EVALUATION OF THE MOBILITY OF [137]CS IN SOIL PROFILES OF THE PANTANAL REGION

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ABSTRACT

Radioactive pollutants can cause impact on the environmental quality of soils and represent a risk to human health. Radioecological studies have shown that soils with low pH, low organic matter content and low fertility are more vulnerable to contamination by ^{137}Cs, since the transfer to plants is high. In this study, some surface horizons of soils from Jaraguari, situated at Brazilian Pantanal were assessed in order to map their vulnerability to contamination by [137]Cs. It was also proposed some mitigation measures adapted to the regional scenario in order to optimize radiological protection for rural areas. A conceptual model established to detect the vulnerability of radioactively contaminated soils was applied for soils located in the municipality of Jaraguari (Mato Grosso do Sul). This conceptual model was established based on the relationship between reference values of the soil-to-plant transfer factor (TF) for ^{137}Cs and critical pedological parameters for each radiovulnerability category (pH, CTC and exchangeable K). The application of this conceptual model to a soil

databank using Geographic Information System (GIS) tools generated vulnerability soils maps. This result identified that most of Pantanal soils presented very low radiovulnerability, but it was possible to detect some small areas presenting extreme radiovulnerability. It was possible to conclude that these small areas is not indicated for activities that presents a potential risk for ^{137}Cs contamination and also it must receive priority actions for remediation in the case of accident, since a superficial contamination with ^{137}Cs in these areas can lead to a contamination of subsoil and to a significant spread of contamination via groundwater.

1. INTRODUCTION

The fate of radioactive pollutants in soils is a key information for waste management, water quality control, environmental protection and remediation of contaminated sites [1,2]. Although soils can be considered as geochemical barrier, since they retain the majority of pollutants deposited on the surface, this immobilization is not permanent, as changes in the physical-chemical conditions of the soil due to agricultural practices or to the pedological evolution, can mobilize the retained material and benefit its biological assimilation or migration to adjacent systems [3,4].

In general, studies on the soil-plant transfer of radionuclides in agricultural systems have shown that the radionuclide root uptake pattern is influenced by the following parameters: physical-chemical properties of the chemical element; metabolism and physiology of the species; and, physical, chemical and biological soil properties. It should also be considered that agricultural practices, such as fertilization, liming and irrigation, modify some characteristics of the soil and therefore markedly influence the root uptake pattern.

Frissel and collaborators [5] established a standard in soil-to-plant transfer factor (TF) for ^{137}Cs based on soil properties for a reference plant species (cereals), and on their work it was possible to create a table of values relating some pedological variables of soil with soil-to-plant transfer. This was the base for establish a conceptual model to classify soils in relation to the greater or lesser soil vulnerability to the radioactive contamination.

The soil vulnerability to ^{137}Cs can then be defined as the susceptibility which certain classes of soils have, due to its chemical and physical characteristics, to facilitate the radionuclide mobility, allowing its migration to other layers of soil or root uptake, exposing men and animals to potential hazards [6].

In order to apply this theoretical model to assess soil radiovulnerability, it was used in this study the Geographic Information System (GIS). Generically, this tool can be applied to different regions in order to facilitate the evaluation of soils for choosing suitable locations for the storage of wastes, as well as for collaborating in prevention plans and mitigation of radioactive accidents, from both nuclear power plants and other facilities that use radioactive material.

This study aims to assess and map the vulnerability of some surface horizons of soils from the Pantanal region to a contamination by ^{137}Cs and propose mitigation measures adapted to the regional scenario in order to establish more effective radiological measures for rural areas remediation.

2. METHODOLOGY

2.1. Study area

For this study it was selected the Jaraguari County (MS), located in the region of the Pantanal (Figure 1). The region is characterized by a diversity of soils classes typical of humid tropical environments. Pantanal is one of the largest wetlands in the world and is an ecosystem recognized as National Patrimony by the Brazilian Constitution of 1988, and as Wetland of International Importance by the Ramsar Convention of the United Nations.
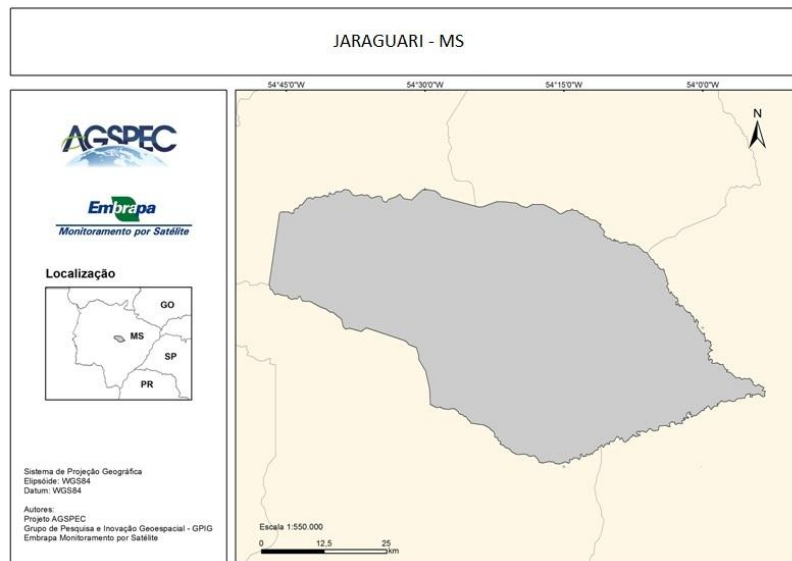

Figure 1: Location of Jaraguari County in the state of Mato Grosso do Sul.

The Pantanal has about 140 square kilometers, distributed in the states of Mato Grosso and Mato Grosso do Sul. The Neosols are the dominant soils in the Jaraguari region. These soils are shallow with the presence of rock about 20 cm deep. In other areas, it is observed the occurrence of Red Ferralsols, Nitosols, Vertisols and Plinthosol. The local vegetation is dominated by *Brachiaria*, intended for grazing. The area reserved for single crop cultivation is located in the only fertile soil of the region: eutroferric red Nitosol.

The procedure for applying the classification of soil radiovulnerability model can be divided into 5 steps:

A. Selection of the input data. Feature class containing polygons that represent the soil from the conceptual test area and from the study area;
B. Selection of polygons which satisfy the characteristics of each class of radiovulnerability;
C. Edition of the table of attributes of the feature class, for the conceptual test area or area of study, relating each feature with the name of its corresponding radiovulnerability class;
D. Application of the symbology defined in the thematic project for the cartographic representation of the soil vulnerability to ^{137}Cs;
E. Final result – map of soil vulnerability to ^{137}Cs.

2.2. Databases

Pedological data are non-geographic data used as variables for the identification of areas vulnerable to contamination with [137]Cs. Pedological data essential to the model are: exchangeable potassium content (K), soil reaction (pH) and cation exchange capacity (CEC). These variables are directly or indirectly correlated with the mobility of ^{137}Cs in the soil/plant system. The pedological databases of the surface horizons (A horizon) used in this work was supplied by EMBRAPA.

Spatial data used as basemap in this work were polygons of soils from a soil map and a list of points with pedological data, developed and supplied by EMBRAPA. It was used the digital ShapeFile (SHP), where the geometry of the polygons was kept in conjunction with its assigned information from the soil conditions. The values from the soil survey were directly related with the spatially corresponding polygon [6].

2.3. The establishment of limits of the critical parameters for radiovulnerability

The concept of soil vulnerability derives from a combination of specific ranges of numerical values for K^+, pH and CEC, which represents a more or less favorable condition to the transfer and/or retention of radioactive contamination of the soil [6].

Table 1 presents the limits of influence of three critical parameters for each of the categories identified of soil vulnerability to a ^{137}Cs contamination [6]. Each thematic class was related to an order of magnitude range of variation of the values of soil-to-plant transfer factors observed for ^{137}Cs in cultivated cereals.

Table 1: Limits of pedological parameter establish for each vulnerability class used in the model to analyze soil vulnerability to ^{137}Cs contamination by

Classes of radiovulnerability	K (cmol$_c$/dm^3)	pH	CTC (cmol$_c$/dm^3)
Extreme FT ≥ 1	< 0.05	< 12.0	≤ 10
High $0.1 \leq FT < 1$	≥ 0.05 < 0.30	≤ 4.8	≤ 10
Moderate $0.01 \leq FT < 0,1$	≥ 0.05 < 0.30	≤ 4.8	>10
Low FT < 0.01	≥ 0.30	> 4.8	>10

2.4. Automation of the thematic project of the radiovulnerability map

For the quantitative representation of phenomena using the primitive graphical polygon, it should be employed the concept of choropleth maps, where the concentration of phenomena is represented by the variation of brightness and/or saturation of the same color tone [6]. In this case, the polygons with lower radiovulnerability, will be represented with the color tone brighter and less saturated (Figure 2).
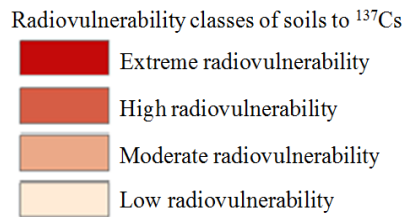
Radiovulnerability classes of soils to ^{137}Cs

Extreme radiovulnerability

High radiovulnerability

Moderate radiovulnerability

Low radiovulnerability

Figure 2: Thematic representation in the maps of categories of radiovulnerability.

Based on the radiovulnerability categories defined for ^{137}Cs and using the symbology functions of the geoprocessing tool, the thematic class area is applied to the polygon features which represent the soils in the studied area.

The implementation of the conceptual model established for detecting the soil vulnerability to the radioactive contamination used the ARCGIS platform.

3. RESULTS

The automated model run for classification of soil vulnerability to ^{137}Cs, based on the pedological indicator parameters generated a vulnerability map for the Jaraguari County, shown in Figure 3.

This result indicated low or moderate vulnerability to ^{137}Cs for most soil polygons of the study area. The only area dedicated to farming is in the region of low vulnerability, dominated by eutroferric Nitosols. This result is similar to the results obtained in earlier studies in which the TF for ^{137}Cs, experimentally determined for cereals in Nitosols from the Rio Grande do Sul, was 0.03 (characteristic FT of soils with moderate vulnerability) [9]. This result was also similar to the outcome obtained by the same conceptual model used in that study, for soils from Castro, Paraná [6]. Those soils, also located in the subtropical region of the country, were classified as moderate vulnerability soils due to their high level of fertility.

Most of the dystroferric Ferralsols were also ranked among the soils of low vulnerability. This was probably due to the high CEC that young and less weathered soils may present.
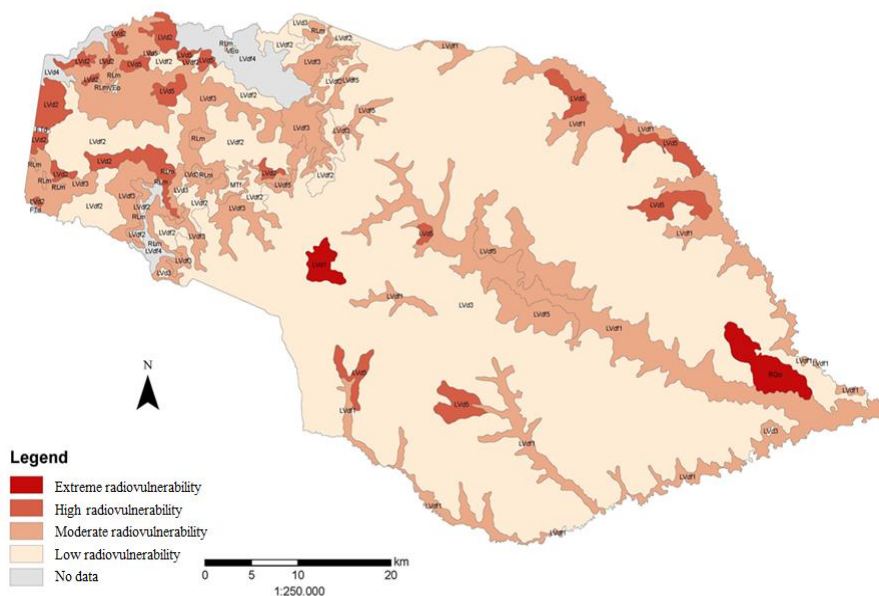
Figure 3: Result of applying the automatic model of vulnerability classification to the A horizon of soils from Jaraguari (MS) to ^{137}Cs.

The dystrophic Red Ferralsols (DRL) was mostly classified as extreme or high radiovulnerability. The grey areas indicate soils for which some pedological data were not available.

The heterogeneity in relation to radiovulnerability presented by soils in this area can be explained by the influence of periodic overflow which the region undergoes. This particularity differentiates the soils of the region, from the highly weathered soils, which occur in most part of country, mainly in the Amazon rainforest and in the Savanna, that are biomas more homogeneous from the pedological viewpoint, which are neighbor from Pantanal.

With the predominance of low vulnerability soils in the region, the remediation actions, if needed, shall be concentrated in the small areas of extreme vulnerability. The mapping of soil properties relevant to radiovulnerability allows identifying, for these areas, the most critical pedological parameter to vulnerability and thereby assisting in actions for remediation of soils.

According to Figure 4, it is observed that the areas with potassium values below 0.05 cmol$_c$/dm^3 correspond to the regions of extreme vulnerability; as so, in these areas, potassium amendment can be efficient to reduce the mobility of ^{137}Cs, since it is known that this countermeasure, is only effective in cases of severe nutritional restrictions indicated by exchangeable K content < 0.05 cmol$_c$/dm^3. Soils with potassium values above 0.3 cmol$_c$/dm^3, correspond to fertile areas whose soils properties naturally act as a geochemical barrier to plant transfer.

According to Figure 5, it is observed that, in the Jaraguari County, pH values are always above the critical values for plants growing. Liming can be an effective countermeasure for soil contamination with ^{137}Cs in areas where pH is below 5 (light yellow areas).
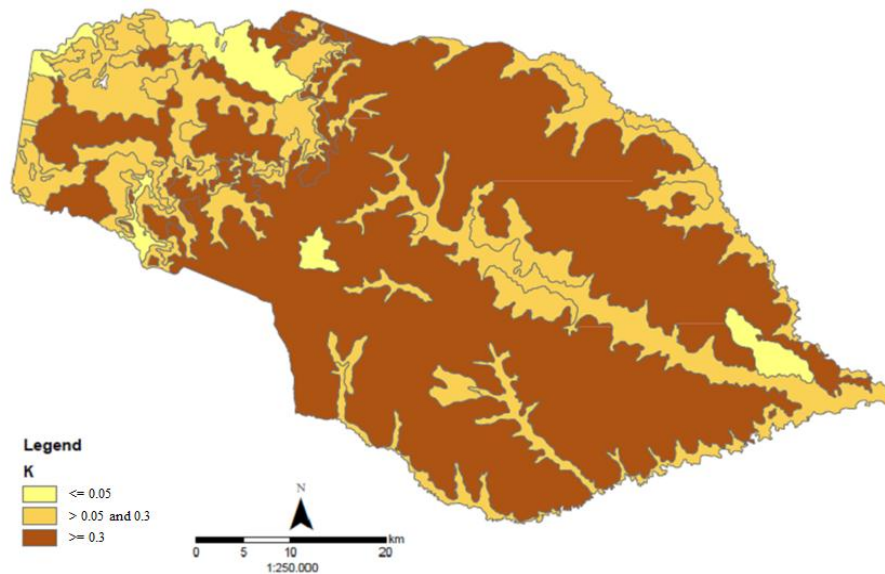
Figure 4: Map of exchangeable potassium values (cmol$_c$/dm^3) of the A horizon of soils from Jaraguari, MS.
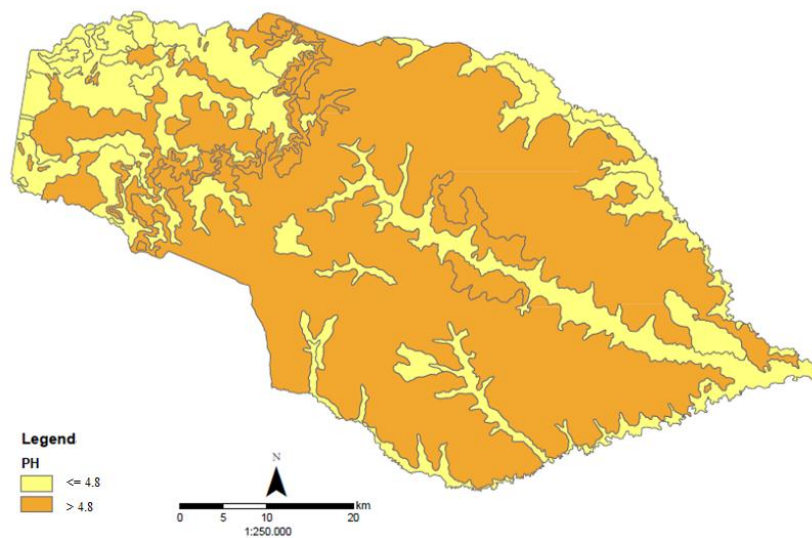

Figure 5: Map of pH values of the A horizon of soils from Jaraguari, MS.

Figure 6 presents the CEC values for the soils of the region. According to the CEC mapping, it can be observed that only the light yellow areas, corresponding to areas of extreme vulnerability, and thus should receive a treatment that increases the CEC of this soil as a measure for the remediation of soil in case of a contamination by [137]Cs. Probably the organic fertilization would be the most recommended practice for the region, aiming to reduce the transfer to the pasture or to farming crops, and thereby minimizing the dose to man via ingestion of meat, milk or foods grown in the region.
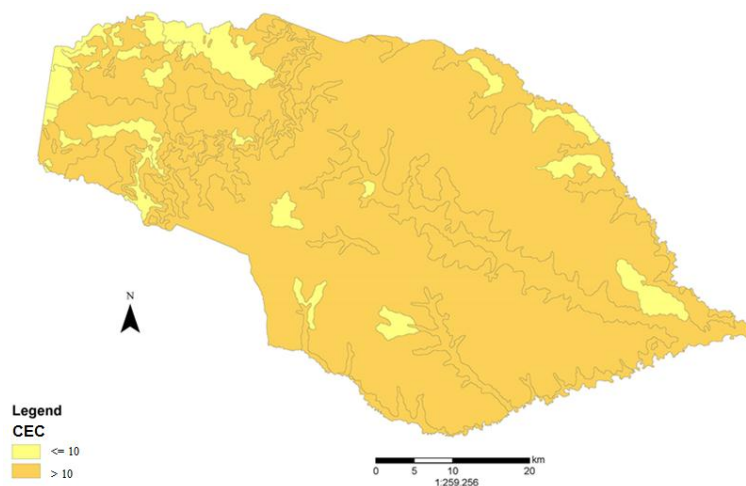
Figure 6: Map of CEC values of the A horizon of soils from Jaraguari, MS.

For the Pantanal region, it has been identified that the surface horizon is an important geochemical barrier to the mobility of ^{137}Cs, since most of the surface soils have low vulnerability to a contamination by ^{137}Cs.

Remediation measures applied to agricultural horizon can be effective for the regions of pH less than 4.8 and exchangeable potassium lower than $0.05 cmol_c/dm^3$, in which procedures such as liming and potassium fertilization are recommended in order to change the level of vulnerability and consequently the TF by about one order of magnitude. The concomitant organic amendment prior to sowing, after a ^{137}Cs soil contamination can reduce, in the areas of extreme vulnerability, the TF about 2 orders of magnitude, since the CEC of the soils can also be modified. Thus, new dose calculations should be performed based on the new values of TF, estimated by the soil parameters modified by the agricultural practices performed.

In any case, these considerations should be based on the dose calculation, which will be a function of the TF estimated for the area (in this case, TF between 0.01 and 0.1 for cereals), adjusted by the conversion factor for the crop species in the place after the accident.

The countermeasures may be applied if the ingestion dose after the soil corrections proposed reduces significantly and if it is economically viable.

3. CONCLUSIONS

The map generated for radiovulnerability identified that the region is very heterogeneous, presenting low levels of vulnerability for most of the region and of extreme vulnerability in some areas. This result identifies the Pantanal as one of the less vulnerable regions to radioactive contamination, compared with Brazilian Savanna and Amazon forest with perominat soils was classified as extreme or high vulnerability soil. However, the few areas of extreme vulnerability at may lead to contamination of subsoil and an important dispersion of contamination may via groundwater.

The conceptual model, which defines radiovulnerability classes, can be not only to predict TF for dose assessment but also can be used in the remediation task in areas contaminated by

^{137}Cs, establishing geographic areas where the treatment should be prioritized and which agricultural practice is more suitable to reduce radiovulnerability. In the case of Jaraguari County, it was observed that in few places, the concomitant liming, organic and potassium amendment can be very effective to reduce TF by about one order of magnitude. For dose assessment purpose, the recommended TF value for ^{137}Cs for cereal is 0.01, for most part of Jaraguari's County soils.

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