders can cover different climatic zones, figure 3 suggests that especially countries in the Mediterranean and Alpine climatic zones are characterized by high SY-values, whereas countries in the Boreal and Atlantic climatic zones generally have lower SY-values. Statistical analysis of the data confirms this trend. The median SY-value for the Mediterranean climatic zone is 218 t km^{-2} a^{-1}, 198 t km^{-2} a^{-1} for the Alpine zone, 144 t km^{-2} a^{-1} for the Anatolian zone, 98 t km^{-2} a^{-1} for the Arctic zone, 70 t km^{-2} a^{-1} for the Continental zone, 60 t km^{-2} a^{-1} for the Steppic zone, 28 t km^{-2} a^{-1} for the Atlantic zone and 6 t km^{-2} a^{-1} for the Boreal zone.

Table 1 displays the regression results between A and SY for the different climatic zones. The R^2-values of these regressions are very low which can be explained by the importance of other factors controlling SY. Each climatic zone covers a large area with a large variation in physical factors such as topography, lithology and land use. Further, the SY-data used for the regressions vary in measuring method and measuring period. Nevertheless, differences can be noticed between the climatic zones. Whereas the Atlantic, Boreal and Continental zone have weak but significant ($\alpha = 0.05$) decreasing trends with comparable slopes and R^2-values, this is not the case of the Anatolian and Alpine climatic zones, showing no significant trend. Also the Mediterranean zone has a significant A-SY relationship. However the slope and R^2 of this trend is considerably lower compared to the other zones with a significant trend. Moreover, it was found that this trend line was strongly influenced by 6 small catchments (A < 0.1 km^2) with a very high SY. If these catchments are left out, the trend is no longer significant. For the Steppic zone, a significant decreasing trend was found. This trend is however based on a relatively small number of catchments. Also for the Arctic climatic zone, the number of observations is too low to draw conclusions.

Table 1 Regression results of A(km^2)-SY (t km^{-2} a^{-1}) relationships for different climatic zones in Europe. ('n' indicates the number of entries for each relationship, 'R^2' the correlation coefficient and 'p' the probability of the F-statistic).

Climatic zone	Regression equation	n	R^2	p
Atlantic	$SY = 64.4 \times A^{-0.13}$	282	0.10	< 0.0001
Boreal	$SY = 22.1 \times A^{-0.14}$	93	0.11	0.001
Continental	$SY = 171 \times A^{-0.14}$	608	0.06	< 0.0001
Arctic	$SY = 45.2 \times A^{0.42}$	7	0.47	0.0874
Mediterranean	$SY = 298 \times A^{-0.07}$	540	0.01	0.0068
Steppic	$SY = 2495 \times A^{-0.37}$	37	0.37	0.0001
Anatolian	$SY = 102 \times A^{0.02}$	70	0.00	0.8799
Alpine	$SY = 247 \times A^{-0.09}$	157	0.01	0.1642

To analyze the differences in scale-dependency of SY-values for different climatic zones, a comparison was made between our SY-data and a dataset of soil erosion rates, measured at runoff plots (≤ 0.0001 km^2) (Maetens et al., 2009). To avoid bias, only plots without soil and water

conservation measures were considered. Figure 4 displays the cumulative distributions of these soil erosion rates and our SY-data. In this figure a distinction is made between catchments and runoff plots in the Mediterranean climatic region and non-Mediterranean catchments and runoff plots. The non-Mediterranean data only contains SY and erosion rate data from the Boreal, Atlantic and Continental climatic zones as insufficient plot data was available for the other zones (i.e. Arctic, Steppic, Anatolian and Alpine). The results of figure 4 should be interpreted with care as these cumulative distributions are based on data, collected under widely varying conditions. Nevertheless some clear differences are visible. Whereas the SY-values from catchments in the Mediterranean zone are generally higher than SY of non-Mediterranean catchments, the plot erosion rates from the Mediterranean zone are generally lower then those of the non-Mediterranean. Consequently, plot erosion rates are generally higher than catchment SY-values in the non-Mediterranean regions, but lower in the Mediterranean zone.

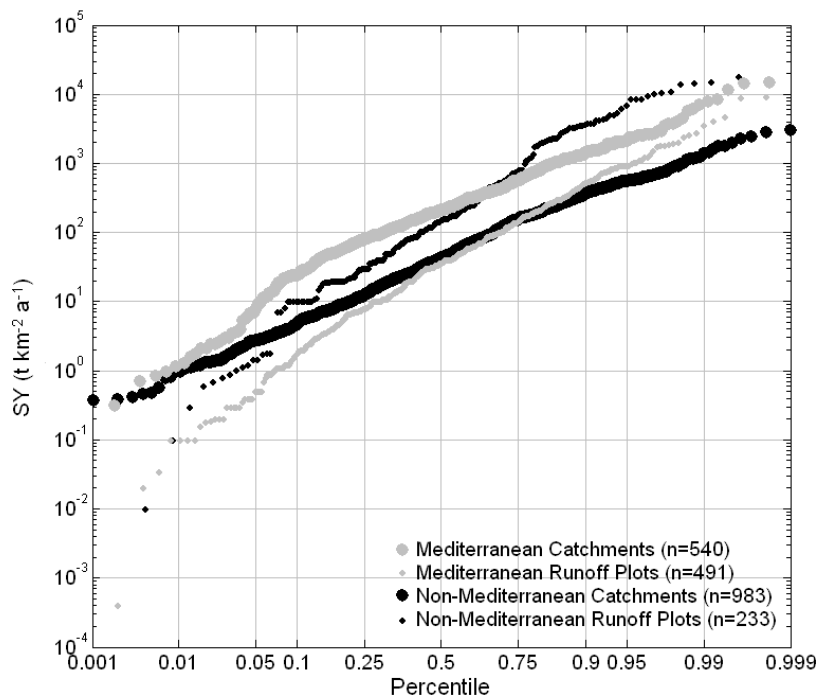

Figure 4 Cumulative distribution of catchment SY-values and plot erosion rates. The non-Mediterranean data contains data from the Atlantic, Boreal and Continental climatic zone.

DISCUSSION

Regarding the spatial variation of SY in Europe, our findings agree well with previous studies, reporting low SY-values in temperate and boreal climates and generally higher values in the Mediterranean world (Jansson, 1988; Walling & Webb, 1996; Woodward, 1995; Verstraeten et al., 2006). Also in a study from the USA, it was found that the highest sediment yields occur in hydrological units with a Mediterranean climate (Gonzales-Hidalgo et al., 2009). It should be noted, however, that the observed differences are not only attributable to differences in climate. Important correlations exist between the used climatic classification and other physical factors, relevant for SY. E.g. the Alpine climatic regions in our analyses generally agree with the

mountain ranges of Europe. Milliman and Syvitski (1992) clearly indicated the importance of topography on SY-fluxes. The observed higher SY-values for this climatic zone are therefore probably more a result of the high relief than of the climatic conditions in these areas. Many regions in the Mediterranean climatic zone are likewise characterized by steep topography and very erodible lithologies, leading to higher sediment yields (Woodward, 1995). Also in the USA, the higher SY in the Mediterranean regions are not only attributed to differences in climate but also to lithology and human interventions (Gonzales-Hidalgo et al., 2009). Furthermore, the majority of R-entries in our SY-database are situated in the Mediterranean and Alpine zones, while it can be expected that differences in methodologies lead in general to higher SY-values for R-entries than for GS-entries (e.g. GS-entries do not include bedload, while R-entries consider the total load) (Vanmaercke et al., submitted).

A negative relationship is generally expected between catchment area and sediment yield due to a decrease in topsoil erosion rates on more gentle slopes and an increase in alluvial sediment deposition with an increase in catchment size. However many examples exist were no relation or a different relationship was found (e.g. Walling, 1983; Church & Slaymaker, 1989; de Vente et al., 2007). For the Boreal, Atlantic and Continental climatic zone, our data seems consistent with this expectation as erosion rates from runoff plots are generally higher compared to SY-values from catchments (figure 4) and a weak decreasing trend was found between A and SY (table 1). For the Mediterranean, Alpine and Anatolian climatic zone, however, the A-SY trends showed a weaker (or no) decrease and more scatter, while plot soil erosion rates are generally lower then SY-values at the catchment scale for the Mediterranean region. This suggests a different relationship between catchment area and sediment yield. The generally lower soil erosion rates at the plot scale in the Mediterranean region have already been reported in previous studies (e.g. Poesen & Hooke, 1997; Cerdan et al., 2006). Poesen & Lavee (1994) show that the Mediterranean region are generally characterized by more stony soils, while Poesen et al. (1994) discuss the significant effect of stoniness on the reduction of sheet and rill erosion rates at the plot scale. However, as catchment area increases, other erosion processes such as gully erosion, bank erosion and mass movements may contribute significantly to SY (de Vente & Poesen, 2005). As catchment area increases, SY can therefore first increase, reach a maximum at the medium-sized catchment scale and then decrease due to an increase in (floodplain) storage. This was for example illustrated with datasets of Spain and Italy (de Vente & Poesen, 2005; de Vente et al., 2007).

The importance of other erosion processes (such as gullying, bank erosion and mass movements) and their effects on the scale-dependency of SY has important consequences for modelling sediment fluxes at the catchment scale. For example, the WATEM-SEDEM model (Van Oost et al., 2000; Van Rompaey et al., 2001) makes a RUSLE-based estimation of the sheet and rill erosion rate for each pixel and then assesses how much of the eroded sediment is routed to a next pixel and how much is deposited. This model was found to predict average sediment yields reasonably well for catchments in Belgium and the Czech Republic, but was unable to predict the SY for catchments in Spain or Italy (Van Rompaey et al., 2001; Van Rompaey et al., 2003). de Vente et al. (2008) compared different spatially distributed erosion and sediment yield models for Mediterranean catchments. They observed that the catchment SY was higher then the gross-erosion rate due to sheet and rill erosion, predicted by the PESERA model (Kirkby et al., 2004), illustrating the importance of other erosion processes. A model (SPADS) that takes other

sediment sources into account was found to perform better then models that only consider the erosion processes on the hillslope and the sediment delivery.

CONCLUSIONS

Although significant improvements in understanding the controlling factors of sediment yield at the catchment scale have been made over the last decades, our insight into the regional variation of sediment fluxes on the European continent is limited. An important factor, hampering a better understanding of these fluxes, is the lack of integration of existing (local) studies on sediment yield. Based on an extensive literature review, a database was developed which aims at bridging this gap. Measured SY-data from gauging stations and reservoirs in Europe was collected from various sources. This paper presented an overview of this dataset and first results obtained from analysis of the SY-data.

Important differences in SY were found between different climatic regions of Europe, with the highest median SY-values occurring in the Mediterranean and Alpine regions and the lowest values in the Boreal and Atlantic zones. Also in the A-SY relationships, significant differences were noticed. These differences can, however, not only be attributed to climatic characteristics. Other physical factors also play an important role. This is reflected in the low correlation coefficients of the A-SY relationships per climatic zone. The results should therefore be interpreted with care. Nevertheless, our data suggests differences in scale-dependency between the non-Mediterranean (i.e. Atlantic, Boreal and Continental) zones and the Mediterranean zone. Whereas in the non-Mediterranean zone plot soil erosion rates are generally higher than catchment SY and SY tends to decrease with A, this seems not the case in the Mediterranean zone. In the latter, other sediment sources (such as gullies, bank erosion and mass movements) are often more important than sheet and rill erosion. Models that do not take these erosion processes into account, therefore often fail to predict SY in Mediterranean catchments.

ACKNOWLEDGMENTS

The research described in this paper was conducted in the framework of the EC-DG RTD- 6th Framework Research Programme (sub-priority 1.1.6.3) - Research on Desertification- project DESIRE (037046): Desertification Mitigation and Remediation of land – a global approach for local solutions. M. Vanmaercke received grant-aided support from the Research Foundation – Flanders (FWO), Belgium. The authors further wish to thank all researchers and institutes who provided data, publications or additional information on the sediment yield measurements discussed in this study.

REFERENCES

Aalto, R., Dunne, T., Guyot, J. L. (2006) Geomorphic Controls on Andean Denudation Rates. *J Geology* **114**, 85-99.

Boardman, J., Poesen, J. (2006) *Soil Erosion in Europe*. John Wiley & Sons Ltd., Chichester, England.

Cerdan, O., Poesen, J., Govers, G., Saby, N., Le Bissonnais, Y., Gobin, A., Vacca, A., Quinton, J., Auerswald, K., Klik, A., Kwaad, F., Roxo, M.J. (2006) Sheet and Rill Erosion. In: *Soil*

Erosion in Europe (ed. by J Boardman & J. Poesen), 501-513, John Wiley & Sons Ltd., Chichester, England.

Church, M. and Slaymaker, H.O. (1989) Disequilibrium of Holocene sediment yield in glaciated British Columbia. *Nature* **337**, 452–54.

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

de Vente, J., Poesen, J., Bazoffi, P., Van Rompaey, A., Verstraeten, G. (2006) Predicting catchment sediment yield in Mediterranean environments: the importance of sediment sources and connectivity in Italian drainage basins. *Earth Surf Processes* **31**, 1017–1034.

de Vente, J., Poesen, J., Arabkhedri, M., Verstraeten, G. (2007) The sediment delivery problem revisited. *Prog Phys Geog* **31**, 155-178.

de Vente, J., Poesen, J., Verstraeten, G., Van Rompaey, A., Govers, G. (2008) Spatially distributed modelling of soil erosion and sediment yield at regional scales in Spain. *Global Planet Change* **60**, 393–415.

Gonzales-Hidalgo, J. C., Batalla, R. J., Cerdá, A., De Luis, M. (2009) Contribution of the largest events to suspended sediment transport across the USA. *Land Degrad Dev*. DOI: 10.1002/ldr.

Jansson, M. B. (1988) A Global Survey of Sediment Yield. *Geogr Ann A* **70**, 81-98.

Jetten, V., Favis-Mortlock, D. (2006) Modelling Soil Erosion in Europe. In: *Soil Erosion in Europe* (ed. by J Boardman & J. Poesen), 695-716, John Wiley & Sons Ltd., Chichester, England.

Kirkby, M.J., Jones, R.J.A., Irvine, B., Gobin, A, Govers, G., Cerdan, O., Van Rompaey, A.J.J., Le Bissonnais, Y., Daroussin, J., King, D., Montanarella, L., Grimm, M., Vieillefont, V., Puigdefabregas, J., Boer, M., Kosmas, C., Yassoglou, N., Tsara, M., Mantel, S., Van Lynden, G.J. and Huting, J. (2004). Pan-European Soil Erosion Risk Assessment: The PESERA Map, Version 1 October 2003. Explanation of Special Publication Ispra 2004 No.73 (S.P.I.04.73). *European Soil Bureau Research Report No.16*, EUR 21176, 18 and 1 map in ISO B1 format. Office for Official Publications of the European Communities, Luxembourg.

Kovalchuk, I. P., Vishnevskiy, V. I. (2004) Investigation of sediment yield of lowland rivers in Ukraine. In: *Sediment Transfer through the Fluvial System* (Ed. by V. Golosov, V. Belyaev & D. Walling), 130-137. IAHS Publ. 288, IAHS Press, Wallingford, UK.

Maetens, W., Vanmaercke, M., Poesen, J. (2009). Assessment of the effectiveness of soil and water conservation measures in reducing runoff and soil loss: establishment of a European database. In: *Advances in studies on desertification. Contributions to the international conference on desertification in memory of Professor John B. Thornes, Murcia 2009* (Ed. by A. Romero Diaz, F. Belmonte Serrato, F. Alonso Sarria & F. López Bermúdez), 303-306, ICOD.

Merritt, W.S., Letcher, R.A., Jakeman, A.J. (2003) A review of erosion and sediment transport models. *Environ Modell Softw* **18**, 761–799.

Metzger, M.J., Bunce, R.G.H, Jongman, R.H.G, Mücher, C.A. & Watkins, J.W. (2005) A climatic stratification of the environment of Europe. *Global Ecol Biogeogr* **14**, 549-563.

Meybeck, M., Ragu, A. (1995) River discharges to the oceans : an assessment of suspended sediment solids, major ions and nutrients. *U.N. Environmental Programme (UNEP) report*, Nairobi.

Milliman, J. D., Syvitski, J. P. M. (1992) Geomorphic/Tectonic Control of Sediment Discharge to the Ocean: The Importance of Small Mountainous Rivers. *J Geology* **100**, 525-544.

Milliman, J. D., Rutkowski, C. M., Meybeck, M. (1995) River discharge to the sea. A global river index (GLORI). *LOICZ Reports & Studies, No. 2*. The Netherlands.

Mücher, C.A., Wascher, D.M., Klijn, J.A., Koomen, A.J.M., Jongman, R.H.G. (2006) A new European Landscape Map as an integrative framework for landscape character assessment. In: *Landscape Ecology in the Mediterranean: inside and outside approaches* (Ed. by R.G.H. Bunceand R.H.G. Jongman), 233-243. Proceedings of the European IALE Conference 29 March – 2 April 2005, Faro, Portugal. IALE Publication Series 3.

Poesen, J., Hooke, J. M. (1997) Erosion, flooding and channel management in Mediterranean Environments of southern Europe. *Prog Phys Geog* **21**(2), 157-199.

Poesen, J., Lavee, H. (1994) Rock fragments in top soils: significance and processes. *Catena* **23**, 1-28.

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.

Rekolainen, S., Ekholm, P., Heathwaite, L., Lehtoranta, J., Uusitalo, R. (2006) Off-site impacts of Erosion: Eutrophication as an Example. In: *Soil Erosion in Europe* (ed. by J Boardman & J. Poesen), 775-789, John Wiley & Sons Ltd., Chichester, England.

Syvitski, J. P. M. & Milliman, J. D. (2007) Geology, Geography, and Humans Battle for Dominance over the Delivery of Fluvial Sediment to the Coastal Ocean. *J Geol* **115**, 1-19.

Vanmaercke, M., Poesen, J., Verstraeten, G., de Vente, J., Maetens, W., Ocakoglu, F. (submitted) Sediment Yield in Europe: spatial patterns, scale dependency and comparison with soil erosion rates. *Earth-Sci Rev* (**submitted**).

Van Oost, K., Govers, G., Desmet, P. (2000) Evaluating the effects of changes in landscape structure on soil erosion by water and tillage. *Landscape Ecol* **15**, 577-589.

Van Rompaey, A., Verstraeten, G., Van Oost, K., Govers, G., Poesen, J. (2001) Modelling mean annual sediment yield using a distributed approach. *Earth Surf Proc Land* **27**(11), 1221-1236.

Van Rompaey, A.J.J., Vieillefont, V., Jones, R.J.A., Montanarella, L., Verstraeten, G, Bazzoffi P., Dostal, T, Krasa, J, de Vente, J., Poesen, J. (2003) Validation of soil erosion estimates at European scale. *European Soil Bureau Research Report No. 13*, EUR 20827 EN, (2003), 26 Office for Official Publications of the European Communities, Luxembourg

Verstraeten, G. (2006) Regional scale modelling of hillslope sediment delivery with SRTM elevation data. *Geomorphology* **81**(1-2), 128-140.

Verstraeten, G., Poesen, J. (2000) Estimating trap efficiency of small reservoirs and ponds: methods and implications for the assessment of sediment yield. *Prog Phys Geog* **24**, 219–251.

Verstraeten, G., Bazzoffi, P., Lajczak, A., Radoane, M., Rey, F., Poesen, J. & de Vente, J. (2006) Reservoir and Pond Sedimentation in Europe. In: *Soil Erosion in Europe* (ed. by J Boardman & J. Poesen), 759-774, John Wiley & Sons Ltd., Chichester, England.

Walling, D. (1983) The sediment delivery problem. *J Hydrol* **65**, 209-237.

Walling, D. E., Webb, B. W. (1996) Erosion and sediment yield: a global overview. In: *Erosion and Sediment Yield: Global and Regional Perspectives* (Ed. by D. E. Walling & B. W. Webb) (Proceedings of the Exeter Symposium, July 1996), 3-19, IAHS Publ. no. 236, IAHS Press, Wallingford, UK.

Woodward, J. C. (1995) Patterns of Erosion and Suspended Sediment Yield in Mediterranean River Basins. In: *Sediment and Water Quality in River Catchments* (Ed. by I. Foster, A. Gurnell & B. Webb), 365-389, John Wiley & Sons Ltd., Chichester, England.