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Methodological approach for the categorisation of the soil vulnerability. A Spanish case study

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Abstract. The aim of the study is to develop a qualitative method to estimate the radiological vulnerability of soils to a radiocaesium contamination. In this context, the vulnerability is defined as the soil potential, to transfer or retain, the radionuclide deposited, according exclusively to its own soil properties. Two exposure pathways are considered, the internal exposure from the ingestion and the external irradiation exposure. The methodology combines hydrological and pedological processes, including specific soil parameters and properties, which are qualitatively represented by means of vulnerability indexes. All the input data needed for the assessment are collected from any complete and normalised soil sample analysis. The results obtained, identify the soil vulnerability in five indexes, that vary from a minimum to a maximum potentiality to transfer or fix the deposited radiocaesium. These allow the categorisation of the associated human exposure and could constitute a previous step in the design of an intervention strategy for the recovery of a contaminated area. The methodology has been applied to the different soil types of the Spanish Peninsula. For a same soil type, a wide variability of indexes is observed. This is expected, as the same soil type has a different evolution regarding the parent material and climate. The influence of the exposure pathway is also reflected, as the methodology considers different critical soil horizons in each case.

1. INTRODUCTION

The ^{137}Cs deposited on the soil, following a nuclear accident, may contribute significantly to the external and the internal dose to humans. The prediction of the fate of ^{137}Cs in the soil, has to be taken into account in the management of a contaminated area, in order to recover its normal usage, reducing the radiological risk.

The behaviour of the radionuclides in the soil is mainly governed, among other factors, by the soil properties and the nutrient status. The bioavailability of ^{137}Cs for plant uptake will depend on the available fraction and the potassium status in the soil solution, while its retention in soils will depend on the content and type of clay minerals. Therefore, a complete characterisation of the soils, in terms of their pedological properties, will allow a qualitative prediction of the behaviour of ^{137}Cs in them. The knowledge of these properties will lead to the assessment of the soil potential, to transfer or fix, the radiocaesium deposited on them. This potentiality is defined as the radiological vulnerability of soils which is represented by means of vulnerability indexes. These indexes, have been estimated for different soil types of the Spanish Penninsula, providing their categorisation from least to most vulnerable.

This paper gives an overview of the methodology developed and the results obtained for three different and characteristic Spanish soil types.

2. METHODOLOGICAL DEVELOPMENT

2.1 Soil processes and properties considered

The soil profile is the reference unit in which the methodological approach is applied. In many studies the first few centimeters of the soil are considered. This work takes into account the differences in physical and chemical properties between the existing different horizons that constitute any soil profile. Figure 1 shows the different soil processes and properties that affect the behaviour of ^{137}Cs in a soil profile, taking into account the different horizons.

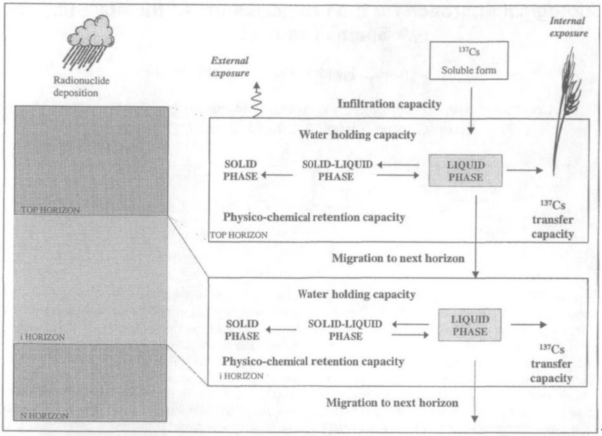

Figure 1: Physical and chemical processes and properties affecting the behaviour of radionuclides in a soil profile.

The processes considered are: i) *infiltration* defined by the infiltration capacity of the soil, ii) *vertical migration* defined by the water holding capacity of the soil, iii) *sorption/desorption* defined by the physico-chemical retention capacity, and iv) *root absorption* related to the fraction of radiocaesium available in the soil and its potential transfer to plants. The methodology does not take into account the amount of contamination which can be transfered to a plant or crop, however, the potassium status in the soil is defined as the ^{137}Cs transfer capacity.

According to this processes, the methodology developed [1] considers two exposure pathways: the external irradiation and the internal exposure from the ingestion of contaminated foodstuffs (hereafter food chain pathway). For each case the critical soil depth has been determined as, the top soil horizon and a maximum depth of 60 cm, respectively. The latter case assumes the maximum root system development and activity to take place within this depth, and can include more than one soil horizon.

The external exposure is influenced by, the infiltration capacity, the water holding capacity and the physico-chemical retention capacity. The more these properties contribute to the fixation of ^{137}Cs on the top soil horizon, increasing its retention potentiality, the more vulnerable the soil will be to this exposure. The same soil properties including the potassium exchangeable content, will most contribute to the food chain exposure. In this case, the less the ^{137}Cs is fixed in the soil matrix within the critical depth of 60 cm, and the lower the potassium status is, the potentiality of transfer to plants will increase and therefore the risk to ingestion exposure. Table 1 shows the relationships between the processes and the soil properties and parameters related to the behaviour of ^{137}Cs in the soil.

The infiltration capacity is the rate of water entering the soil at any given instant (mm h^{-1}). If no direct measure is available an estimation can be made from other soil data such as texture, structure, clay content, organic matter content and cation exchange capacity.

The water holding capacity is a soil property which estimates the maximum storage capacity of water in the soil pore space (mm cm^{-1}), depending on the soil texture, the bulk density, the organic matter content and the permeability and taking into account the slope.

The soil parameters that determine its physico-chemical retention capacity are the clay content and its cation exchange capacity, due to the specific sorption of ^{137}Cs on the soil clay fraction. Once the soils are classified as organic, sandy or clayey, it is necessary to determine the prevailing type of clay present.

This is obtained with the cation exchange capacity as a result of the specific radiocaesium adsorption sites shown by the different clay minerals.

The above mentioned properties allow the evaluation of the behaviour of ^{137}Cs in the soil matrix. The assessment of its transfer from soil to plant is made by means of its stable analogue, potassium. This nutrient, which is easily measured in exchangeable form in any soil sample analysis (cmol kg^{-1}), gives an idea of its supply.

Table 1: Soil processes, parameters and properties associated to the behaviour of ^{137}Cs.

Soil processes and parameters	Soil properties for the exposure pathways	
	External irradiation (Top soil layer)	**Food chain (60 cm depth)**
INFILTRATION PROCESS Texture Structure Clay content, organic matter content Cation exchange capacity	Infiltration capacity	Infiltration capacity
VERTICAL MIGRATION PROCESS Texture Bulk density Organic matter content Permeability	Water holding capacity	Water holding capacity
SORPTION/DESORPTION PROCESS Clay content, organic matter content Cation exchange capacity	Physico-chemical retention capacity	Physico-chemical retention capacity
ROOT ABSORPTION PROCESS Exchangeable potassium content		^{137}Cs transfer capacity

2.2 Soil characterisation

The different Spanish soil types, have been obtained through an extensive bibliographical compilation of soil profiles, from published and unpublished sources. All the information and data has been submitted to a pre-processing in order to harmonise the classification systems, normalise soil units and to filter irregularities. A database of 2176 soil profiles [2] has been created, from which 1655 have been selected to characterise the different soil types and have been used as input in the methodology.

2.3 Methodological approach

Each of the four soil properties considered in the methodology, is defined by a range of values which are divided into five categories. These are described from the lowest to the highest capacity shown by a soil. The influence of these capacities, on the two types of human exposures considered, is what is assessed in terms of vulnerability indexes. For this purpose five indexes, classified from value 1, very low vulnerability, to value 5, very high vulnerability, have been established.

The methodology is applied to each soil horizon, where the soil profile presents the reference unit. In order to assess the vulnerability, it is necessary to determine the category that represents the whole profile for each exposure pathway. In the case of the external irradiation pathway, the soil profile is represented by the value obtained from the top horizon. For the food chain pathway, a mean value for all the horizons within the maximum critical depth of 60 cm, will be taken as representative. The category will be then associated to a vulnerability index as a function of the exposure pathway considered.

According to the external exposure risk, a soil with a maximum infiltration capacity, will show a very low vulnerability index due to the high rate of water entering, that will avoid the permanence of ^{137}Cs in the top soil horizon. With respect to the food chain exposure risk, this high rate will increase the content of ^{137}Cs in solution at the soil-root interface included in the critical depth, rising the potential transfer of the radionuclide from soil to plant and resulting in a very high vulnerability index.

A very low water holding capacity gives way, for both exposure pathways, to a very low soil vulnerability index. This is reasonable as no retention of water, and therefore, retention of the radionuclide will take place in the soil matrix to the critical soil depth considered.

Clayey soils, with a dominant illitic clay type, will show the highest physico-chemical retention capacity, because of the existence of specific ^{137}Cs sorption sites. In case this capacity takes place in the top soil layer, the soil will show a very high vulnerability index to the external exposure risk. With respect to the food chain exposure risk, this prevailing clay type, in the critical depth considered will reduce the transfer of radiocaesium to plants, as it increases its fixation, showing the soil a very low vulnerability index.

It is assumed that the highest ^{137}Cs transfer capacity from soil to plants, that is, the maximum vulnerability index wil be shown by those soils with a minimum exchangeable potassium content.

All of these indexes are called *partial vulnerability indexes*, as they assess the influence of the soil properties on the radiocaesium behaviour individually, according to the exposure pathway, EI, external irradiation and FC, foodchain pathway. They are, therefore, defined respectively as infiltration capacity index: IF_EI and IF_FC, water holding retention capacity index: IH_EI and IH_FC, physico-chemical retention capacity index: IFQ_EI and IFQ_FC and ^{137}Cs transfer capacity index: IK_FC. The final combination of them determines, for each exposure pathway a *global vulnerability index*, shown by a soil.

3. RESULTS

As an example of the results obtained from this methodology, a Spanish case study is shown. Three characteristic Spanish soil types have been selected: Dystric Cambisol, Calcic Cambisol and Rhodo-chromic Luvisol represented with 67, 83 and 74 soil profiles, respectively. The data of these soil profiles have been used as input in the methodology.

The Dystric Cambisols frequent in acidic areas are characterised by having mainly, coarse textures and low base saturation. Their infiltration capacity indexes (Figure 2a), for both pathways, shows a wide variability, showing a dominant medium-low index with respect external irradiation and medium-high index with regard the food chain pathway. These soils have in general, capacity to infiltrate, behaviour in accordance with the coarse texture they usually have. Because of this property, they show low and very low water holding capacity indexes. Although they have a relative high frequency of sandy soils, the clays present, retain the ^{137}Cs in an exchangeable way, giving for the external irradiation pathway high vulnerability indexes and low ones for the food chain pathway. The low content of potassium in these soils is influenced by the acidic origin, giving way to a dominant medium-high ^{137}Cs transfer capacity.

The Calcic Cambisols (Figure 2b) have predominantly loamy textures and high base saturations. The infiltration and water holding capacities show the same tendency as the Dystric Cambisols. The capacity to retain the radiocaesium increases due to the medium fine texture, with a significant clay content. In relation with these properties, the exchangeable potassium content is higher, reducing the ^{137}Cs transfer capacity.

The Rhodo-chromic Luvisols (Figure 2c), are well developed soils with a fine texture and are located in calcareous areas, generally used for olive and wine cultivation. They have low infiltration and water holding capacities in the top horizon, but tend to retain more water in the 60 cm critical depth due to the high clay content. However, the argillic horizon could be situated below the critical depth, so that although the physico-chemical retention capacity is high, the potassium content is lower than expected.

The global vulnerability indexes shown by these soils (Figure 2d) reflects the influence of the exposure pathway. The value that represents the global vulnerability index, in each case, is obtained by soil profiles with the most frequent values. The medium vulnerability index shown by the Calcic Cambisol according to the external irradiation pathway is mainly dominated by the medium infiltration and high clay content of the top horizon. In the case of the food chain pathway, the medium vulnerability index shown by the Distric Cambisol and Rhodo-chromic Luvisol, reflects, in the critical depth, the low potassium content in both soil types as well as the coarse texture in the primary soil profile.

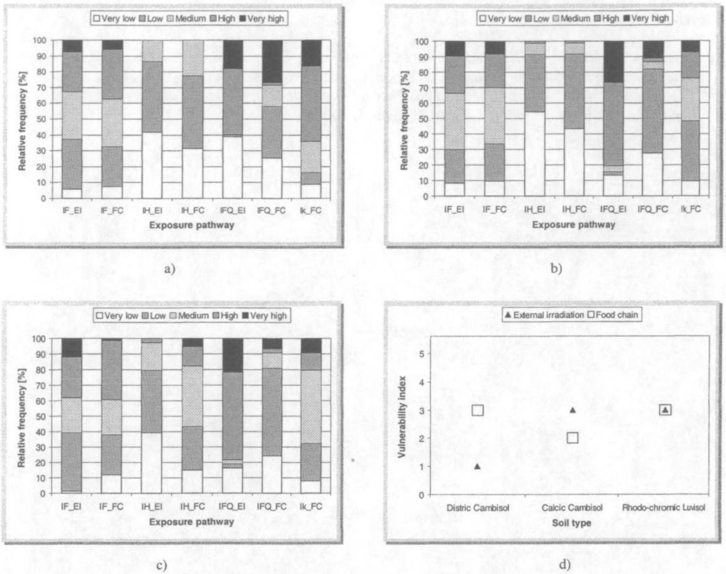

Figure 2: Relative frequency of the partial vulnerability indexes as a function of the exposure pathways on a) Dystric Cambisol, b) Calcic Cambisol and c) Rhodo-Chromic Luvisol. d) Global vulnerability indexes of the soil types according to the exposure pathway.

4. CONCLUSIONS

This methodology can assess the vulnerability for all the different soils found under varying conditions in Spain.

Detailed soil properties from individual horizons for a corresponding soil type is included in order to account for a more detailed behaviour of ^{137}Cs.

A detailed and extensive database containing analytical and morphological data for Spanish soils has been compilated.

The results obtained for the different soil types clearly reflect their characteristics and form the basis for a future intergration in an intervention strategy.

Acknowledgments

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References

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