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The need for harmonizing methodologies for assessing soil threats in Europe

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Abstract

Central to the EU thematic strategy for soil protection is that areas affected by soil degradation through erosion, soil organic matter (SOM) decline, compaction, salinization and landslides should be identified in a clear and consistent way. However, the current methodologies to achieve this often differ and this can result in different perceptions of risks amongst EU Member States. The aims of this paper are to: (i) assess the current status of assessment methodologies in Europe (EU27) associated with erosion, SOM decline, compaction, salinization and landslides and (ii) discuss the issues associated with harmonization of these methodologies throughout the EU27. The need for harmonization is assessed using the relative share of common elements between different methodologies. The results demonstrate that the need for harmonization in methodology is greatest for erosion and compaction and least for SOM decline and landslides. However, many of the methodologies which were investigated are still incomplete and there are significant differences in terms of: (i) understanding the threats, (ii) methods of data collection, (iii) processing and interpretation and (iv) risk perception. We propose two options for the harmonized assessment of soil threats: (i) a two-tiered approach based on data availability and spatial scale and (ii) a combination of standardization and harmonization for each assessment methodology. Future assessments should focus on the advantages and disadvantages of these options as the current situation will result in endless discussions on differences and the merits of particular methodologies instead of taking appropriate measures to reduce or eliminate the actual threats.

Keywords: EU soil strategy, erosion, compaction, salinization, landslides, soil organic matter decline

Introduction

Land clearance for agriculture and intensification of land use put soils under increased stress (Vitousek *et al.*, 1997; McNeill & Winiwarter, 2004; Diamond, 2005). Reports such as by van Camp *et al.* (2004) highlight the need for the protection of soil as a natural resource for agricultural production and nature conservation. As a result the European Commission launched in 2002 the EU thematic strategy on soil protection (European Commission, 2002). This strategy distinguishes seven possible soil threats [soil compaction, soil erosion, soil salinization, soil organic matter (SOM) decline, landslides, pollution and sealing] with pollution and sealing resulting from external factors not related to soil specific conditions and thus need a general or national protection strategy (European Commission, 2006). For five other soil threats the vulnerability depends on specific environmental conditions. For these threats, vulnerable areas need to be defined using explicit assessment methodologies. These methodologies are generally referred to as risk assessment methodologies (RAMs).

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Various countries have developed RAMs to identify vulnerable areas for one or more soil threats. Most of these RAMs have been developed regionally and often independent of each other. The use of different RAMs for the same soil threat within the EU-27 will hamper consistent evaluation of vulnerability related to the soil threats. Moreover, the use of different RAMs for the same soil threat will affect soil protection levels and thereby competition between farmers from different regions and/or Member States. Hence, as long as different and idiosyncratic methodologies are used, a future EU soil directive will be futile and likely to suffer from debates on methodologies.

There are various ways to bring together different methods and procedures, usually described as 'harmonization' and/or 'standardization'. Harmonization is commonly interpreted in terms of ensuring that results from different methods are comparable and consistent. Standardization requires the use of identical assessment procedures for each soil threat in EU-27 and hence involves the selection of one assessment methodology for all Member States. However, there is a gradual transition between standardization and harmonization. Harmonization encompasses a wide range of issues, ranging from choosing sampling points to the final perception of the actual risks and often includes elements of standardization. In this paper, the term 'harmonization' is used in a generic way, in line with common usage, i.e. harmonization is considered to be the processes leading to the production of comparable results between different assessment methodologies.

In addition to assessment methodologies for vulnerability, the quantification of risk also involves the identification of influencing factors and affected organisms (Christensen *et al.*, 2003). For soil threats, the identification of these is not evident. For instance, for SOM decline, the influencing factors can be a combination of several including climate, land use and water management. However, affected organisms cannot easily be identified although in some more holistic approaches the soil itself can be regarded as the affected system, e.g. Arquette *et al.* (2002). The same is true for others such as compaction, soil erosion and salinization. Only for landslides can affected organisms be identified as the population in risk prone areas. As a consequence of the difficulties in identifying influencing factors and affected organisms, many RAMs are *de facto* vulnerability assessments. However, in this paper, we use the phrase 'RAMs' to refer to all methods that are currently used to assess vulnerability and/or risks related to soil threats.

The development of a generic framework to assess soil threats is difficult because of the heterogeneous nature of soils, the range of soil functions as well as the many knowledge gaps (Tzilivakis *et al.*, 2005). The assessment chain in Figure 1 shows the steps that are taken to assess the risk of a soil threat from the initial understanding of the threat to data collection, data processing, data interpretation and the final risk perception. Data can be obtained from field measurements, remote sensing images and/or statistical sources. Subsequently, data can be processed to give a rate or soil threat assessment using simulation modelling, empirical modelling, factorial assessment and/or expert judgment. Data interpretation is based on comparing the severity of the soil threat with previously defined threshold values. In the final risk perception step, the soil threat is assessed in terms of the sense of urgency for required actions and remedial measures. In 2008, the EU funded the RAMSOIL project which was designed to explore the options for harmonization of soil RAMs in EU27. In this paper, we provide an overview of our results and present two options for harmonizing procedures.

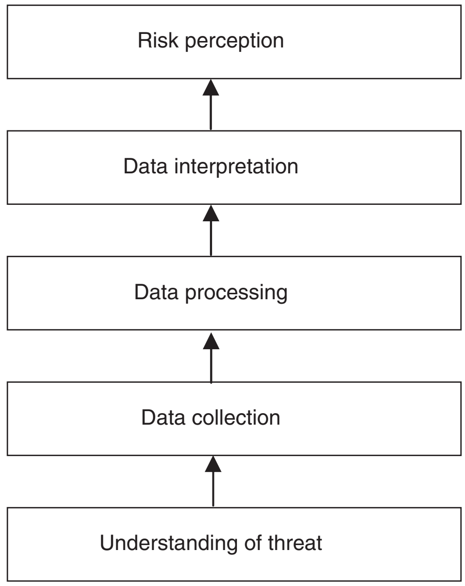

Figure 1 The risk assessment chain from understanding of the soil threat to ultimate risk perception.

Materials and methods

Collection of information via questionnaires

To obtain an overview of RAMs in current use within EU-27, two questionnaires were distributed: a thematic questionnaire for each soil threat was sent to scientists in all Member States, and a policy questionnaire was sent to policy makers in all Member States. In the case of decentralized governments (Spain, Germany), questionnaires were sent to regional contacts. The thematic questionnaires focused on the methodology that was applied in the RAMs, whereas the policy questionnaire focused on the decision factors affecting policy regarding the use, or absence, of RAMs. Details on the questionnaires and results are given by Heesmans (2007), Geraedts *et al.* (2008), Malet & Maquaire (2008), van den Akker & Simota (2008), Bloem *et al.* (2008) and Kuikman *et al.* (2008).

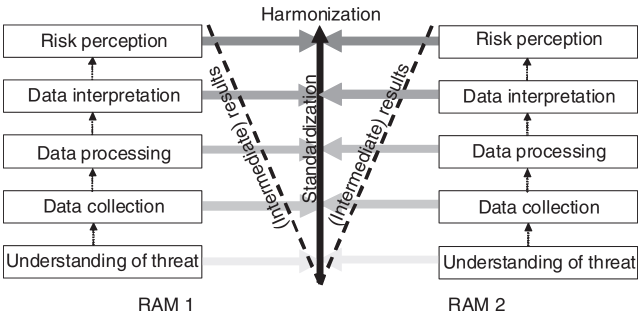

Figure 2 Conceptual representation of the meanings of harmonization and standardization of risk assessment methodologies as used in this paper. Standardization (bold vertical arrow) applies to prescribed procedures and activities in each step of the risk assessment chain, whereas harmonization (horizontal arrows) implies the use of conversion factors at the highest possible level (most direct way, indicated by dark colour) and possibly at other steps.

Assessment of the needs for harmonization

The concepts of harmonization and standardization as used in this study are visualized in Figure 2. We consider standardization as an extreme form of harmonization: harmonization is applied during one or more steps of the risk assessment chain and standardization is applied during all steps of the risk assessment chain. The need for harmonization is shown in the variation in results from different RAMs for an identical situation. Ideally the need for harmonization should be analysed by applying all RAMs to each studied situation and then comparing the results. However, this was practically impossible given the number of RAMs, the differences in objectives between RAMs and the complexities involved in applying RAMS. Instead, the need for harmonization was assessed using the relative number of different approaches per step of the risk assessment chain in a so-called matching index (MI). The MI is defined as the fraction of common elements within different RAMs:

$$\mathrm{MI} = \frac{\text{Common elements per step in the risk assessment chain}}{\text{Total number of elements in RAMs}} \quad (1)$$

Because of the different nature of activities in each step of the risk assessment chain, the definition of MI requires adjustment for each successive step.

For data collection, the MI was defined as the shared common criteria as provided in Annex 1 of the EU thematic strategy on soil protection (European Commission, 2002). Although this list is not exhaustive and was not meant to be, it provides a common understanding for important soil parameters and some disturbing factors. An example of the MI for data collection is provided in Box 1. For data processing, the MI was defined on the basis of the common main approach in the RAMs involving process modelling, factorial assessments, empirical modelling and expert judgment (Eckelmann *et al*., 2006). For example, the MI equals 1 when two RAMs both use empirical modelling for data processing. In the data interpretation step, MI was defined as the reciprocal of the number of different threshold values that were used. A lower number of dynamic or fixed thresholds, therefore results in a high MI. For example, when three RAMs use 1 t/ha/yr as a threshold for erosion loss, but a fourth RAM uses 5 t/ha/yr, the MI for data interpretation equals 0.5.

We could not quantify the MI for risk perception because of the absence of this final step in the risk assessment chain for the majority of the soil RAMs. We assumed that RAMs using the same underlying elements should show less variation in outcomes compared with RAMs based on different elements. The MI provides a number between 0 and 1 and was interpreted as: (i) relatively high need for harmonization (MI < 0.25), (ii) intermediate need for harmonization ($0.25 < \mathrm{MI} < 0.75$) and (iii) little need for harmonization (MI > 0.75).

Box 1

Example calculating the MI for data collection on salinization RAMs.

For salinization, there are six parameters listed in Annex 1 of the EU thematic strategy on soil protection (soil type, soil texture, climate, soil hydraulic properties, irrigation and groundwater). We received eight completed questionnaires on salinization, corresponding to eight different RAMs. All RAMs included information on climate, but information about the other parameters was lacking for one or more RAMs (Table 2). In total, 39 parameter-RAM combinations were covered from the possible total of 48 (= 6 parameters × 8 RAMs) which results in an MI of 39/48 = 0.81 (Table 3).

Case study

A case study was undertaken on the vulnerability to soil erosion in Romania. The case study focused on the data processing step in the risk assessment chain using the SIDASS-WEPP and the PESERA approaches. The objective of the case study was to illustrate the consequences of using different though scientifically sound RAMs on spatial distribution within vulnerable areas. Therefore, the purpose of the case study was not to make a detailed comparison with field data, nor to investigate different algorithms as done by Simota *et al*. (2005) for SIDASS-WEPP and Kirkby *et al*. (2004) for PESERA. The distribution of soil erosion was determined using soil properties from the Corine Land Cover Database (scale 1:1 000 000 with a 1-km grid). For the SIDASS-WEPP methodology, slopes were based on slope

Table 1 Responses to questionnaires sent to EU contact persons on the status of soil RAMs

	Erosion	SOM decline	Salinization	Compaction	Landslides
Austria					
Belgium	×*	*		*	×
Bulgaria					
Czech republic	×	×	×	×	×
Denmark	*	*		*	
Estonia					
Finland	×*				
France					×
Germany	×*	*		<u>×*</u>	
Greece	*	*	*	*	*
Hungary	×	*	×	×	
Ireland					
Italy	*	+		×	+
Latvia					
Lithuania	*				
Luxembourg					
Malta					
Netherlands	×	×			*
Poland	×	*			
Portugal					
Romania	×				
Serbia	*	*	*	*	*
Slovakia					
Slovenia		*			
Spain	<u>×</u>	*	+		×
Sweden					
UK	×	+			

Symbols indicate soil RAMs used in practice (×) or in development (*). Underlined symbols indicate regional organization of RAMs. Additional soil RAMs found in the literature are indicated by a plus (+). RAMs, risk assessment methodologies; SOM, soil organic matter.

indices linked to each polygon of the soil map of Europe (scale 1:1 000 000) (Tóth *et al.*, 2009).

Results and discussion

Questionnaire results

Contact persons were asked to forward the questionnaire to other relevant scientists and policy makers. From the returned questionnaires, it became clear that this had indeed happened which was appreciated, but also complicated our estimation of return rates. Based on the assumption that all forwarded questionnaires were returned, the average return rate of the questionnaires was 52% and ranged between 21% for salinization and 58% for erosion. The relatively low response for salinization reflects that this is a regional or local phenomenon in EU-27 and is therefore only relevant to a few Member States. However, the absence of some countries and variable interpretation of the questions resulted in a considerable shortcoming in our assessment. For example, it was rather surprising that Serbia has RAMs in development for all soil threats, whereas France has only one. Nevertheless, although quite a few RAMs were used, the total number was far below the maximum of 162 (= 6 soil threats × 27 Member States) as many Member States did not yet have a fully operational RAM (Table 1).

The most important decision factor on whether to adopt or disregard a soil RAM was cost efficiency, whereas ambiguous results and complexity of the RAM were minor decision factors. The majority (54%) of the respondents stated that RAMs were still in development while 34% of the respondents reported RAMs in use (Table 1). The majority of the RAMs (58%) were used by research institutions with the remainder used by consultancies and governmental bodies. There were only a few RAMs (11%) incorporated into official legislation. The question 'for what reason was the RAM developed?' resulted in 72% of the respondents responding 'for scientific understanding'. Only 14% reported 'for legislation' and another 14% was not aware of the original purpose of the RAM. The results of our questionnaires suggest that the development of the RAMs in EU-27 has mainly been by scientists and that the adoption by policy and practice has still to be made.

Current state of soil RAMs in Europe

Table 1 presents an overview of the current status of RAMs across the EU-27. Only one country (Czech Republic) has RAMs for all threats. Hungary and Italy have RAMs for three threats, three countries have RAMs for two threats, and another three countries have RAMs for one threat. The majority of Member States (15 out of 27) has no RAMs or only RAMs in the development. Based on the questionnaires returns, we conclude that no two Member States use identical RAMs. However, many RAMs have similarities, yet differ in details and/or spatial scales. Consequently, it is impossible to discriminate between one RAM and another and instead the situation could be considered as a continuum where particular RAMs more or less slightly merge into others. Though the overlap in RAMs hampers their discrimination, it can facilitate future harmonization as there is a common understanding of elements that should be part of the RAM for a particular soil threat.

Landslide RAMs are used in four Member States (Table 1). The development of RAMs for landslides seems to be ahead of the development of others in terms of completion of the risk assessment chain and harmonization. This is due to several reasons: (i) landslides occur in a limited number of countries; (ii) most landslides occur instantaneously and the consequences are almost always catastrophic which is a strong driver for policy makers; and (iii) external parties, e.g. insurance companies, require risk assessments. The landslide

RAMs combine expert judgment, empirical approaches and to a lesser extent mathematical simulations.

For soil erosion, there are many different RAMs in use (e.g. Boardman & Poesen, 2006) and most are based on empirical modelling. Differences between RAMs are related to the complexity of approaches and spatial scales (regional vs. national). All but one empirical modelling approach uses a modification of the Universal Soil Loss Equation (Wischmeier & Smith, 1978) which in principle provides a strong basis for harmonization, notwithstanding some major limitations of this methodology (Boomer *et al*., 2008).

For SOM decline many RAMs were still in development at the time of the survey (Table 1). Several studies focus on the relationships between land use and SOM dynamics (e.g. Bellamy *et al*. 2005; Sleutel *et al*., 2006). These studies give incomplete risk assessments because they lack the last two steps of the risk assessment chain. Furthermore, the process models differ in their description of SOM dynamics. Simple models consider one homogeneous SOM pool, whereas more complex models divide SOM or soil organic carbon (SOC) into several pools with different characteristics (de Willigen, 1991; de Willigen *et al*., 2008; Diekkrüger *et al*., 1995).

For soil compaction all but one RAM is based on the same deterministic approach (Horn *et al*., 2005; Simota *et al*., 2005). The Alcor (http://www.microleis.com) and the SIDASS models (Horn *et al*., 2005) are the most recent versions of the family of deterministic compaction RAMs. In these models compaction is related to wheel load, soil strength, climatic conditions, drainage conditions, land cover and soil properties. In contrast, the Italian RAM considers soil compaction as the sole result from the weight of agricultural machinery.

Salinization is most severe in Hungary and only Hungary and the Czech Republic have an official assessment methodology (Table 1). RAMs for salinization differ mainly in the indicators used to evaluate the risk, which is in part related to the specific objective of the RAM. Possible indicators for salinization are electrical conductivity (EC), soil water quality, irrigation water quality, exchangeable sodium percentage and sodium adsorption ratio. The assessments are based on expert judgment, similar to the salinity hazard classification of the USDA Salinity Laboratory (Richards, 1954).

Assessment of the completeness of RAMs

For soil erosion and SOM decline all RAMs are limited to the first three steps of the risk assessment chain of Figure 1. For compaction and salinization, some RAMs also include data interpretation but the final step (risk perception) is still missing. For landslides, most RAMs are complete, although some lack the final step of risk perception. The frequent absence of the two last steps in the risk assessment chain, i.e. data interpretation and risk perception may be because many RAMs are still in development. Hence, many so-called soil RAMs that are currently used in EU member states focus on quantifying processes and should be referred to as vulnerability assessments rather than risk assessments.

Assessment of needs for harmonization

The common criteria in Annex 1 of the soil thematic strategy (European Commission, 2006) are summarized in Table 2 for each threat. The MIs for data collection were calculated for each soil threat and range from 0.58 for compaction to 0.88 for SOM decline (Table 3). This suggests that consensus is most lacking about required data for compaction and is greatest for SOM decline. The MI for erosion is 0.60. This relatively low value can be explained by the absence of information on agro-ecological zones in all RAMs and the absence of land cover in most of the RAMs. For salinization, a relative high coverage (81%) of the common criteria was found and several RAMs took all criteria into account (Table 2). For compaction, the criteria 'topography' and to a lesser extent 'land cover' are frequently missing in the RAMs, yielding a MI of 0.58. For landslides, a relatively high MI of 0.77 was calculated, though the criteria 'climate' and 'seismic risks' were commonly missing (Table 2). However, the criteria in Annex 1 are very general and a more detailed and prioritized list has been developed by Huber *et al*. (2007) which includes amongst others, DPSIR classes, applicability and monitoring type. A comparison of calculated MIs for the different RAMs with the indicators of Huber *et al*. (2007) and with the criteria of Annex 1 yielded different results, but the order of magnitude and relative scores remained similar (not shown).

For data processing, MIs are highest for landslides and salinization. The commonly used methods are empirical modelling (erosion), expert judgment (salinization) and process modelling (compaction and landslides). For SOM decline, expert judgment, factorial approaches and process modelling are used. For data interpretation, the most contrasting threshold values are for compaction. For this soil threat, different indicators (e.g. saturated hydraulic conductivity, air capacity and penetrometer values) and different values are used per indicator. For salinization, threshold values are defined for different indicators (e.g. exchangeable sodium percentage, EC and leaching requirement). For erosion, thresholds values are under debate, but 6 out of 11 RAMs report the use of a threshold value. Thresholds are commonly related to baseline (or 'natural') erosion rates using 'benchmark' sites, but this is not yet practice and reported tolerable erosion rates range from 1 to 2 t/ha/yr (Huber *et al*., 2007).

Ultimately, the MI of risk perception is the most relevant indicator for assessing the potential for harmonization. However, for most threats, the MI for risk perception is

Table 2 Inclusion of common criteria in RAMs per soil threat

Soil threat	Country (RAM)	Soil type	Soil texture	Soil density, hydraulic properties	Topography	Land cover	Land use	Climate	Hydrological conditions	Agro-ecological zone	Soil hydraulic properties	Irrigation	Ground water	Bulkdensity	Soil organic matter	Occurrence/ density of existing landslides	Bedrock	Seismic risk	Soil organic carbon content	Soil organic carbon stock
Erosion	Germany	×	×	×	×	–	×	×	×											
	Finland	×	×	×	×	–	×	×	×											
	Spain	×	×	×	×	–	–	×	×											
	Hungary	×	×	–	–	–	×	×	×											
	Belgium	×	×	–	×	–	×	×	–											
	Norway	×	×	×	×	–	–	×	–											
	Poland	×	–		×	–	×	×	–											
	France	×	×	×	×	–	×	×	–											
	CORINE	–	×		×	–	×	×	–											
	PESERA	–	×	×	×	–	×	×	×											
	GLASOD	–	–	–	–	–	–	–	–											
Salinization	Cyprus		×					×			×	×	×							
	Hungary 1	×	×					×			×	×	×							
	Hungary 2	×	×					×			×	×	×							
	Hungary (TIM)	×	–					×			–	–	–							
	Romania	–	×					×			–	×	×							
	Slovakia	×	×					×			×	–	×							
	Spain	–	×					×			×	×	×							
	Greece	×	×					×			×	×	×							
Compaction	Romania	×	×			–	×	×						×	×					
	Germany	×	×			–	–	–						×						
	Germany	×	×			×	×	×						×	×					
	Germany	–	×			–	–	–						×	×					
	Germany	–	×			–	–	×						×	×					
	Poland	–	–			–	–	×						×						
	Poland	×	×			–	–	–						–	×					
	Denmark	×	×			–	×	×						–	×					
	France	×	×			–	×	×						×	×					
	Spain	×	×			×		×						×	×					
	Greece	×	×			×	×	×						×	×					
	Italy	–	–			–	–	–						–	–					
	Finland	–	×			–	×	×						–	×					
	Slovakia	×	×			–	×	–						×	–					
	Hungary	×	×			–	×	×						×	×					
	Belgium	×	×			–	×	×						–	–					
	Belgium	×	×			–	×	–						–	–					
Landslides	France	×			×	–	×	–								×	×	–		
	Italy	×			×	×	×	×								×	×	×		
	Sweden	×			×	×	×	×								×	×	–		
	Switzerland	×				×	×	–								×	×	–		
	Belgium	×			×	–	–	–								×	×	×		

Table 2 (continued)

Soil threat	Country (RAM)	Soil type	Soil texture	Soil density, hydraulic properties	Topography	Land cover	Land use	Climate	Hydrological conditions	Agro-ecological zone	Soil hydraulic properties	Irrigation	Ground water	Bulkdensity	Soil organic matter	Occurrence/ density of existing landslides	Bedrock	Seismic risk	Soil organic carbon content	Soil organic carbon stock
	Cyprus	–			×	×	×	×								×	×	×		
	Czech republic	–			×	–	×	×								×	×	–		
	Ireland	×			×	–	×	–								×	×	–		
	Hungaria	×			×	×	×	×								×	×	×		
	Slovenia	×			×	×	×	×								×	×	×		
	Slovakia	–			×	×	×	×								×	×	×		
	Spain	×			×		×	×								×	×	×		
	United Kingdom	×			×	×	–	–								×	×	–		
	Portugal	–			×	×	×	–								×	×	–		
	Greece	×			×	×	×	–								×	×	–		
	Poland	–			×	×	–	×								×	×	–		
	Belgium	×	×		×	×	×	×								×	×	×		
SOM decline	France	×	×		×	×	×	×											×	–
	Slovak Republic	×	×		×	×	×	×											×	–
	United Kingdom	×	×		×	×	×	×											×	–
	Slovenia	×	×		×	×	×	×											×	–
	Denmark	×	×		×	×	×	×											×	–
	Greece	×	×		×	×	×	×											×	–
	Germany	×	×		×	×	×	×											×	–

Cells in grey are not part of the criteria for the specific soil threat, x = included in RAM, – = not included in RAM. Brief descriptions of the common criteria are given in the column headings, more elaborate descriptions can be found in Annex 1 of the proposal for a framework directive (European Commission, 2006) and in Eckelmann *et al.* (2006). RAMs, risk assessment methodologies; SOM, soil organic matter.

Table 3 Summary of matching indices (MIs) per soil threat and per step in risk assessment chain

	Data collection	Data processing	Data interpretation	Risk perception
Erosion	0.60	0.50	0.17	n.c.
Salinization	0.81	0.62	0.13	n.c.
Compaction	0.58	0.35	0.09	n.c.
Landslides	0.77	0.63	0.55	0.50
SOM decline	0.88	0.50	n.c.	n.c.

MIs are a measure for the relative common elements of different soil RAMs. n.c., nonconclusive; RAMs, risk assessment methodologies; SOM, soil organic matter.

inconclusive because of lacking information, presumably as a result of the ongoing debate about threshold values. The steps in the risk assessment chain are in sequence and hence incomplete information in a previous step will hamper the execution of the following one. The best options for harmonization of data interpretation are for landslides and SOM decline (Table 3). This conclusion is supported by the fact that there is already much coordination of approaches within the landslide scientific community. RAMs for SOM decline also have good potential for harmonization because many RAMs for SOM decline are under development and can still be modified as a result of continuing discussions.

In general, to achieve harmonization of RAMs least efforts are required in the data collection stage. In our approach, compliance of data collection with the common criteria was used as a basis for assessing the extent of work required for harmonization of the RAMs. However, even when data collection is harmonized, considerable differences in outcomes can occur, e.g. owing to differences in sampling schemes and laboratory protocols. For harmonization of sampling schemes, Morvan *et al*. (2008) conclude that an additional 4100 sampling sites are needed to achieve a harmonized, i.e. comparable, scheme across EU-27. Likewise, the MI for data processing refers to the common use of data processing methodologies, but even when similar methodologies are used, the results may differ because of differences in parameterization, scaling, etc. Despite these limitations, the use of similar methodologies demonstrates a common understanding of how the data should be processed. This highlights that relatively little effort is needed for harmonization of data processing.

Case study

Results from the case study on soil erosion in Romania are shown in Figure 3. Differences were found in delineation as well as in patchiness of erosion. The affected areas equaled 20×10^6 ha using the SIDASS-WEPP approach and 23×10^6 ha using the PESERA approach for a threshold value of 1 t/ha/yr. Although differences between the two approaches were only moderate at the national level, regional results showed considerable differences. For example, in the Harghita and Bistrita-Nasaud regions, the PESERA approach resulted in considerably lower soil erosion estimates compared with the SIDASS-WEPP approach; the opposite was true for the Arad region. For some counties, a fairly good match was obtained (e.g., Cluy, Alba and Timis counties). Moreover, the choice of the threshold level had a considerable impact on the comparison of both RAMs. A change in threshold value from 1 to 2 t/ha/yr resulted in a 34% better match between the two approaches at the national level (Tóth *et al*., 2009).

Consequences of not harmonizing risk assessment methodologies

Several case studies have shown conflicting results when different RAMs are used for the same soil threat (e.g. Smith *et al*., 1997 and Gobin *et al*., 2003). Differences in RAMs in EU-27 occur because of: (i) independent development of RAMs, (ii) different definitions of the soil threat, (iii) different environmental conditions, (iv) different driving forces and (v) different objectives for the RAMs. de Smedt (2004) identifies four arguments for harmonizing EU environmental legislation to also accord with the EU's launch of a thematic strategy on soil protection (European Commission 2006):

1. Transboundary character of externality; this argument refers to threats that act across international borders, e.g. erosion processes occurring in one Member State may have consequences in another Member State.

Figure 3 Soil erosion loss (t/ha/yr) in Romania evaluated using the SIDASS-WEPP model (left) and using the PESERA model (right). Erosion rates increase from light to dark.

2. 'Race to the bottom' versus 'level playing field'; this argument refers to the need for equal standards and fair market competition between states. The term 'race to the bottom' refers to the reluctance of states to implement environmental protection standards, for example, for polluting industries unless members with competing industries do the same. Conversely, the 'level playing field' refers to equal quality standards throughout states.
3. Market access and the prevention of trade distortions; this argument refers to restrictions to markets through environmental liability.
4. Minimum level of protection; through harmonization of environmental legislation all citizens can be guaranteed some minimum level of protection against environmental hazards.

de Smedt (2004) concludes that for environmental legislation harmonization is not warranted. In her view, trade exists on the basis of different environmental factors that favour specific regions for the production of specific products. These arguments mainly refer to harmonization of threshold values and risk perception, i.e. the last two steps of the risk assessment chain in Figure 1, whereas scientific studies on harmonization (e.g. Theocharopoulos *et al*., 2001; Wagner *et al*., 2001; Morvan *et al*., 2008) most often refer to the understanding of the soil threat, data collection and data processing, i.e. the first three steps of the risk chain. Hence, at present the discussion about harmonization of environmental RAMs and soil RAMs is taking place at different organizational levels. In our view, the use of different RAMs at the European level is detrimental because it may result in different assessments for similar vulnerabilities. An example of such an unwanted consequence is provided by Kamrin (1997) who reports conflicting advice on consuming fish from different states sharing the same Great Lake in the USA. Eventually such conflicting advice can result in loss of public support for environmental policies.

Conclusion

At present harmonization of soil RAMs is far from achieved. Although many RAMs have some similarities, differences in comprehensiveness, and spatial and temporal scales result in different evaluations of a similar exposure to a soil threat. Harmonization of RAMs is often difficult to achieve owing to differences in one or more steps in the risk assessment chain of Figure 1. To achieve consensus on the assessment of soil threats, we propose two options:

1. A two-tier approach based on data availability as suggested by Eckelmann *et al*. (2006), where Tier 1 is at a relatively low spatial resolution and is used to identify areas at risk. At the Tier 2 level, a more detailed and/or site-specific assessment is made using a more detailed RAM. The Tier 2 approach should be harmonized, i.e. made compatible with Tier 1. A number of explorative studies on the occurrence of soil threats in EU-27 has been done as a consequence of several EU funded projects (e.g. European Commission 2005, Simota *et al*., 2005; Kirkby *et al*., 2008; Tóth *et al*., 2008). These studies serve as a starting point for the development of Tier 1 methodology.
2. Combination of harmonization and standardization for the different steps in the risk assessment chain. The understanding of the threat, data collection and risk perception steps of the risk assessment chain are standardized (i.e. prescribed), whereas the data processing and data interpretation steps are harmonized. This would entail that member states can use the models and threshold values that are most applicable to their environmental contexts. For data collection, several programmes or manuals are available that provide standardized data inventories (Kibblewhite *et al*., 2008).

Future assessments should focus on the advantages and disadvantages of these options as the current situation will result in endless discussions on differences and the merits of particular methodologies instead of taking appropriate measures to reduce or eliminate the actual threats.

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