Harmonization of risk assessment methods of soil erosion by water in the European Union

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ABSTRACT

In order to effectively formulate mitigation strategies and implement conservation measurements to counteract soil erosion, it is essential to objectively identify and quantify areas at risk. With the adoption of the European Union (EU) Thematic Strategy for soil protection, a first step is made towards adequate measures to combat soil erosion and other soil degradation processes. However, to provide an effective tool at European level, risk assessment methodologies should be harmonized (i.e. similar although adapted to local circumstances), providing criteria and standardized definitions of risk areas within the EU. This chapter provides an overview, evaluation and assessment of risk assessment methods of water erosion currently existing and applied within the EU, in the framework of the EU-funded RAMSOIL project (www.ramsoil.eu). Only methods with an official status and/or those that are widely scientifically acknowledged were considered and included in this review. Information on RAMs for soil erosion was identified through both questionnaires and scientific literature review. Questionnaires were sent to scientists and policy makers in EU Member States and Norway. The methods were compared, based on five indicators such as scale, transparency, complexity, cost efficiency and ambiguousness, after which a final statement is made about their *soundness*, *flexibility* and *acceptability*, reflecting the potentials for harmonization.

Keywords: soil erosion, EU soil protection, risk assessment methods, harmonization, Europe

INTRODUCTION

Soil erosion is perceived as a major and widespread form of soil degradation and it has large environmental and economic impacts at different scales (Cohen et al., 2006; Zhang et al., 2009) especially in agricultural areas (Zalidis et al., 2002). Even though erosion originally is a natural process, influenced by physical factors, current human interventions in the landscape often accelerate natural erosion rates tremendously (Grimm et al., 2002; Karydas et al., 2009). Consequently, social, economic and political factors are decisive in determining soil erosion risk (Boardman et al., 2003; Lundekvam et al., 2003; Gobin et al., 2004; Oñate and Peco, 2005; Eckelmann et al., 2006). The anthropogenic pressure is essentially reflected in the land cover, where land use change and -intensity and cultivation practices, such as tillage and implementation of conservation strategies, determine the vulnerability to erosion (Batjes, 1996; Drake and Vafeidis, 2004; Boardman, 2006; Lesschen et al., 2007).

In Europe, wind erosion affects significant areas (Eckelmann et al., 2006, Kertész and Centeri, 2006). The EU-projects WEELS (Bônner et al., 2003) and WELSONS (Gomes et al., 2003) suggest that the area affected by wind erosion is probably much larger than previously thought. However, water erosion is the main erosion process affecting the European territory. Erosion imposes direct and indirect, on-site and off-site effects on the environment and society as a whole. On-site problems are mostly obvious, e.g. soil loss, gully development and decreasing soil fertility with consequent productivity decline. However, erosion also includes less obvious or off-site impacts, such as environmental pollution, enhanced flood risks due to river sedimentation and reduced water retention capacity and damage to buildings and infrastructure, consequently affecting areas located on a further distance from the location where actual erosion is taking place (Bakker et al., 2008). These on-site and off-site impacts have been frequently expressed in economic terms, demonstrating that soil erosion has huge costs for society (Pimentel et al., 1995; De Graaff, 1996; Bielders et al., 2003). For developed countries the costs involved with off-site effects of soil erosion tend to be higher than its on-site costs (Verstraeten et al., 2003). For example, Pretty et al. (2000) estimated the off-site costs of soil erosion for the United Kingdom at £14 m per annum. In Flanders (Belgium), the annual costs related to soil erosion range from €60 to €95 million (Verstraeten et al., 2006).

Obviously, also Europe is facing erosion, leading to irreversibly degraded soils in southern Europe. Though evidence is less observable in the rest of Europe, also the temperate region suffers from hazardous erosion (Grimm et al., 2002; Jones et al., 2003). The perception of the relevance of the environmental issues associated with soil erosion and other soil degradation processes (e.g. salinization, loss of organic matter, soil compaction, soil contamination) at European level resulted in the adoption of a Communication on Soil Protection by the European Commission in 2002, –"Towards a Thematic Strategy for Soil Protection"- (European Commission, 2002). The Communication considers soil erosion as one of the major threats to European soils, particularly in the Mediterranean areas. With the adoption of the European Union (EU) Thematic Strategy for soil protection (European Commission, 2006), a first step is made towards adequate measures to combat soil erosion and other soil degradation processes.

In order to effectively formulate mitigation strategies and implement conservation measurements to counteract soil erosion, it is essential to objectively identify and quantify areas at risk. However, to provide an effective tool at European level, risk assessment methodologies should be harmonized (i.e. similar although adapted to local circumstances) (Gobin et al., 2004), providing criteria and standardized definitions of risk areas within the EU (Eckelmann et al., 2006). Currently, numerous efforts within individual countries have taken place to identify areas at risk, however each using its own methodologies, type and quality of data (Baade and Rekolainen, 2006). To facilitate national and EU wide comparability and evaluation of erosion risk, a common framework has to be developed, linking European soil erosion, risk assessment methods and coherent data - such as local climate, topography and land use characteristics provided by each individual country (e.g. Gobin et al., 2004) – contributing to an effective consideration of soil protection within the EU. Data quality and extent are essential in this respect (e.g. Gobin et al., 2006), although these often form the most limiting factors (Grimm et al., 2002).

To initiate risk assessment harmonization, the aim of this chapter is to provide an overview, evaluation and assessment of risk assessment methods of water erosion currently existing and applied within the EU. For this overview, only methods with an official status and/or those that are widely scientifically acknowledged were considered and included in this review. Similarities, differences, advantages and disadvantages of the methods are discussed, after which possibilities for harmonization are proposed. For this purpose, an inventory was made of the water erosion risk assessment methods, primarily based on questionnaires sent to policy makers and erosion scientists, although supplemented with scientific literature review.

METHODS

Approaches to assess water erosion risk

Different countries use different methodologies for water erosion risk assessment. Even within countries various methods are used, as local circumstances vary (soil, climate, and political framework), interests differ and similar problems may have varying causes, or comparable problems may be viewed differently. As a result, numerous risk assessment methodologies have evolved and are in use across the EU, and erosion estimates within and between countries are far from comparable (Verheijen et al., 2009). Consequently, an objective view of erosion risk is hampered and harmonization of methods is currently limited. It must be noted that there does not exist a best method to assess erosion risk, since conditions differ from location to location. Nevertheless, common and specific aspects can be explored for each individual situation.

Risk assessment methods can be subdivided in qualitative and quantitative approaches, the former using expert knowledge to provide a relative indication of risk, the latter offering quantitative (absolute) erosion estimates, based on measured data and/or modeling. However, this separation is not strict and approaches are frequently integrated (Eckelmann et al., 2006). A more practical and accurate differentiation is based on the kind of activities actually performed, i.e. a) expert judgment, b) the use of indicators, factorial approaches and process monitoring and c) process modeling, possibly integrated with Geographical Information System (GIS) and/or monitoring (Van der Knijff et al., 2000; Grimm et al., 2002; Gobin et al., 2006).

A) Expert judgment

Local erosion experts assess erosion risk from the current state of erosion in a specific area. An example of an expert-based approach is GLASOD – Global Assessment of Soil Degradation - (Oldeman et al., 1991). The GLASOD map identifies areas that are more or less equally degraded, irrespective of the conditions that would produce this land degradation. It is based on responses to a questionnaire sent to recognized experts in all countries and thus depends on a set of expert judgments. Although this is a simple and relatively quick method, scientific soundness and reproducibility remain questionable (Sonneveld and Dent, 2009), as erosion status does not necessarily reflect erosion risk (Sánchez et al., 2001). Moreover, the when and why of erosion remain unknown (Gobin et al., 2006). The soil erosion risk map of Western Europe (De Ploey, 1989) is another example of an expert approach. The map was produced by various experts who delineated areas where erosion processes are important. The spatial representation of areas at risk for erosion is too general to be of use to policy makers.

B) Indicators, factorial approaches and process monitoring

Monitoring the state and condition of systems to detect changes can be done by means of indicators, directly providing information of the system's state and important interactions (Riley, 2001; Gobin et al., 2004; Boardman, 2006). Subsequent ranking (weighting) of factors influencing erosion susceptibility (i.e. the factorial approach) provides a measure to indicate, evaluate and classify areas at risk for erosion. The CORINE programme assessed the risk of soil erosion in Mediterranean Europe by overlaying soil erodibility, erosivity and topography using a factorial approach (CORINE, 1992). To assess actual erosion risk, the potential soil erosion risk is combined whit a land cover factor. CORINE assessments show significant differences from risks assessed by other methods (Sánchez et al., 2001). Le Bissonnais et al. (2001) and Wawer and Nowocień (2007) developed factorial methods for France and for Poland, respectively. The main advantage of this type of methods is that integration with GIS offers possibilities for wide-scale application, although accuracy of the results depends on data quality (Kirkby et al, 2004). However, the algorithms used to integrate indicators and the weighting of such indicators remains a difficult issue in this type of methods.

C) Process modeling

Models serve to consider interrelationships between processes, understand systems, formalize, simplify and test theories and to predict future developments through scenario studies. Within this approach, generally two types of models are used to estimate erosion rates, i.e. empirical models and physically based models (Morgan and Quinton, 2001). Empirical models are based on statistically significant relationships between desired model output and input. Their main advantage is their relative simplicity, although results can not be generalized to other areas and processes underlying erosion remain implicit. The most well-known and widely applied empirical model to predict soil losses by water erosion is the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and its derivates (RUSLE). This empirical equation considers the effects of rain, soil erodibility, slope length, slope steepness, vegetative cover and protection measures. It predicts soil loss through sheet and rill erosion, disregarding other types of erosion. Although its development is based on data from the USA, it has been used widely all over the world. Most of the European countries have applied this model in their territories (Baade and Rekolainen, 2006; Eckelmann et al., 2006).

Physically based models use mathematical relations to describe processes, consequently being more uniformly applicable. Moreover, feedbacks between diverse factors are taken into account and erosion can be simulated at multiple (temporal and spatial) scales. Nevertheless, their applicability is limited by their large data request, resulting in mostly small-scale, relatively complex, time consuming and sometimes user-unfriendly models (Drake and Vafeidis, 2004; Mulligan, 2004; Gobin et al., 2006). Europe has made some attempts to develop its own physically-based runoff and erosion models for research and conservation purposes (Jetten and Favis-Mortlock, 2006). Although process modeling is a more transparent and scientifically sound method to estimate erosion rates (generally in absolute figures), it is time-consuming and consequently not always efficient in use. Moreover, validation and extrapolation of models often forms a major problem, especially when estimations over large areas are provided based on detailed, local measurements.

Criteria to evaluate water erosion risk assessment methodologies and to evaluate options for harmonization

Information on risk assessment methodologies (RAMs) for soil erosion was identified through both questionnaires and literature review in the framework of the RAMSOIL project. Questionnaires were sent to scientists and policy makers in EU Member States and Norway. The methods were compared, based on five indicators such as scale, transparency, complexity, cost efficiency and ambiguousness.

- *Scale* implies scale of the maps and is also linked to the availability of existing maps.
- *Transparency* reveals reproducibility and clearness of the method, where expert analysis has lowest and physical models having highest transparency.
- *Complexity* is related to processing of input data and amount of output data and is ranked according to number of techniques used (e.g. laboratory experiments, applying GIS, Remote Sensing, historic data, etc) in respect of the total range of techniques mentioned in this chapter.
- *Cost efficiency* reflects costs and means to achieve a goal. A high cost efficiency will be achieved by, for instance using existing data and simple methods, while use of new field data and complex models leads to a low cost efficiency.

- *Ambiguousness* relates to uncertainty in computations and predictions. Generally, it can be stated that physical modeling has a relatively lower uncertainty than methods based on expert analysis, although they have different grounds.

Each indicator is coded from 0 – 10 (indicated by the left hand scale bar), with differing values for different options, as is shown in Figure 1. The risk assessment methods are subsequently ranked for each indicator, presented in spider graphs having five axes for the five different indicators as shown in the Results (Figure 2). The indicators have been quantified per risk assessment methodology, based on the questionnaires and background information of the methods.

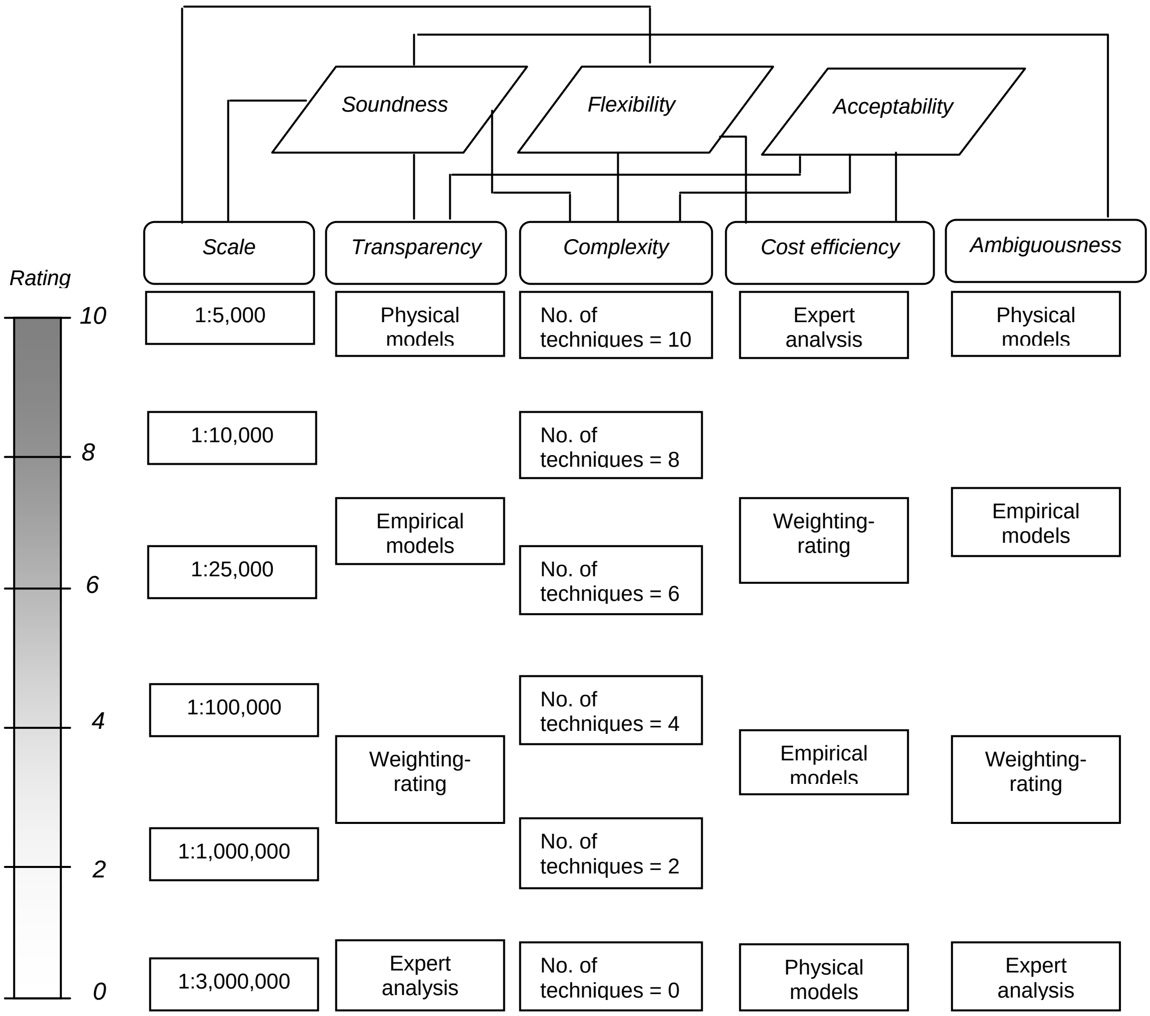

Figure 1. Chart with the criteria to evaluate water erosion risk assessment methodologies through five indicators (Geraedts et al., 2008).

Soundness, flexibility and *acceptability* are, within the RAMSOIL project, regarded to be essential criteria that a good, potentially harmonizable risk assessment methodology preferably should comply with:

- *Soundness* has to do with scientific acceptance and legitimacy.
- *Flexibility* signifies the applicability under various circumstances.
- *Acceptability* relates to the ease to understand the method and results without prior (scientific) knowledge and simplicity to translate results to explicit measures.

These aspects can be related, however not exclusively, to the five indicators used to compare RAMs (Figure 1). For each risk assessment methodology, the ratings of the individual indicators give rise to a specific score of each harmonizing criterion and subsequently to an overall classification of the risk assessment methodologies. These criteria have been used within the framework of the RAMSOIL project in order to analyze RAMs concerning different soil degradation processes such as soil salinisation (Bloem et al., 2008), landslides (Malet and Maquaire, 2008) and soil erosion (Geraedts et al., 2008,) and identify options for harmonization (www.ramsoil.eu).

RESULTS

The spider-graphs shown in Figure 2 present the diversity of methods, even though approaches can be similar (e.g. USLE based). Figure 3 shows the scorings of the risk assessment methods on the harmonizing criteria. Overall, approaches using expert analysis, exclusively (no. 11) or in combination with other methods (no. 2), have a rather large uncertainty and low transparency and consequently they score very low on soundness. Expert based approaches are highly cost efficient and relative flexible methods, although not widely accepted. Generally, factorial approaches are poorly transparent and have a large uncertainty, resulting in relatively low soundness, as goes for the CORINE approach (no. 9). However, the French method referred here to the INRA (Institute National de la Recherche Agronomique) method (no. 8) has defined rules to which every expert should adhere to, which allows for a relatively transparent and consequently flexible and highly acceptable procedure. The PESERA method (no. 10) applies a physically based process model, resulting in a transparent, sound and widely acceptable method, with relatively certain results, although uncertainty increases when larger areas are considered. However, the method is also complex, not the most cost efficient and moderately flexible

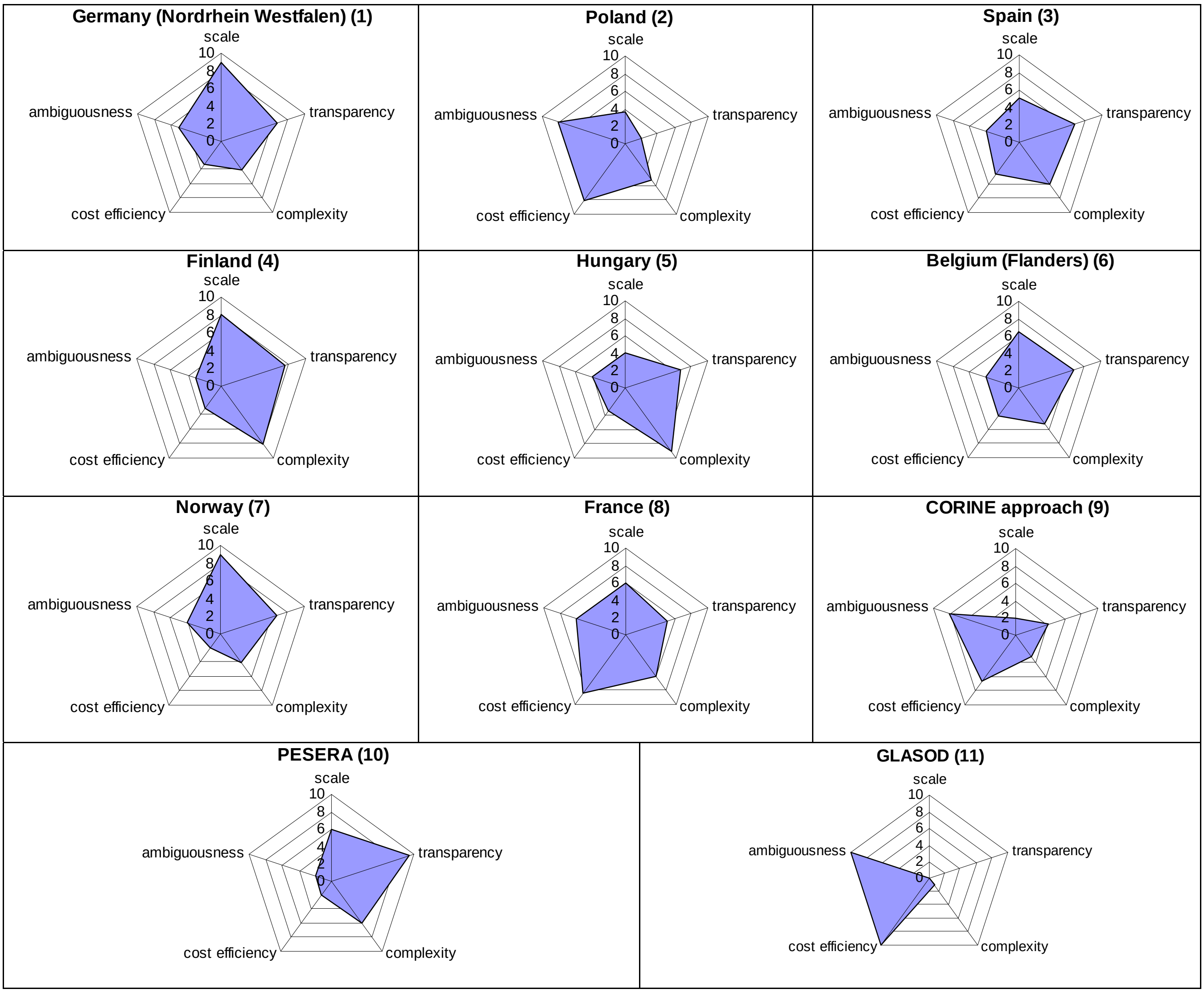

Figure 2. Spider graphs of the identified erosion risk assessment methodologies.

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(R)USLE based approaches (no. 1, 3, 4, 5, 6, 7) have a low cost efficiency, since they require much effort to apply the models effectively (e.g. adaptation to local circumstances, validation, calibration, etc), besides a frequent monitoring requirement. Consequently, their flexibility is low. Surprisingly, the methods are moderately sound, largely attributable to the large range of side-techniques, besides the USLE approach. However, in spite of the low cost efficiency, a relative high transparency and relative low uncertainty result in good acceptability of the USLE based methods, supported by the widespread and long history of the USLE.

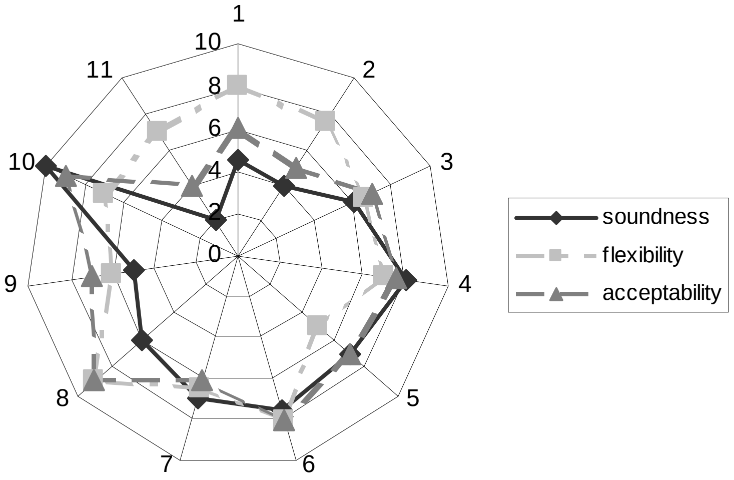

Figure 3. Options for harmonization; the lines respectively present *soundness*, *flexibility* and *acceptability* of each risk assessment methodology identified, which are represented by the axes. Numbers refer to the RAMs cited in the text.

The risk assessment methods are compared and visualized based on their scorings in relation to the three harmonizing criteria (see Figure 1). Figure 3 represents the spider graph constructed from this comparison, in which each axis corresponds to a risk assessment methodology. The PESERA approach (no. 10) offers the best balancing between soundness, flexibility and acceptability and the highest scores on these criteria. On the other side of the spectrum are the GLASOD approach (no. 11) and the Polish RAM (no. 2), lowest in rank, since their expert based approach especially results in low soundness and low acceptability.

DISCUSSION

Generally, the methodologies described in this chapter use rather similar approaches to assess soil losses (except the GLASOD approach), and results are mainly presented in rates [t.ha^{-1}.yr^{-1}] or volumes [ton or ton.ha^{-1}], either in absolute values or relative classes. However, the way in which these rates are derived is far from universal and different approaches are applied. Although frequently a modeling approach is used, a distinction exists between the application of empirical models and physically based models. First of all, it must essentially be noted that the validity of the model output apart from the model itself depends on the quality and resolution of input data (Van der Knijff et al., 2000; Grimm et al., 2002; Gobin et al., 2006). Therefore, whatever a risk assessment method will finally be selected for European-wide application, a vital requirement is the deliverance of good quality input-data. Model structure amongst others determined by model type (quantitative or qualitative, physical or empirical) and application scale are other important determinants of the validity of outcomes.

The USLE model and its derivatives are the most frequently used models for erosion risk assessment (RAMs no. 1, 3, 4, 5, 6, 7). Their main advantage is their user-friendliness due to a relatively simple model formulation. Moreover, if databases of common input data on climate, topography and land management are available, integration with GIS allows for easy derivation and pre-processing of parameters (Van der Knijff et al., 2000; Morgan and Quinton, 2001; Drake and Vafeidis, 2004; Lewis et al., 2005; Jetten and Favis-Mortlock, 2006). Consequently, the model might be used to simulate erosion over large areas, without intensive additional work for model parameterization. However, the original development for USA conditions and the rill and interrill erosion issues are limitations to apply the model for erosion risk assessment in European settings (Baade and Rekolainen, 2006; Jetten and Favis-Mortlock, 2006). Moreover, it is an empirical model, thus concealing underlying physical processes and thorough understanding of the whole system, limiting soundness of the method. Above mentioned aspects imply that, when applying the model throughout Europe, it has to be recalibrated and validated for each specific country or even region (Mulligan, 2004), resulting in less flexibility. Furthermore, channel erosion and sediment delivery are in first instance not taken into account (e.g. Lewis et al., 2005; Gobin et al., 2006). Nevertheless, Jetten and Favis-Mortlock (2006) conclude that when large areas are considered, empirical models can perform as well as physically based models. Moreover, Grimm et al. (2002) state that the USLE approach is able to provide detailed information within small areas, although reliability remains questionable. The (R)USLE approach provides erosion estimates of moderate quality (Van der Knijff et al., 2000) and although the method is acceptable, flexibility and soundness are rather limited.

The PESERA model (RAM no. 10) is a good example of a physically based model able to simulate erosion at various scales, hereby showing its flexibility. Although physically based, and therefore more sound than empirical models, formulas are rather simplified and data demand is relatively restricted, consequently remaining generally accessible (Grimm et al., 2002). However, as a result of this simplification, appropriateness under particular local circumstances remains questionable (Gobin et al., 2006). Cross-scale validation of the model provides an indication of accurateness of predictions, although validation is only performed at specific locations (Gobin et al., 2006). The model was developed to enable the analysis of land use and climate change scenarios, providing a tool for policy makers. However, many more data of actual erosion rates (measurements) and up-to-date land use, climate and soil data are needed (Kirkby et al., 2004; Kirkby et al., 2008) to comprehensively validate the model (Micheli et al., 2008) and guarantee the validity. Overall, the PESERA model provides the highest scores and is best balanced with regard to soundness, flexibility and acceptability.

Expert based approaches such as the Polish method (no. 2) and the GLASOD approach (no. 11) and factor based risk assessment methods such as the INRA approach for France (no. 8) and the CORINE risk assessment method (no. 9) heavily rely on expert based assessment, consequently being rather subjective (Grimm et al., 2002). Although expert-based approaches are generally non-replicable and highly uncertain, the INRA approach remains relatively replicable (and therefore more certain) by setting defined rules. Detailed assessment and evaluation of effects of land use or climate changes is difficult, since only a relative risk indication is provided (Van der Knijff et al., 2000; Gobin et al., 2006). As a result of this qualitative and subjective assessment, they score low on soundness (except the INRA approach). The CORINE and INRA approach are based on the same methodology, although the INRA approach is favored for erosion risk assessment (Grimm et al., 2002; Gobin et al., 2006) since it is based on more detailed input data, takes erosion processes more realistically into account (i.e. considers soil crusting) and presents outputs with higher resolution. Factorial approaches are proven to be flexible and applicable at various scales, i.e. continental scale for the CORINE approach and national to regional scale for the INRA approach. Moreover, the relative simplicity of factor based methods (Grimm et al., 2002) makes them understandable for non-experts and ensures acceptability.

From the comparison of risk assessment methodologies it can be concluded that despite the fact that many approaches display outputs in similar units, results are far from transferable and applying different methods to the same area will most likely result in different outcomes. These deviations may be caused by incorporation of different factors, varying parameter computation methods, varying quality of input data, differences in model sensitivity, subjective expert judgment, differences in model and output scale, etc.

When only relative indication of erosion rates and identification of areas at risk is needed, harmonization of results is possible, without obliging the individual countries to use similar methods. Outputs have to be mutually comparable, which can be achieved by presenting them in terms of similar (quantitative or qualitative) erosion classes. When in this case different methods are used (e.g. USLE-based approaches and expert analysis), results can be presented similarly. However, the problem remains that when different methods are used, diverse results might be obtained, i.e. it is not verifiable whether erosion estimates of different methods are mutually comparable. Harmonized results presented in equal erosion classes therefore appear comparable; however they are based on different methods and are therefore not necessarily absolutely comparable. When this problem has to be overcome, *standardization of methods* is necessary, implying uniform application of similar methods to quantify erosion rates or estimate risks throughout the entire EU, as is recommended by Eckelmann et al. (2006). This standardization guarantees accurate and absolute comparison of results between various areas. When such standardization is desired, currently the PESERA model provides the best opportunities for European wide erosion assessment, as confirmed by the ENVASSO project (Micheli et al., 2008), although the approach data demanding (Karydas et al., 2009). Furthermore, according to De Vente et al. (2008), it is expected that performance of the PESERA model can be increased using a higher resolution DEM (Digital Elevation Model).

The discussion about harmonization or standardization is not confined to risk assessment methods alone, but also concerns input data. When a comprehensive set of input data, including requirements concerning methods of data collection and processing and level of detail, is decided upon – implying a great level of standardization of input data – one could more readily suffice with a simple harmonization of methods. For example the USLE approaches can be regarded as generally standardized (Van der Knijff et al., 2000), however the large variety in (derivation of) input factors results in incompatible outputs. When, in this case, input data would be standardized (i.e. derived from similar databases with comparable scales and classes based on similar methods of data collection), comparability and compatibility of results would be possible, as is confirmed by Grimm et al. (2002).

CONCLUSION

Various risk assessment methodologies are or have been operational within the EU, all with their own (dis)advantages, site-specific suitability and diverse levels of complexity. In addition to the method used for erosion risk assessment the quality and resolution of input data is essential for reliable erosion assessments (Van der Knijff et al., 2000; Grimm et al., 2002; Gobin et al., 2006; Kirkby et al., 2008).

Moreover, this data quality also tends to be decisive for the final presentation of results, i.e. in relative or absolute figures (Grimm et al., 2002). Various risk assessment methods for soil erosion applied in Europe or in Europe-wide risk assessment were evaluated with respect to the scale of output, transparency, complexity, cost-effectiveness and ambiguousness of the methods. The evaluations were integrated in three criteria expressing the possibility to harmonize the risk assessment method with other methods: soundness, flexibility and acceptability. Based on these criteria, the PESERA approach was found to be the most sound, flexible and acceptable method, provided that good quality data are available. The method is capable to analyze scenarios, and therefore also provides a tool for policy makers.

Whether at European level harmonization (i.e. differing approaches delivering comparable and compatible results) or standardization (i.e. uniform procedures delivering absolutely comparable results) of water erosion risk assessment methodologies is the most desirable option, depends on the preferred level of accuracy and comparability versus acceptability and cost efficiency. When an initial identification of risk areas and relative indication of erosion risk based on extremes is sufficient, harmonization of methods enables the countries to continue with their own approach, preventing them from extra efforts and coherent costs. This is the option requiring the least efforts for implementation by the EU Member States. However, harmonization of risk assessment methodologies does not implicitly result in mutually comparable results. When, on the other hand, erosion estimates of different countries have to be absolutely comparable, standardization of methods for data collection and processing is probably necessary. The processes of harmonization and standardization would benefit from the establishment of a set of uniform input data with regard to methods of data collection and spatial and temporal support, giving rise to comparable output data. Moreover, to facilitate harmonization of national datasets, common classification of erosion assessments is needed, for example in terms of fixed erosion classes (Baade and Rekolainen, 2006).

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