ELSEVIER

Journal of Hazardous Materials 61 (1998) 85–90

JOURNAL OF HAZARDOUS MATERIALS

GIS-based modelling to identify regions of Ukraine, Belarus and Russia affected by residues of the Chernobyl nuclear power plant accident

M. van der Perk [a,*], P.A. Burrough [a], G. Voigt [b]

[a] *The Netherlands Centre for Geo-ecological Research (ICG), Department of Physical Geography, Utrecht University, PO Box 80115, 3508 TC Utrecht, Netherlands*

[b] *GSF-Forschungszentrum für Umwelt und Gesundheit, Institut für Strahlenschutz, Ingolstädter Landstraße 1, D-85764 Neuherberg, Germany*

Abstract

Within the framework of the EC-financed RESTORE project (EC DGXII Nuclear Fission Safety Programme), a GIS-based Environmental Decision Support System (EDSS) will be developed to help local authorities identify vulnerable collective units (e.g. settlements, collective farms) having population groups with critical radiocaesium doses. The EDSS will include methods for modelling the spatial and temporal variation of radiocaesium in alluvial and peaty soils through flooding, radiocaesium transfer from different soil types to food products, and the collection and intake of food products by the human population. The spatial models will be written in PCRaster, a raster GIS and dynamic modelling toolkit that includes geostatistical analysis, conditional simulation, and topological modelling. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Geographical Information Systems; Chernobyl; Radiocaesium; Radioecology; Radionuclide transfer; Dose estimation

1. Introduction

As a result of the accident in the Chernobyl nuclear power plant on April 26, 1986, large areas of Ukraine, Belarus, and Russia were contaminated with radiocaesium (Fig. 1). Although in many areas, the initial deposits were much lower than in the immediate vicinity of Chernobyl, local radiocaesium contamination of foodstuffs may still be a source of increased radiation exposure for population groups with certain

* Corresponding author.

PII S0304-3894(98)00111-3

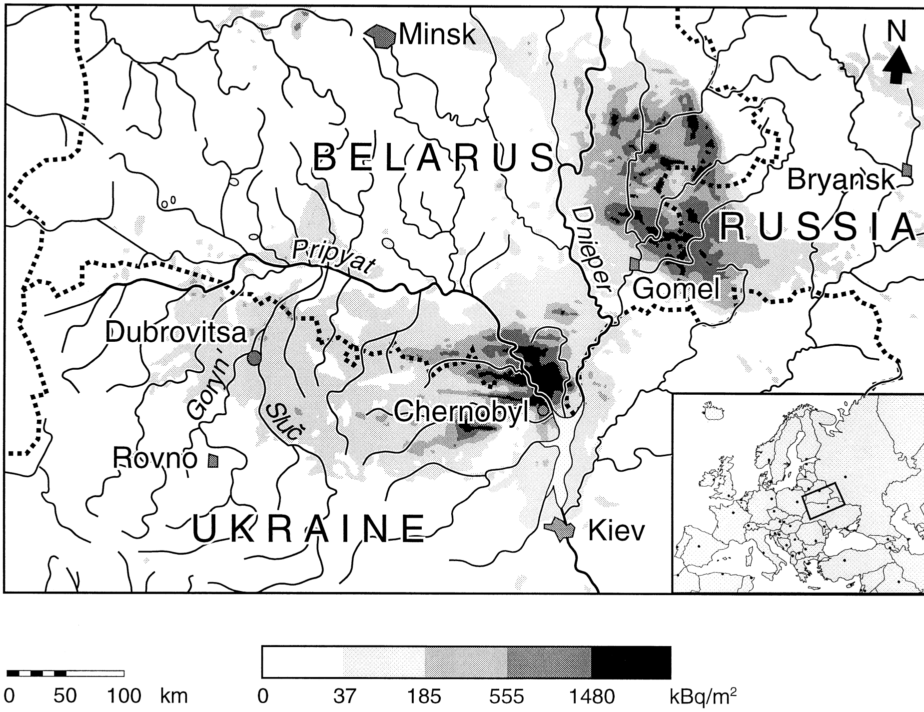

Fig. 1. Soil contamination by radiocaesium released by the Chernobyl accident (situation December 1989) (Source: Ref. [12]).

dietary habits [1]. Recent research has shown that private milk and wild foodstuffs, like wild mushrooms, berries, fish and game, may still contribute significantly to elevated radiocaesium levels in the food of the rural population [2]. Studies in the Novozybkov district (Russia) show that there is a significant positive correlation between consumption of fish and mushrooms and whole body radiocaesium content of humans [3].

The mobility and fate of radiocaesium in landscapes is largely determined by its hydrochemistry. Radiocaesium is very soluble in water, but also readily specifically adsorbed on illitic clay minerals [4]. As a consequence, the environmental mobility in peaty soils is much greater than in mineral soils, which has been demonstrated by many authors [5–8]. The transfer rates of radiocaesium from peaty soils into food chains is likewise greater than from mineral soils. Since extensive peatland ecosystems, known as the Pripyat marshes, are a major feature of the border between Belarus and Ukraine, extensive areas affected by the Chernobyl accident are potentially vulnerable for enhanced uptake of radiocaesium.

Another feature of the Pripyat marshes is that they are very flat, so that the floodplain of the Pripyat River and its tributaries are several kilometres wide. Several authors [9,10] showed that radiocaesium contamination and uptake on such a floodplain may not only vary considerably in space, but also in time. For example, in summer 1993, a conspicuous peak in radiocaesium activity concentrations occurred in milk from privately owned cows grazing on a peatland pasture soils adjoining the Sluc River near Dubrovisa, Northwest Ukraine, which had been inundated for three weeks. Soil data from the same area showed that the surface contamination in 1993 was significantly greater than in 1988 and 1994, especially in the flooded areas [9]. In the floodplain near Chernobyl, the opposite occurs and floodplains are a source of contamination of the river waters [10]. This suggests that flooding may contribute considerably to temporal variation of radiocaesium contamination of water, soil and foodstuffs.

It is obvious that the variation of radionuclide contamination in space and time affects the uptake into food chain and, consequently, the radioactive doses to the human population in the areas of concern. This may particularly be the case in areas known as 'relatively minor contaminated areas', especially if this is accompanied by biased dietary habits of special population groups, such as fishermen, foresters, or private farmers. Local enhancement of contamination and/or transfer due to hydrochemical conditions and/or additional inputs should be considered, also in large-scale investigations, for a proper assessment of radiation doses to humans, which are essential for selecting the most appropriate countermeasures.

2. Scope of the project

Existing models of radionuclide transfer through food chains to humans and dose assessments pay little attention to spatial variability of radioecological parameters and to possible short-term temporal variation due to flooding. These models are mainly based on information of collective farm systems and do not adequately consider private farming or different consumption behaviour of special population groups. The choice and effect of countermeasures, however, is largely determined by these factors. Therefore, it is essential to build spatial models taking these factors into account. This project has been designed to contribute to these aspects.

The main aim of the RESTORE project is to develop an environmental decision support package (EDSS) based on understanding of the nature of contamination, the

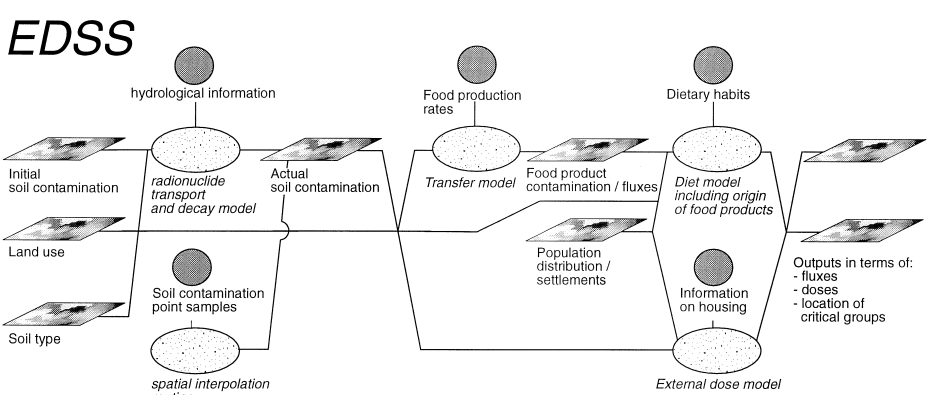

Fig. 2. Schematic overview of the Environmental Decision Support System (EDSS).

processes involved and the different pathways by which radioactivity is transferred in a variety of ecosystems. The EDSS integrates spatial models of transfer of radionuclides from soil via various food products to human population groups on the scale of collective unit (e.g. settlement, collective farm) or groups of collective units including the adjacent semi-natural and urban areas. In addition, the EDSS contains a geostatistical module for interpolation from point samples to areas, a module for external dose assessment and special modules for dynamic inputs into the modelled food chain, e.g. through flooding (see Fig. 2). The system of environmental models should enable local authorities to identify vulnerable areas within these units and to evaluate possible countermeasures for reclaiming contaminated land and restoring traditional farming.

3. Spatial analysis and modelling programme

The input for the EDSS consists of data on surface contamination, soil type, land use, food production rates, population density and structure. Since these parameters vary in space, it is a logical inference to investigate the radionuclide transfer from soil to food products and the subsequent intake of these foodstuffs by the human population using Geographical Information Systems. The raster GIS PCRaster, a dynamic modelling toolkit that includes geostatistical analysis, conditional simulation, and topological modelling, offers a convenient framework to build the submodels within a GIS environment. In this manner, a full and flexible integration of the transfer models and the geographical database is achieved. Fig. 2 presents a schematic overview of the submodels within the EDSS. The function of the various submodels is explained in further detail below.

The basic input for the EDSS is a map of actual soil contamination. This input can be achieved either through the geostatistical interpolation of point samples, or by using information on the initial deposition and running a model accounting for the different physical and hydrological processes that affect the evolution of soil contamination in time. These include physical decay, leaching from the soil profile, and redistribution through the landscape due to erosion and sedimentation processes. Together with maps of land use and soil type, the transfer model is run to simulate food product contamination. The calculation of radionuclide transfer in this submodel is based on either aggregated transfer coefficients (i.e. the ratio of food product contamination (Bq kg^{-1}) and surface contamination (Bq m^{-2})), or, if more detailed information is available, on a mechanistic approach using more detailed data on soil chemistry [11].

The next step is to model the collection and intake of food products for the estimation of the internal doses. The spatial relations of food product origin, fate and dietary habits need special attention. Fig. 3 demonstrates an example of such spatial relations. To model the collection of wild food products such as mushrooms and berries in the neighbourhood of a settlement, a probabilistic approach will be chosen. Theoretically, the probability of collecting wild food products decreases with distance from a settlement. The fact that wild food products grow in the forest areas, and that the access to forests is influenced by the presence of roads or rivers, can be included by using weight functions and/or resistance functions in the spatial model. These weight functions will be obtained from dietary surveys in selected areas. In this way, the mean and variation

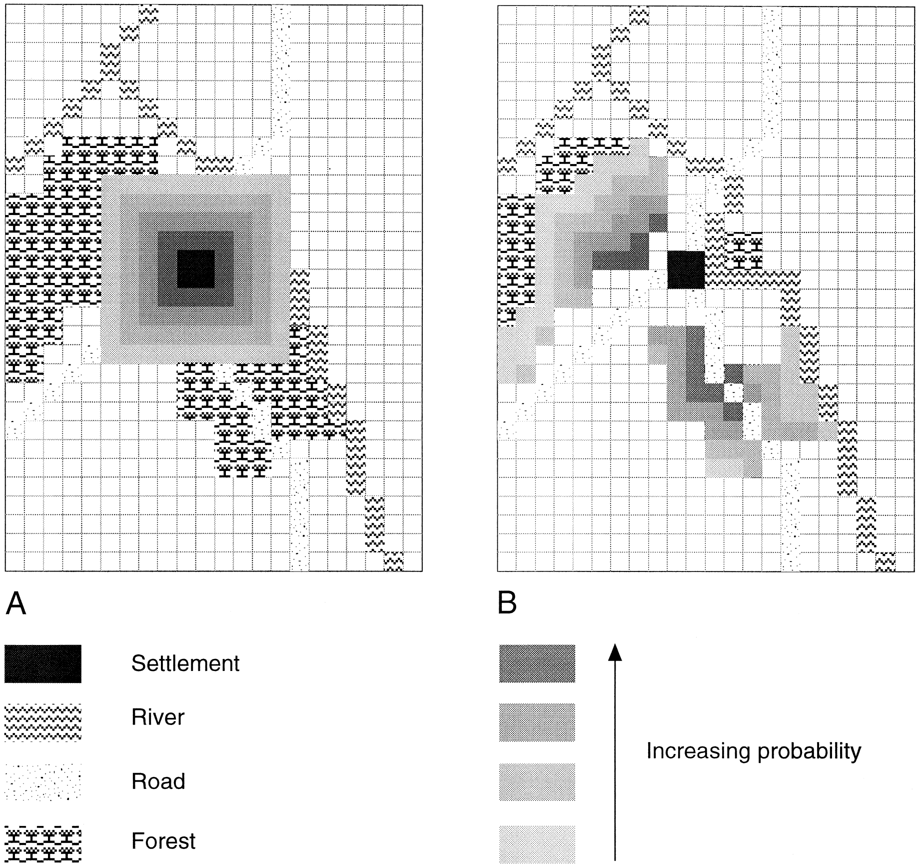

Fig. 3. Examples of a probability functions for collection of wild food products around a settlement: (A) Probability as function of distance from settlement; (B) Idem, corrected for the presence of forests, roads, and rivers using weights.

of the contamination of wild food product consumed by inhabitants of a settlement can be estimated. Similar approaches can be followed for both collective and private agricultural food products.

Together with the outcomes of the external dose model, the diet model yields output maps indicating areas that are vulnerable because of the presence of critical population groups suffering an increased radioactive doses. Because the EDSS includes the entire chain of soil contamination–food product contamination and diet, a detailed insight in the fluxes of radionuclides through the landscape, and the food chain in particular, is obtained.

4. Concluding remarks

The environmental decision support system being developed in the RESTORE-project comprises a wide variety of GIS-based environmental submodels. These include, among others, data-driven geostatistical interpolation techniques, physical-based models for modelling transport of radionuclides and food products over the landscape, empirical and semi-empirical cartographic point models for modelling radionuclide transfer to agricultural and wild food products and external doses. The execution of these models within the raster GIS environment accomplishes a full integration between the geographical database and the various models, and enables a flexible choice of submodels. Accordingly, the system can be adjusted easily to the needs of the user depending on the amount and quality of available data.

Acknowledgements

This project is funded by the European Commission DGXII Nuclear Fission Safety Programme (Contract No. F14P-CT95-0021) and the Inco-Copernicus Programme. All project participants are acknowledged for their indispensable inspiration and support for the realisation of the EDSS.

References

[1] R. Alexakhin, S. Firsakova, G. Rauret, I. Dalmau, N. Arkhipov, C. Vandecasteele, Y. Ivanov, S. Fesenko, N. Sanzharova, Fluxes of Radionuclides in Agricultural Environ.—Main Results and Still Unresolved Problems, in: A. Karaoglou, G. Desmet, G.N. Kelly, and H.G. Menzel (Eds.), The Radiological Consequences of the Chernobyl Accident. European Commission EUR 16544 EN, Luxembourg, 1996, pp. 39–47.

[2] P. Strand, B. Howard, V. Averin (Eds.), Transfer of radionuclides to animals, their comparative importance under different agricultural ecosystems and appropriate countermeasures. Exp. Collaboration Project No 9. Final Report EUR 16539 EN, European Commission, Luxembourg, 1996.

[3] L. Skuterud, I.G. Travnikova, M.I. Balanov, P. Strand, B.J. Howard, Contribution of fungi to radiocaesium intake by rural populations in Russia, Sci. Total Environ. 193 (1997) 237–242.

[4] F.R. Livens, P.J. Loveland, The influence of soil properties on the environmental mobility of caesium in Cumbria, Soil Use and Management 4 (1988) 69–75.

[5] J. Hilton, F.R. Livens, P. Spezzano, D.R.P. Leonard, Retention of radioactive caesium by different soils in the catchment of a small lake, Sci. Total Environ. 129 (1993) 253–266.

[6] J.P. Absolom, S.D. Young, N.M.J. Crout, Radio-caesium fixation dynamics: measurement in six Cumbrian soils, Eur. J. Soil Sci. 46 (1995) 461–469.

[7] A.B. Hird, D.L. Rimmer, Total caesium-fixing potentials of acid organic soils, J. Environ. Radioactivity 26 (1995) 103–118.

[8] A.V. Kudelsky, J.T. Smith, S.V. Ovsiannikova, J. Hilton, Mobility of Chernobyl-derived ^{137}Cs in a peatbog system within the catchment of the Pripyat River, Belarus, Sci. Total Environ. 188 (1996) 101–113.

[9] P.A. Burrough, M. Gillespie, B.J. Howard, D.M. Howard, V. Pronevich, B. Prister, P. Strand, L. Skuterud, G.M. Desmet, Redistribution of Chernobyl ^{137}Cs in Ukraine wetlands by flooding. Grange-over-Sands/Utrecht: NERC/ICG, 1996.

[10] U. Sansone, O. Voitsekhovitch (Eds.), Modelling and Study of the Mechanisms of the Transfer of Radioactive Material from Terrestrial Ecosystems to and in Water Bodies around Chernobyl. Exp. Collaboration Project No. 3. Final Report EUR 16529 EN. Luxembourg: European Commission, 1996.

[11] A.G. Gillet, J.P. Absolom, Progress Report for Restore Dynamic Modelling Work at NU. Internal Rep. Nottingham Univ., 1997.

[12] IAEA, The Int. Chernobyl Project; Distribution of Surface Ground Contamination by Caesium-137 Released in the Chernobyl Accident and Deposited in the Byelorussian SSR, the Russian SFSR and the Ukrainian SSR, December 1989, 1:1,000,000, Int. Atomic Energy Agency, Vienna, 1991.