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RISK ASSESSMENT METHODS OF SALINITY

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RAMSOIL

Risk Assessment Methodologies for Soil Threats

Glossary of terms used in salinity risk assessment methodologies

Hazard
Property of a threat having the potential to cause unfavourable effects.

Vulnerability
Liability to injury or damage.

Risk
The probability of an unfavourable effect in a system by exposure to a threat.

Zoning
The division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential salinity susceptibility, hazard or risk.

Risk assessment
A process to calculate or estimate the risk to a system, following exposure to a particular threat.

Elements at risk
Economic activities and environmental features in an area, potentially affected by the salinity hazard.

EU European Union
GIS Geographical Information System
RAM Risk Assessment Methodology
RS Remote Sensing

Abstract

The objective of the RAMSOIL project is to provide scientific guidelines for EU wide parameter harmonization concerning Risk Assessment Methodologies for soil threats. This report focuses specifically on the soil threat salinity.

Policy summary

A first analysis of risk assessment methodologies (RAMs) for salinization over the EU 25 reveals that most countries affected by the problem do not have official methodology and some countries do not have any methodology at all. We received rather few questionnaires. Only Hungary has an official recognized assessment. Slovakia and Spain has a RAM used by scientists. Greece and Cyprus provided information about the RAM that they would prefer. However, salt-affected soils occur in Bulgaria, Cyprus, France, Greece, Hungary, Italy, Romania and Slovakia (figure 1) that did not respond. We got information about more RAMs from scientific papers.

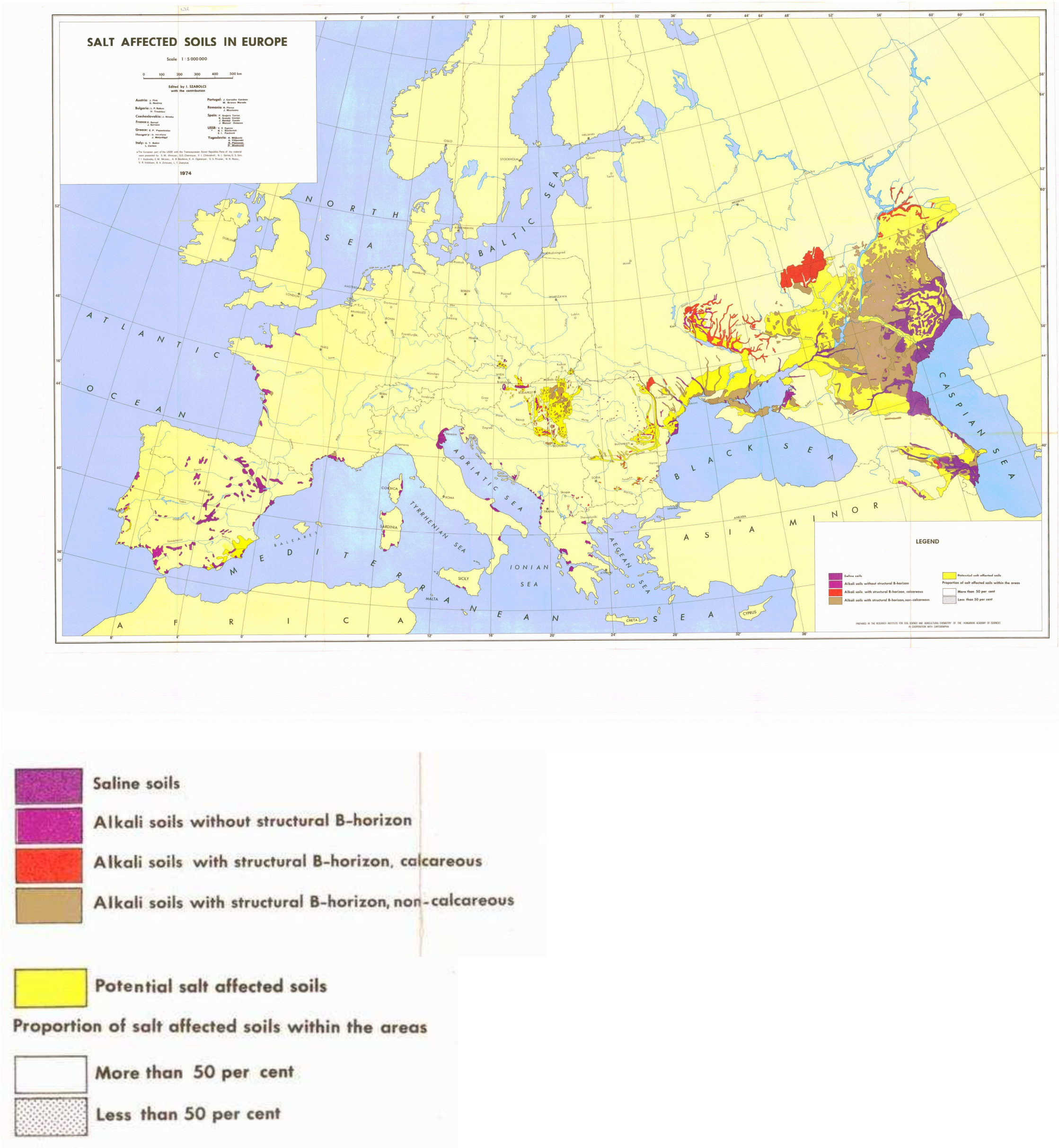


Figure 1: Map of salt-affected soil in Europe.

Contents

Introduction: salinity causes and salinity impacts

Salt Affected Soils (SAS)

The threat of soil salinization has been recognized since long ago. In particular during the last 5 decades, much research has been conducted in relation with Salt Affected Soils (SAS). Salt Affected Soils (SAS) are soils for which the influence of common cat- and anions dominates with regards to physical, chemical, and biological properties. The basic problem encountered with SAS is that the balance between the inputs and outputs of salts is upset, leading to an increase of generally soluble salts or leading to an improper composition of salts in soil. With salt, we refer to naturally occurring compounds that as such are not regarded as contaminants. Commonly, salinity involves the alkali and earth alkali cations and anions such as chloride, sulphate, and (bi) carbonates.

Problems for plant and soil

The basic problems associated with salinization may be diverse. A rather direct effect is that increasing salinity leads to higher osmotic values of soil water, which is considered to contribute to water stress of plants. In that case, the crop or vegetation is unable to extract the available water. The osmotic pressure, which can be added to the pressure that roots have to establish to extract water from soil (Koorevaar et al , 1983) can be calculated with Van 't Hoff law.

In addition, the special case of sodium (Na) warrants mentioning. Upon an imbalance of the ratio of monovalent compared with higher-valent cations, the structural stability of soil and soil organic matter may be adversely affected. In particular cases, this may lead to (an almost irreversible) deterioration of soil structure, making land unsuitable for crops and limiting the composition of natural vegetations, besides altering the regional hydrological system. The SAS that are affected by the ratio between monovalent and divalent cations are also referred to as sodic or alkali soils.
Also the composition of salts affects plant well-being, as an unbalanced composition may cause toxicity effects for plants, or inhibited nutrient uptake of essential elements.

Futhermore, if the ions are reactive, the pH may change which commonly causes changes in the chemistry of ions in aqueous solutions and which may have direct and indirect effects such as induced toxicity, nutrient deficiency, etc.

Cause

Salinity/sodicity problems are caused by an imbalance in the quantity or composition or a combination thereof, of the salts entering soil. In most cases, the salt accumulation derives from two sources:

- Infiltrating water (from rainfall, or irrigation water such as river water, pumped-up water)
- Capillary rise water (from relatively shallow ground water)

Basically, the problem concerns the net input of salts or particular salts into the soil profile (such as soil surface and rhizosphere), compared to the elimination of these compounds due to leaching.

SAS-formation is not only by natural causes but to a significant extent due to improper water management. The source of primary salinization originates from natural weathering of minerals or from fossil salt deposits and connate water originating from ancient seas . The source of secondary salinization is human-induced sources such as irrigation, municipal runoff or water treatment. The effects of poor drainage, concentration of indigenous salts, and elevated water table tend to exacerbate these problems by moving these salts into the root zone and potentially to the surface.

The predominant mechanism causing the accumulation of salt in irrigated agricultural soils is evapotranspiration, which concentrates salts in the remaining soil water (Corwin et al., 2007). This happens mostly in arid and semi-arid regions. Here water supply is often the growth limiting factor. In case irrigation water is sufficiently available, this does not assure that no salt accumulation occurs.

The hazard of SAS-formation, and the problem of SAS remediation may differ regionally quite significantly, due to differences in

- Sources and quality of rainfall and irrigation water
- The evaportranspiration demand of crops and vegetation
- The quality and proximity to the soil surface of ground water
- Soil textural and mineral composition
- Temporal and seasonal variations in soil dessication
- Managed or natural leaching of salts towards drainage infrastructure or groundwater.

Management

Once the areas with high salinity risk are known the main question arises how to manage these soils. Wrong management results into an increase in saline areas (secondary salinity). Within the RAMs management is not included although this aspect can becomes more important once the areas are not in direct risk, but might become in the long term.

There are three ways to manage saline soils. First salts can be moved below the root zone by applying more water than the plant needs. This method is commonly based on the leaching requirement concept. The second method, where soil moisture conditions dictate, combines the leaching requirement with artificial drainage. Third, salts can be moved away from the root zone to locations in the soil, other than below the root zone where they are not harmful. This third method is called managed accumulation.

One important thing to keep in mind with regard to soil treatment: Saline soils cannot be reclaimed by chemical amendments, conditioners or fertilizers.

Different classification systems exist, which often differ between different nations. Salt-affected soils are traditionally divided into three broad categories depending on the extend to which they are saline or sodic (also called alkali) (Richards, 1954). These categories are based upon the electrical conductivity of the saturation paste (ECe), exchangeable sodium percentage (ESP), and pH (Richards, 1954). A different approach is necessary to reclaim each category.

Stakeholders

The problem of SAS involves in principle many different stakeholders. Prominent stakeholders are farmers, whose crop and land may be affected, irrigation/water authorities, that must take precautionary or remedial action, but also stakeholders that are involved in the broader management of land use, such as concerning ecosystem services, tourism, etcetera.

Due to such differences, as well as due to differences on a regional or even national scale in salinity awareness of various stakeholders, soil salinity is a regionally different problem. However, the problem may exhibit on national scales, if central authorities are unaware of present or potential problems.

Salinity risk assessment methodologies

Introduction

This chapter provides a general overview of the different types of scientifically acknowledged soil salinity risk assessment methods found in literature and those obtained from the questionnaires.

Different countries use various methodologies for risk assessment, as local circumstances vary (soil, climate, political framework), differing interests of countries, similar problems may have varying causes or comparable problems may be approached differently by each country. As a consequence, numerous RAMs have evolved and are in use, and are far from the aspect of harmonization. However, one can take advantage and learn from each other's experiences, harmonizing best parameters and approaches. It must be noted that there does not exist such a thing as the best RAM for salinity, since conditions differ from location to location, nevertheless common and specific aspects can be explored for each individual situation.

A first step in risk assessment involves general identification of the threat and areas at risk, derived from existing data. Subsequently, within the delineated zones, specific locations with high salinity risks have to be identified, preferably using process-based models at high resolutions (Eckelmann et al, 2006). The other areas are taken out of the scope. Eckelmann et al (2006) named this procedure the tiered approach, where tiers refer to the different levels of scale and related level of information detail.

Generally, three types of approaches exist to identify areas at risk (Eckelmann et al, 2006):

1. Qualitative approach, using expert knowledge to evaluate important processes, formulate criteria and discover (local) areas at risk.
2. Quantitative approach, based on measured data, providing relative comparisons regarding baselines and thresholds.
3. Model approach, using models to predict the extent of soil degradation, taking local conditions into account. This approach enables assessment of trends by scenario analysis.

The information needed to assess salinity risk depends on the approach taken.
However, there is no strict separation between the approaches, since integration of methods is sometimes desirable and/or necessary. Modeling, for example, requires model validation and calibration, which involves quantitative measures. Moreover, models can help in up-scaling results obtained from qualitative and/or quantitative approaches.

In a broad sense, SAS-RAMs are commonly based on meaningful indicators of soil and water quality. Such indicators have been developed to assess whether or not a soil is salt affected and whether or not a soil is potentially salt affected. The underlying complexity of such indicators is, however, quite different for different situations. A major distinction is that between soils threatened by the level of salt accumulation and those that are threatened particularly by the composition of accumulating salts. The first 7 of the following RAMs have been developed several decades ago and are well summarized in USDA Salinity Handbook 60 (Richards, 1954).

Overview of salinity RAMs in the literature

RAM 1: Water composition EC

As salts are derived from irrigation/atmospheric water or ground water, it is common to determine the quality of such water for a first assessment of the hazard of salinization. Regarding the hazard of too large overall salt concentrations, use is made of the 1:1 relationship between salinity concentration and electrical conductivity EC (in mS/cm). To this purpose, the EC is classified in different classes with regard to salinity hazard. An important classification is that of USDA Salinity Laboratory (Richards, 1954), that is still commonly used.

Table 1: Classification of the electrical conductivity or irrigation water with regard to the hazard of adverse salinity effects.

EC (mS/cm)	Salinity hazard
0-0.25	Low; water use is safe
0.25-0.75	Medium; water quality is marginal
0.75-2.25	High; water unsuitable for use
>2.25	Very high

RAM 2: Soil water composition ECe

An indicator that directly refers to whether a soil must be considered to be saline or not, is based on the electrical conductivity of the saturated soil paste. The procedure is comparable to the RAM 1 approach, but involves a soil paste at water-lubrication level and intrinsically involves an expert judgement regarding crop vulnerability.

Table 2: Classification of electrical conductivity of soil saturated paste with regard to salinity effects.

ECe (mS/cm)	Class	Effect
0-2	Non saline	Negligible
2-4	Mildly saline	Yield reduction of sensitive crops
4-8	Medium saline	Yield reduction for many crops
8-12	Very saline	Normal yields for salt tolerant crops only
>16	Extremely saline	Reasonable crop yield for very tolerant crops only

RAM 3: Crop vulnerability

It has been recognized early that crops have a different vulnerability for soil salinity. For this purpose, the RAM 2 has been related to a classification for different crops.

Table 3: Vulnerability of different crops for salt damage.

ECe (mS/cm)	Crop
2-4	Clover
3-4	Bean, sellery, radish
4-10	Flax, maize/corn, oats, wheat, rye, cucumber, peas, onions, carrots, potato, lettuce, cauliflower, cabbage, tomato
10-12	Spinach, asparagus, cabbage flower, red beet
10-16	Rape, sugar beet, barley

RAM 4: Leaching Requirement

To assess the salinity hazard of soils, EC (RAM 1) has been used worldwide. However, the relationship between EC and ECe is not so concrete, that it is apparent which ECe will develop if water enters soil with a particular EC. In principle, it is quite easy to develop an equation that does relate these two RAMs, and this relationship is commonly known as the Leaching Requirement (LR). Leaching requirement can be defined as the fraction of infiltrated water

that must pass through the root zone to keep soil salinity from exceeding level that would significantly reduce crop yield under steady-state conditions with associated good management and uniformity of leaching.
This concept can be formulated in terms of easily measurable properties, such as the water content of soil at field capacity and in the saturated paste, which are quite robust measures. Hence, also LR is quite a robust RAM for soil salinization.

$$LR = \frac{D_{DW}}{D_{IW}} \approx \frac{w_{FC}}{w_{SP}} . \frac{EC_{IW}}{EC_e^*}$$

Where *D* denotes an amount of water (mm/year), *w* stands for water content by weight, and *EC* is the electrical conductivity. Subscript *DW*, *IW*, *FC*, and *SP* denote drainage water, irrigation water, field capacity of soil, and saturated paste, respectively. Finally, the asterisk denotes that the electrical conductivity of the saturated paste may not exceed this particular value.

The leaching requirement is a measure for the seriousness of possible salinization. The level at which salinity becomes constant on the long term. Leaching requirement quantifies the minimal fraction of applied irrigation water that has to drain from the root zone to limit the salinity level.

The leaching requirement equation has found widespread use in attempts to regulate and constrain the salt content of soils. However, it also turned out that its use does not always ascertain the required effect. One major reason it that the spatial variability of many soil processes and soil properties has not been taken into account in this equation. Another main cause that the leaching requirement does not work out well is heterogeneity. One way to account for such severe causes of hydrodynamic dispersion is to introduce a “leaching efficiency factor”.

RAM 5: ESP

As has been mentioned, the hazard of salinization is not the same as the hazard of an imbalance of salt composition. In particular, the ratio of monovalent (Na, K) and divalent (Ca, Mg) cations is important in this respect. To assess the hazard of structural instability of soil, a new concept has been derived, called the Exchangeable Sodium Percentage or ESP (of the soil exchange complex, CEC). The ESP quantifies the relative abundancy of Na (mainly) compared with divalent cations, at the exchange complex, and gives a direct impression of the hazard for structural instability, for soils that are vulnerable to that issue.

$$ESP = \frac{\gamma_{Na}}{\gamma_T} .100\%$$

Where *y* refers to the exchangeable quantity of cations (subscripts are *Na* for sodium, and *T* for the total cation exchange capacity). If ESP exceeds 15%, a soil is called sodic (in Australia, this is already the case if ESP exceeds 8%).

RAM 6: ESP/EC

Taking into account RAM 4 and RAM 5, it is relatively easy to expand RAM 4 into a concept to assess the sodicity hazard of soil. Omitting the derivation, we can approximate the resulting *ESP* using the concept of *SAR* (Sodium Adsorption Ratio of irrigation water) by

$$\frac{ESP}{100-ESP}=0.015.SAR_{IW}\cdot\left[\frac{w_{FC}}{w_F}\cdot\frac{D_{IW}}{D_{DW}}\right]^{0.5}$$

If we assume that soil has a minimum water content, immediately prior to irrigation of w_F. Comparison with the definition of the Leaching Requirement reveals that the latter equation is proportional with $LR^{-0.5}$. Hence, the Leaching Requirement can be expressed in terms of the electrical conductivity (to limit the salinity of soil) as well as the exchangeable sodium percentage (to limit sodicity), whichever hazard is the most prominent.

RAM 7a: ECe, and ESP, or SAR

The USDA Soil Salinity Laboratory (Richards, 1954) has developed a widely adopted salinity classification system that considers the total salt level estimated from the electrical conductivity of the saturation extract (ECe), expressed in dS/cm at 25 degrees C temperature, and the exchangeable sodium present (ESP) or sodium adsorption ratio (SAR) to classify among saline, saline-alkaline and alkaline soils, and different degrees of them.

Table 4

Soil type	Soil property SAR	ESP	pH	ECe (mS/cm)
Non saline, non alkaline	< 13	< 15	< 8.5	< 4
Saline	< 13	< 15	< 8.5	> 4
Alkaline	> 13	> 15	> 8.5	< 4
Saline - alkaline	> 13	> 15	> 8.5	> 4

RAM 7b: ECe, ESP and pH

Salt-affected soils are traditionally divided into three broad categories depending on the extend to which they are saline or sodic (also called alkali) (Richards, 1954). These categories are based upon the electrical conductivity of the saturation paste (ECe), exchangeable sodium percentage (ESP), and pH (Richards, 1954). These categories are defined as: (i) saline, (ii) saline-sodic, (iii) sodic. A different approach is necessary to reclaim each category.

Table 5

Class	ECe (mS/cm)	ESP (%)	pH
Saline	> 4	< 15	< 8.5
Saline-Sodic	> 4	> 15	< 8.5
Sodic	> 4	> 15	> 8.5

RAM 8: Type of anion

The system from RAM 7 makes no distinction between ion types that enable to differentiate harmful from harmless salts, unlike the classification system based on anion types developed by Russian soil scientists (Plyusnin, 1964) (Table 5). In this approach, salt-affected soils are classified on the basis of salt types, in terms of chloride, sulphate and carbonate anion ratios present in the soil saturation extract. As not all salts are equally harmful, and so require different reclamation and management measures, it is of value to know the spatial distribution of salt-affected soils and their composition. The World Reference Base for Soil Resources also follows an approach based upon anion assemblages, distinguishing six facies of salt affected soils (Spaargaren, 1994). (Source: Metternicht, 2003)

Table 6: Harmful (above the line) and harmless (below the line) salts (Plyusnin, 1964).

NaCl	Na_2SO_4	Na_2CO_3	$NaHCO_3$
$MgCl_2$	$MgSO_4$	$MgCO_3$	$Mg(HCO_3)_2$
$CaCl_2$	$CaSO_4$	$CaCO_3$	$Ca(HCO3)_2$

Table 7: The World Reference Base for Soil Resources salinity approach upon anion assemblages (Spaargaren, 1994).

Soil type	Facie	Characteristics
Chloride soils	Acid chloride soils	Cl >> SO_4 > HCO_3, and Na >> Ca
	Neutral chloride-sulphate soils	Nearly neutral pH
Sulphate soils	Neutral sulphate soils	Nearly neutral pH, Na >> Ca, and SO_4 >> HCO_3 > Cl
	Acid sulphate soils	Very low pH (< 3.5)
Carbonate soils	Alkaline bicarbonate-sulphate soils	pH > 8.5, HCO_3 > SO_4 >> Cl, and Na > Ca
	Strongly alkaline soils	pH > 10, HCO_3 >> SO_4 >> Cl, and Na >> Ca

RAM 9: Classification of two soil types

Classifications for distinguishing them. Two main groups: the Solonchak, the soils where large quantities are found, and Solobetz, the soils where the cation balance is unfavorable as particular Na (sodium) is abundantly present and divalent Ca en Mg are poorly present, which affects structure stability

Overview of salinity RAMs in the EU25 member states

A questionnaire has been sent to several researchers and policy makers within EU25 member states in order to proceed to an inventory of methodologies used for assessing salinization risks. The aim of the questionnaire is to examine the current situation of methodologies for salinization risk assessments and to assess its pros and cons, in order to unravel for what reasons an EU member state uses a specific kind of risk assessment methodology.

The questionnaire consisted of 7 main questions about RAMs for salinization. The main topics regarded the questions:

- General information: if the country has a risk assessment methodology at present or in development and if yes, how long has it already been in use. We asked for references and/or weblinks about the RAM.
- Data used in the RAM: we offered possibilities to indicate if the RAM uses that factor (soil typological units, irrigation characteristics, climate, soil characteristics, groundwater information, pedotransfer functions, soil hydraulic properties, land use).
- Description of the RAM: these questions allowed to evaluate the relations with policy, the sensitivity, the type of methodology and used techniques, the data quality, availability and time resolution, the geographical coverage of their work.
- Output documents of the RAM: these questions allowed to describe the output type, scale and comprehensibility.

We received filled questionnaires from five countries. There are salinity RAMs in use in Hungary, Slovakia and Spain. Only Hungary has an official recognized assessment. Slovakia and Spain has a RAM used by scientists. Greece and Cyprus do not have an implemented RAM, but they provided information about their preferred RAM.

Table 8: Overview of salinity RAMs.

Name	Type	Parameters	Country	Reference
RAM of Cyprus	Quantitative-process based-model, expert analysis	-Irrigation water quality and sodicity -Soil profile description -soil salinity in different layers -Soil moisture balance -Soil texture in different layers -pH in different layers -soil calcium carbonate content -SOM levels - Groundwater depth (fluctuation) Groundwater salinity Groundwater sodicity Groundwater composition	Cyprus	Calcareous Soils of Cyprus (Cypriot- German Geological and Pedological Project, BGR)
Tisza irrigation project evaluation	Quantitative -process-based	-Soil typological unit -Soil processes -Soil salinity in different layers	Hungary	Szabolcs, I., Várallyay, Gy., Darab, K., 1976. Soil and hydraulic survey for the prognosis and monitoring of salinity and alkalinity. In: Prognosis of Salinity and Alkalianity. Report of an Expert Consultation, Rome, 3-5 June, 1975. Soil Bulletin No. 31. 119–129. FAO. Rome.

		-Soil moisture balance -pH in different layers -Soil hydraulic properties -Groundwater depth and fluctuation -Groundwater salinity -Groundwater sodicity -Groundwater composition -Height of the water table above a reference level -Horizontal flow of groundwater -sources of groundwater supply -Evaluation of groundwater as a potential irrigation water -Surface water conditions		
TIM evaluation	Quantitative - Expert anaylysis	Climate Soil pH Soil salinity	Hungary	1. Kovács, D., T. Tóth, and P. Marth. 2006. Soil Salinity between 1992 and 2000 in Hungary. http://www.taki.iif.hu/english/soilsci/toth/abstr/KTM2006_2_FULL.pdfAgrokémia

	based on temporal changes of monitored data	Groundwater depth		és Talajtan. 55: 89-98. 2. Várallyay, Gy. (2005) Soil Survey and Soil Monitoring in Hungary. In: Jones R.J.A., Houshkova B., Bullock P., Montanarella L. Soil Resources of Europe (2nd edition) EC JRC, Ispra. 420 pp.
Salt accumulation processes and artificial drainage	Quantitative - expert analysis	Climate Soil texture Groundwater depth Groundwater salinity Groundwater composition Irrigation water quality	Romania	Florea N. Geochimia si valorificarea apelor din Cimpia Romana de nord-est. Editura Academiei Republicii Socialiste Romania. 1976. 201 p.
Expert-based RAM of Slovakia	Qualitative - Expert-based	-climate -Soil profile description -soil salinity in different layers -soil sodicity in different layers -Soil moisture balance -Soil texture in different layers -pH in different layers -soil calcium carbonate content -SOM levels -Groundwater	Slovakia	-

		depth (fluctuation) -Groundwater salinity -Groundwater sodicity -Groundwater composition -Crop systems		
Integration of two simple models in a GIS to evaluate salinization risk in irrigated land in Valencia	Quantitative -process-based Qualitative-weighting-rating	Chemical additions Irrigation water quatity -climate Soil drainage soil salinity in different layers Soil moisture balance Soil texture in different layers -pH in different layers -soil calcium carbonate content -SOM levels Groundwater depth (fluctuation) Groundwater salinity Groundwater	Spain	De Paz, J.M., Visconti, F., Zapata, R. & Sánchez, J. (2004). The Use of Two Logical Models Integrated in a GIS to Evaluate the Soil Salinization in the Irrigation Land of Valencian Community (Spain). *Soil Use and Management*, 20: 333-342.

		composition Soil hydraulic properties Land use: Conventional or organic; with or without desalinization organic compounds, crop systems		

RAM of Cyprus

Table 9: Overview questionnaire Cyprus.

Country		Cyprus
Aim		Vulnerability and risk mapping
Performing institution		Government, Department of Agriculture
Methodology		Quantitative- process based-model, expert analysis
	Data	Soil texture, chemical properties of irrigation water, climate, soil characteristics, groundwater information
	Techniques	Field observations and laboratory analysis
	Application scale	1:25000
Documents		Vulnerability zone map Risk zone map
Comments		The available data derive from previous projects and studies.
Website		Not available
Literature		Calcareous Soils of Cyprus (Cypriot- German Geological and Pedological Project, BGR)
Resolution	Spatial	1:25000
	Temporal	The time interval depends on the sort of data
Data requirements		
Use of models & calibration/validation data		
Existing data & scale		Only case studies
Sensitivity		
Estimated results		

RAM of Greece

Table 10: Overview questionnaire Greece.

Country		Greece
Aim		Vulnerability mapping
Performing institution		Soil Science Institute of Athens (National Agricultural Research Foundation)
Methodology		Qualitative expert based, Quantitative empirical model, Expert analysis
	Data	Soil typological unit (STU) (soil type), chemical properties of irrigation water, climate, soil characteristics, groundwater information, pedotransfer functions, soil hydraulic properties, land use, simulation model
	Techniques	Field observations and laboratory analysis
	Application scale	1:5000
Documents		Vulnerability zone map
Comments		RAM for salinization in Greece can be based on parameters such as topography, soil texture, hydrogeology, ground water level and quality, water usage, distance from the sea and balance of rainfall vs. evapotranspiration. Direct measurements of soil electrical conductivity either in the field or in the lab might be an acceptable approach.
Website		http://www.science.org.au/nova/032/032sit.htm http://www.kcl.ac.uk/projects/desertlinks http://www.ciseau.org/index.jsp http://www.fao.org/ag/agl/aglw/aquastat/regions/neast/index9.stm
Literature		
Resolution	Spatial	1:5000
	Temporal	Once every 5-10 years
Data requirements		Direct measurements of a state/trend
Use of models & calibration/validation data		
Existing data & scale		Only case studies
Sensitivity		Fast, immediate response
Estimated results		

Hungarian RAMs

Table 11: Overview questionnaire Hungary.

Country		Hungary
Aim		Hazard mapping, vulnerability mapping, risk mapping
Performing institution		Research Institute for Soil Science and Agricultural Chemistry (RISSAC) of the Hungarian Academy of Sciences
Methodology		Qualitative expert-based, Quantitative empirical model, Quantitative process based-model, Expert analysis, Historical documents
	Data	Soil typological unit (STU) (soil type), soil texture (STU level), chemical properties of irrigation water, soil characteristics, groundwater information, soil hydraulic properties, land use, spatial soil information
	Techniques	Field observations, geographical information systems, and laboratory analysis
	Application scale	1:10000
Documents		Hazard zone map Vulnerability zone map Risk zone map
Comments		xx
Website		xx
Literature		G. Várallyay, G. Tóth, T. Tóth, 2006. Salinisation/Sodification. Identifying Risk Area for Soil Degradation in Europe by Salinisation/Sodification. In: W. Eckelmann, R. Baritz, S. Bialousz, P. Bielek, F. Carré, B. Houskova,, R. J. A. Jones, M. Kibblewhite, J. Kozak, Ch. Le Bas, G. Tóth, T. Tóth, Gy. Várallyay, M. Yli Halla, M. Zupan: Common Criteria for Risk Area Indentification according to Soil Threats. 43-59. Euroepean Soil Bureau Research Report No. 20. JRC. Ispra. Szabolcs, I., Várallyay, Gy., Darab, K., 1976. Soil and hydraulic survey for the prognosis and monitoring of salinity and alkalinity. In: Prognosis of Salinity and Alkalianity. Report of an Expert Consultation, Rome, 3–5 June, 1975. Soil Bulletin No. 31. 119–129. FAO. Rome. Várallyay, Gy., Szücs, L., Zilahy, P., Rajkai, K., Murányi, A. 1985. Soil factors determining the agroecological potential of Hungary. Agrokémia és Talajtan. 34. Suppl. 90–94.
Resolution	Spatial	1:10000
	Temporal	Annually, once every 1-5 years or once every 5-10 years: Depending on the changeability of parameters
Data requirements		Direct measurements of a state/trend

Use of models &	
Existing data & scale	National and regional
Sensitivity	Fast, immediate response
Estimated results	

The questionnaire from Hungary (table 11) can be divided into two RAMs.

1. One of them is the evaluation of the Tisza River irrigation project (Szabolcs et al., 1976) (table 12). It is a quantitative process-based RAM. It takes into account the soil typological unit, soil processes, soil and hydrological characteristics. It includes the survey of salinity and alkalinity status of soils and potential factors of salinization and alkalinization processes. For the estimation of the actual status soil salinity, alkalinity and pH in different layers, general salt balances and exchangeable sodium status are suggested to determine. The potential factors are determined by measuring hydrological conditions, salinity and alkalinity status of deeper soil horizons or geological layers and factorial salt balances. Hydrological characteristics consist of groundwater and surface water conditions. It gives a salt balance equation. The suggested scale of this RAM is 1: 100 000, 1: 200 000, 1: 500 000 or similar. An example map created for the eastern part of the Hungarian Plain is given in figure 2.

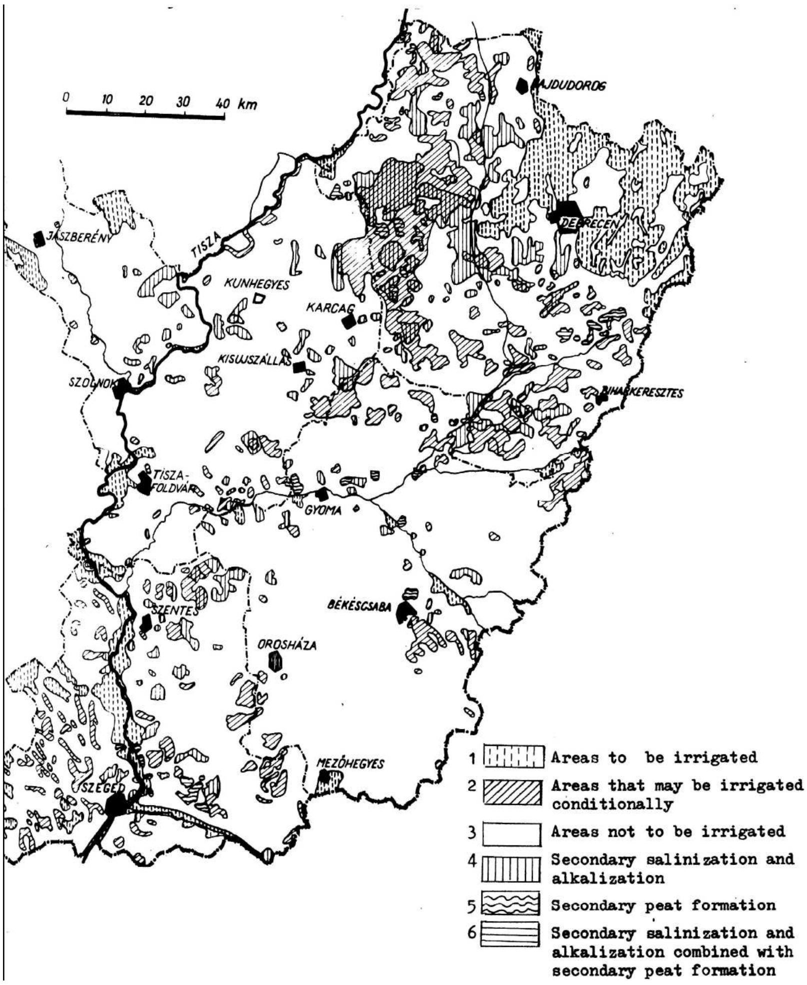


Figure 2: Example map created for the eastern part of the Hungarian Plain.

Table 12: Overview Tisza River irrigation project.

Country		Hungary (Tisza irrigation project evaluation)
Aim		Hazard mapping, risk mapping
Performing institution		Research Institute for Soil Science and Agricultural Chemistry (RISSAC) of the Hungarian Academy of Sciences
Methodology		Quantitative process based-model
	Data	Soil typological unit (STU) (soil type), soil texture (STU level), chemical properties of irrigation water, soil characteristics, groundwater information, soil hydraulic properties, land use, spatial soil information
	Techniques	Field observations, geographical information systems, and laboratory analysis
	Application scale	1:25000
Documents		Hazard zone map Risk zone map
Comments		xx
Website		xx
Literature		Szabolcs, I., Várallyay, Gy., Darab, K., 1976. Soil and hydraulic survey for the prognosis and monitoring of salinity and alkalinity. In: Prognosis of Salinity and Alkalianity. Report of an Expert Consultation, Rome, 3–5 June, 1975. Soil Bulletin No. 31. 119–129. FAO. Rome.
Resolution	Spatial	1:25000
	Temporal	Annually, once every 1-5 years or once every 5-10 years: Depending on the changeability of parameters
Data requirements		Direct measurements of a state/trend
Use of models &		
Existing data & scale		Regional
Sensitivity		Fast, immediate response

2. The other Hungarian RAM is the evaluation of TIM (Soil Protection Information and Monitoring System) (table 13), a quantitative expert analysis based on temporal changes of monitored data. So it is a RAM based on an existing monitoring system. Field observation and laboratory analysis are involved in the RAM. The monitored data consist of climate, soil pH and salinity and groundwater depth. The time resolution of sampling is 1, 3 or 6 years, depending on the soil type and factor. Geographically it covers the whole country representing all the regions and soil types. The database is not easily accessible, but for scientific purposes it is possible to acquire. The output document is risk zone map and elements at risk with a scale of 1: 1,000,000. The system has 1236 points for the 93 000 km^2 of Hungary. The method uses correspondence analyses between the pattern of groundwater depth and soil salinity. Conclusions are made based on the detected changes.

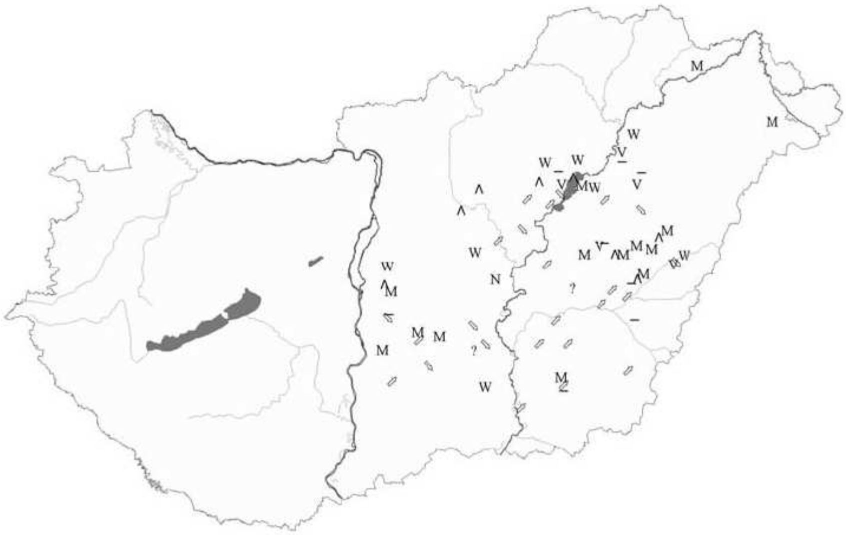


Figure 3: The distribution of the different patterns of yearly soil salinity changes.

Table 13: Overview TIM (Soil Protection Information and Monitoring System).

Country			Hungary (TIM evaluation)
Aim			Hazard mapping (monitoring)
Performing institution			Hungarian Soil Conservation Service
Methodology			Quantitative process based-model
	Data		Climate Soil pH Soil salinity Groundwater depth
	Techniques		Field observations, laboratory analysis
	Application scale		1236/93.000km2
Documents			Kovács et al., 2006
Comments			
Website			http://www.taki.iif.hu/english/soilsci/toth/abstr/KTM2006_2_FULL.pdf
Resolution		Spatial	1: 1 000 000
		Temporal	annually
Data requirements			Direct measurements of a state
Use of models & calibration/validation data			
Existing data & scale			National
Sensitivity			Fast, immediate response

RAM of Romania

Romania did not answer to the questionnaire. The Romanian RAM is described here based on Florea (1976).

The Romanian RAM (Florea, 1976) is a quantitative expert analysis method. It considers climate, soil texture, groundwater depth, salinity and composition, and irrigation water quality. It based on directly measured database. It uses field observation and laboratory analysis methods. It focuses on salt accumulation processes and gives the possibilities and principles for artificial drainage to avoid the risk of salinization. It is developed for the North-Eastern Romanian Lower Danube Plain.

RAM of Slovakia

The *Slovakian RAM* has been in use for 14 years (table 14). It is a qualitative weighting-rating system based on direct measurements with annually data collection and remote sensing. It considers climate. The following soil characteristics are used in it: soil profile description, soil texture, pH, soil salinity and sodicity in different layers, soil moisture balance, soil calcium carbonate content and SOM levels. The groundwater properties are also taken into account (depth, salinity, sodicity and composition). The RAM considers crop systems as land use. It is used for monitoring purposes. It has a geographical coverage for the whole country. Database is accessible for scientific purposes. Output documents are composed of elements at risk. The scale was not indicated and there was not any references given.

Table 14: Overview questionnaire Slovakia.

Country		Slovakia
Aim		
Performing institution		Soil Science and Conservation Research Institute
Methodology		Qualitative expert-based
	Data	Soil typological unit (STU) (soil type), soil texture (STU level), climate, soil characteristics, groundwater information, pedotransfer functions, soil hydraulic properties, land use
	Techniques	Remote sensing
	Application scale	
Documents		Elements at risk
Comments		
Website		
Resolution	Spatial	
	Temporal	Annually
Data requirements		Direct measurements of a state/trend
Use of models & calibration/validation data		
Existing data & scale		National
Sensitivity		Don’t know
Estimated results		

RAM of Spain

The *RAM of Spain* (De Paz et al., 2004) is a process-based model (table 15). It uses the following soil information: soil type, soil texture, soil drainage, soil salinity in different layers, Soil moisture balance, soil hydraulic properties, pH in different layers, soil calcium carbonate content, SOM levels. It considers the groundwater depth (fluctuation), salinity and composition. Land use information is used: it distinguishes conventional and organic land use; management with and without desalinization organic compounds, and different crop systems. It takes into account the irrigation water quality and also climate. It is based on direct measurements and modeling. It is not used yet for monitoring purposes but it is planned. Spain does not have a national system; there are only case studies for salinity risk assessment. Field observation, GIS and laboratory analysis are also used in the RAM. They have regular data source for the implementation. For now, there are data for two years in time resolution of four periods plus irrigation periods and after heavy rain events per year. They are planning to make the database accessible for the general public in three years. The outputs are risk zone maps and susceptibility maps with regional scale.

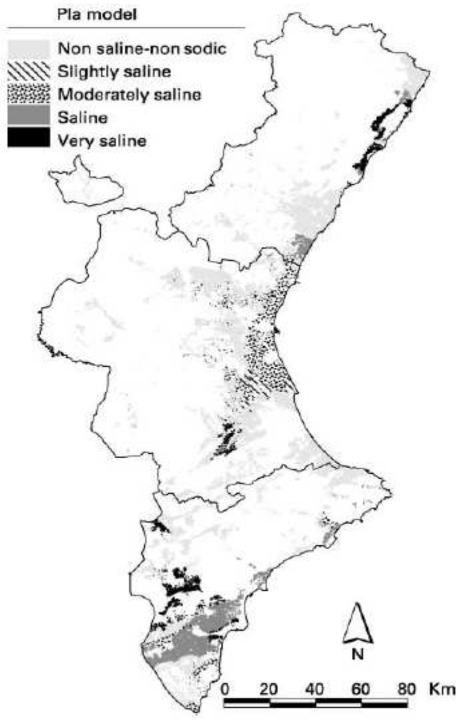


Figure 4: Location of the soil samples used for the model validation (at the left) and map of the salinity predictions obtained by applying the Pla model for Valencia (at the right)
(De Paz et al., 2004).

Table 15: Overview questionnaire Spain.

Country		Spain
Aim		Risk mapping
Performing institution		Desertification Research Centre
Methodology		Quantitative – process based model Qualitative – weighting-rating
	Data	Soil typological unit (STU) (soil type), soil texture (STU level), chemical properties of irrigation water, climate, soil characteristics, groundwater information, pedotransfer functions, soil hydraulic properties, land use, spatial soil information
	Techniques	Using three base maps (drainage map, climate classification map, and irrigation water quality map) in GIS program. Field observations, geographical information systems, and laboratory analysis
	Application scale	Regional (1:?)
Documents		Risk zone map
Comments		
Website		xx
Literature		De Paz, J.M., Visconti, F., Zapata, R. & Sánchez, J. (2004). The Use of Two Logical Models Integrated in a GIS to Evaluate the Soil Salinization in the Irrigation Land of Valencian Community (Spain). Soil Use and Management, 20: 333-342.
Resolution	Spatial	Regional (1:?)
	Temporal	At the moment 2 years data in four period/year+irrigation periods+after intense rain events
Data requirements		Modelled and direct measurements of a state/trend
Use of models & calibration/validation data		
Existing data & scale		Only case studies
Sensitivity		Intermediate response
Estimated results		

Comparison of the RAMs

The RAMs have been compared according to 5 indicators (RAM Scale, RAM Transparency, RAM Complexity, RAM Cost efficiency and RAM Ambiguousness) which are defined in Table 16. With these 5 indicators a spider web can be constructed.

Table 16: Definition of the scientific indicators to compare the RAMs.

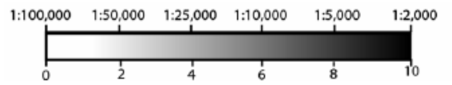
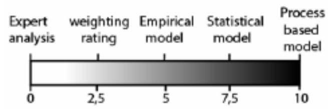
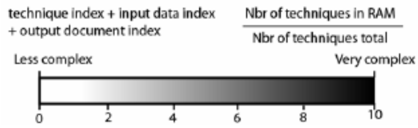
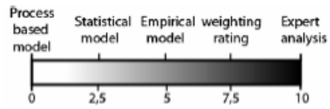
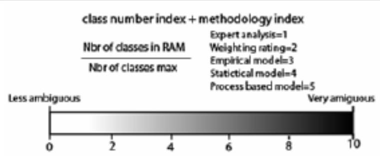
Indicators	Definition	Coding value / indicator
Scale	This indicator is linked to the availability of documents and the scale of the maps to be produced.	
Transparency	It corresponds to the transparency of the human thought and so it depends of the experience of the expert in charge of the assessment. This indicator reveals the applicability of the methodology.	
Complexity	The complexity of the methodology is linked to the processing of the input data and the number of output information. The more input data are used, the more complex is the methodology.	
Cost efficiency	This indicator presents the profitability of the methodology in terms of means and costs to achieve the objective.	
Ambiguousness	This indicator represents the uncertainty in the delineation of hazard and risk zones.	

Table 17: The scientific indicators for questionnaire Cyprus.

Country		Cyprus
Methodology		Quantitative- process based-model, expert analysis
	Techniques	Field observations and laboratory analysis
	Application scale	1:25000
Documents		Vulnerability zone map Risk zone map
Scale		1:25000: 3/6
Transparency		Quantitative- process based-model (5), expert analysis (1): 3/5
Complexity		No. of techniques: 2 Total no. of techniques: 4
Cost efficiency		Quantitative- process based-model (1), expert analysis (5): 3/5
Ambiguousness		No. of classes in RAM: 2 Total no. of classes: 6

Table 18: The scientific indicators for questionnaire Greece.

Country		Greece
Methodology		Qualitative expert based, Quantitative empirical model, Expert analysis
	Techniques	Field observations and laboratory analysis
	Application scale	1:5000
Documents		Vulnerability zone map
Scale		1:5000: 5/6
Transparency		Qualitative expert based, Quantitative empirical model (3), Expert analysis (1): 2/5
Complexity		No. of techniques: 2 Total no. of techniques: 4
Cost efficiency		Qualitative expert based, Quantitative empirical model (3), Expert analysis (5): 4/5
Ambiguousness		No. of classes in RAM: 1 Total no. of classes: 6

Table 19: The scientific indicators for questionnaire Hungary.

Country		Hungary
Methodology		Qualitative expert-based, Quantitative empirical model, Quantitative process based-model, Expert analysis, Historical documents
	Techniques	Field observations, geographical information systems, and laboratory analysis
	Application scale	1:10000
Documents		Hazard zone map Vulnerability zone map Risk zone map
Scale		1:10000: 4/6
Transparency		Qualitative expert-based, Quantitative empirical model (3), Quantitative process based-model (5), Expert analysis (1), Historical documents: 3/5
Complexity		No. of techniques: 3 Total no. of techniques: 4
Cost efficiency		Qualitative expert-based, Quantitative empirical model (3), Quantitative process based-model (1), Expert analysis (5), Historical documents: 3/5
Ambiguousness		No. of classes in RAM: 3 Total no. of classes: 6

Table 20: The scientific indicators for questionnaire Slovakia.

Country		Slovakia
Methodology		Qualitative expert-based
	Techniques	Remote sensing
	Application scale	
Documents		Elements at risk
Scale		??
Transparency		Qualitative expert-based (1): 1/5
Complexity		No. of techniques: 1 Total no. of techniques: 4
Cost efficiency		Qualitative expert-based (5): 5/5
Ambiguousness		No. of classes in RAM: 1 Total no. of classes: 6

Table 21: The scientific indicators for questionnaire Spain.

Country		Spain
Methodology		Quantitative – process based model Qualitative – weighting-rating
	Techniques	Using three base maps (drainage map, climate classification map, and irrigation water quality map) in GIS program. Field observations, geographical information systems, and laboratory analysis
	Application scale	Regional (1:?)
Documents		Risk zone map
Scale		??
Transparency		Quantitative – process based model (5) Qualitative – weighting-rating (2) : 3.5/5
Complexity		No. of techniques: 3 Total no. of techniques: 4
Cost efficiency		Quantitative – process based model (1) Qualitative – weighting-rating (4) : 2.5/5
Ambiguousness		No. of classes in RAM: 1 Total no. of classes: 6

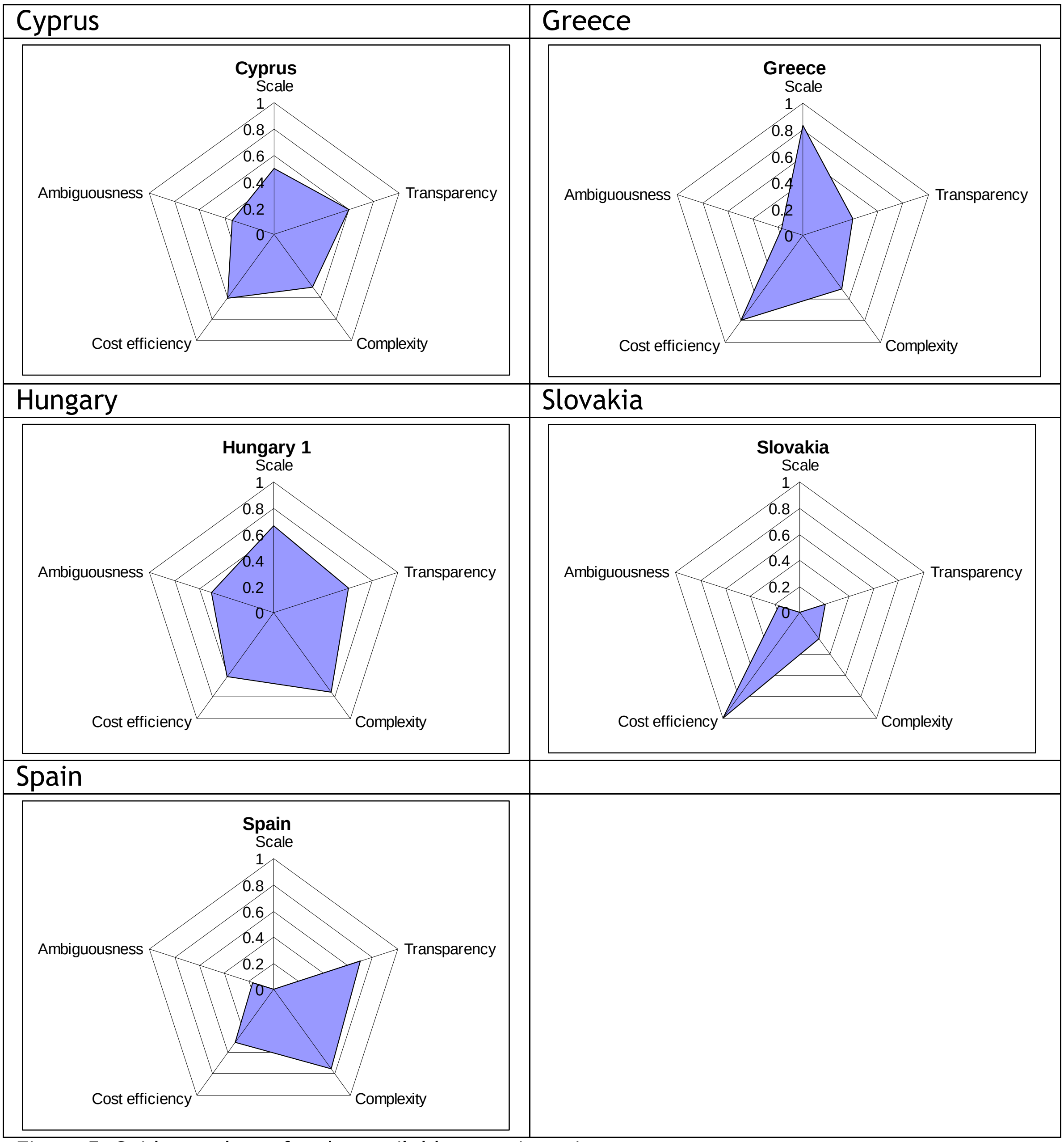


Figure 5: Spider analyses for the available questionnaires.

From the questionnaires it was hard to construct the spider diagrams as the 5 indicators were not direct questions in the questionnaires. We tried to use the spider analyses anyway to get idea of the data. From the questionnaires we used the questions about methodology, techniques, application scale and documents to classify the RAMs according to scale, transparency, complexity, cost efficiency, and ambiguousness (Tables 17 through 21). The RAMs used in the different countries are totally different according to the spider web analyses (Figure 5). None are classified similar.

Besides the fact that we could not derive the spider diagram directly from the questionnaires the indicators are also surficial and it does not provide a basis for harmonization. We therefore also analyzed them in a different way.

So at first sight the RAMs seems totally different, but if we look directly in more detail at the common criteria, methodology, coverage, techniques, and output we see more similarities.

All RAMs use soil characteristics and groundwater information in their assessment (Figure 6). Soil typological, soil texture, chemical properties of irrigation water, climate, soil hydraulic properties, and land use are used in 80 % of the RAMs and pedotransfer function and combinations with models are used in 60 % of the RAMs. From this we can say that there are common criteria in all RAMs. Unfortunately the criteria mentioned can still be divers, so from the questionnaires it is not clear if all countries measure the same properties.

The RAMs found in literature are all based on quantitative based methods (measurement of water and soil properties). The RAMs found in the questionnaires use also quantitative based methods; only Slovakia does not use a quantitative approach. But not only quantitative methods are used; the RAMs in the questionnaires often use a combination of methodologies (Figure 7). In total 69 % of the methods are quantitative and 31 % are qualitative. From the quantitative methods most of them are either expert analysis (23 %) or process based model (23 %). Qualitative expert based is also used for 23 %.

At the moment 50 % of the RAMs have been used in case studies (Figure 8). Hungary and Slovakia have RAMs which are used national or regional.

Four of the five countries use field observations in combination with laboratory analysis. Two of them use also GIS as third technique. Slovakia is the only country with a different approach, they use remote sensing.

Three countries have only one output document. Greece has a vulnerability map, Spain a risk map and Slovakia elements at risk map. Cyprus has an output of risk and vulnerability mapping, and Hungary has an output of risk, vulnerability, and hazard mapping. Risk and vulnerability zone mapping are both used for 30 %; other output maps are less used (Figure 10).

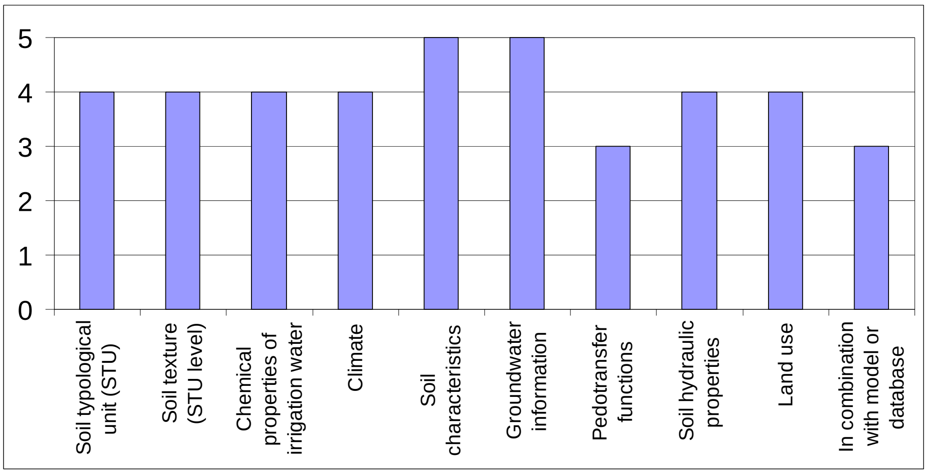


Figure 6: Common criteria.

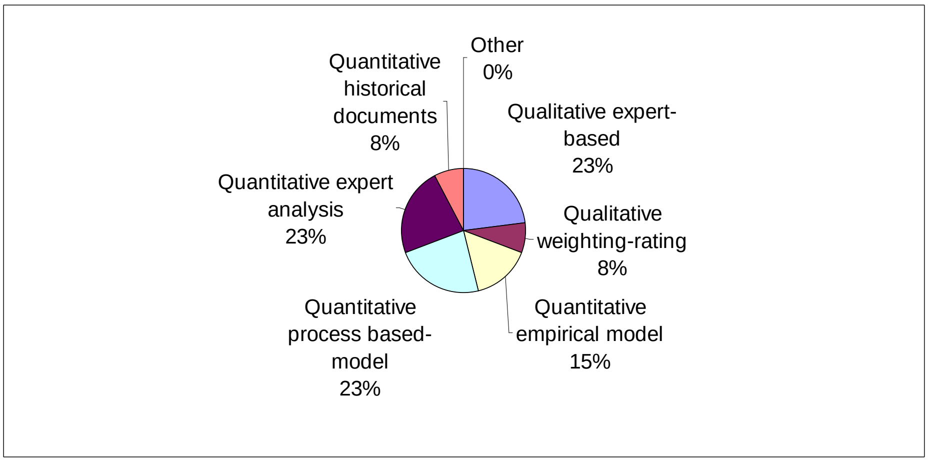


Figure 7: Type of methodology.

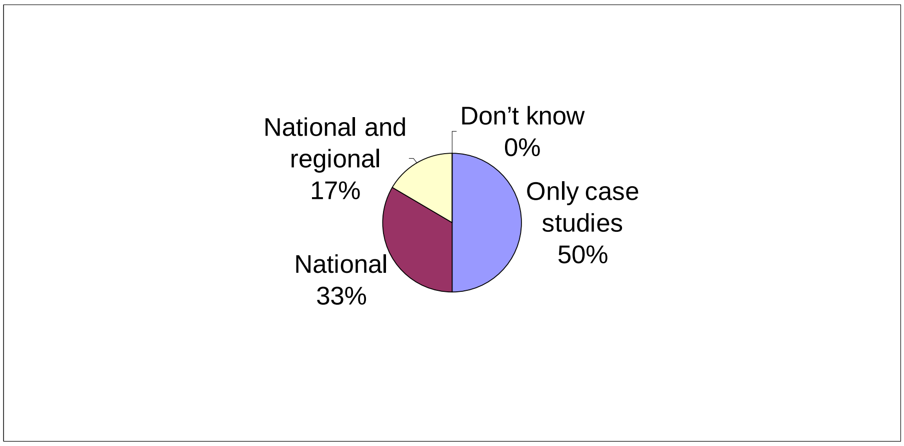


Figure 8: Coverage.

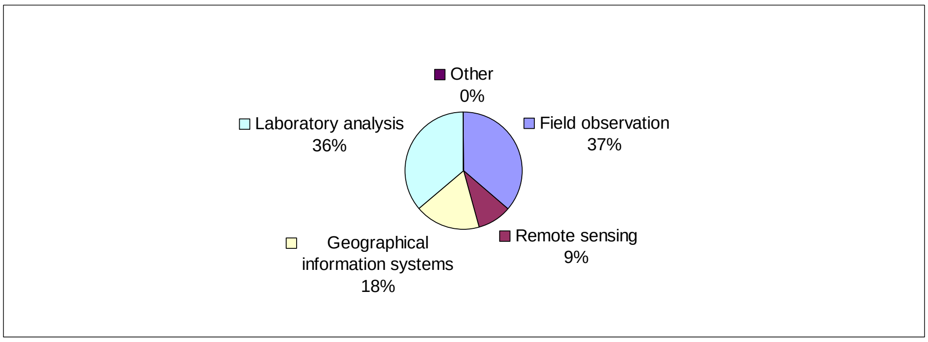


Figure 9: Type of techniques.

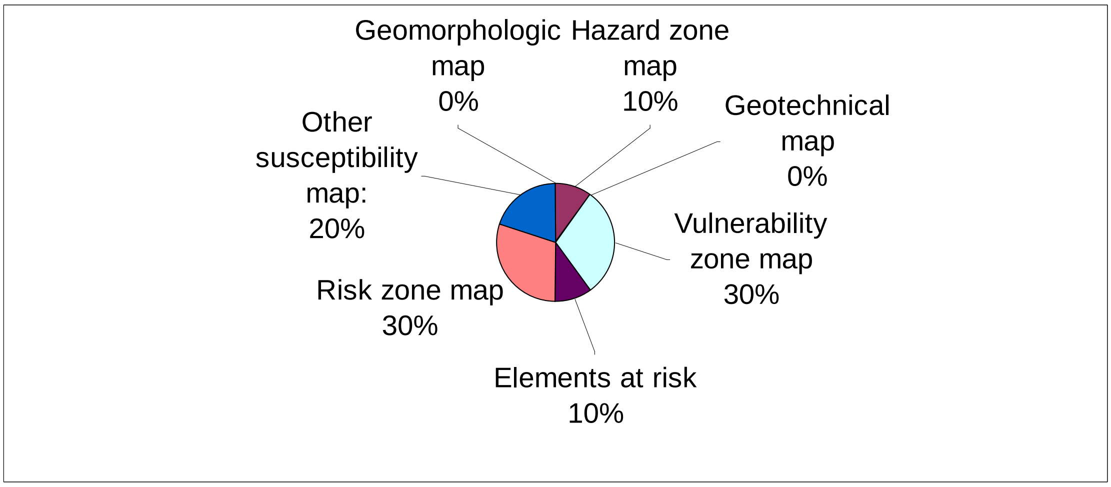


Figure 10: Output documents.

Options for harmonization

Harmonization of RAMs can involve various definitions. However, in the light of the RAMSOIL project, harmonization is understood to be 'the ability to combine and compare results of different RAMs, hereby minimizing differences between standards or measures'. On the other hand, there is standardization, i.e. uniforming of procedures, resulting in absolutely comparable outputs. However, the degree in which harmonization is appropriate, or that standardization is the best option, depends on the kind of soil threat considered and the final purpose of uniting risk assessment methods. For some soil threats, one can suffice with various RAMs providing comparable and compatible results, as for other soil threats, methods have to be identical to facilitate mutual comparison.

A 'harmonizable' RAM has to be:

1) Scientifically sound; methods and results have to be scientifically justifiable.
2) Flexible; the approach must be applicable in every situation.
3) Acceptable; results have to be rather easily understood without specific scientific knowledge and easy to translate to explicit measures.

The RAMs from Cyprus, Greece, Hungary, and Spain seems to have many similarities. According to the methodology, techniques, and output these RAMs could be based on the same, but details are not given in the questionnaires. The RAM from Slovakia is the only RAM which is totally different. The methodology, techniques, and output are all different than the others.

In the literature all RAMs are based on the same principles. Higher RAM numbers become more specific and complex, they combine the previous RAMs. As all RAMs from the literature are based on the salinity Handbook no. 60 (Richards 1954), the thresholds are the same. Only RAM 8 and RAM 9 are not based on the salinity Handbook no. 60. Here the type of anion or the soil types are important.

In the questionnaires is not clear which properties are exactly measured (for example is EC measured), further thresholds are not given. This makes it impossible to tell if the RAMs are harmonizable as they are at the moment.

The techniques in de RAMs are mainly field observations in combination with laboratory analysis. The properties needed for the RAMs found in literature could be easily implemented if these techniques are used.

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