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Research note

Indoor terrestrial gamma dose rate mapping in France: a case study using two different geostatistical models

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ABSTRACT

Terrestrial gamma dose rates show important spatial variations in France. Previous studies resulted in maps of arithmetic means of indoor terrestrial gamma dose rates by "departement" (French district). However, numerous areas could not be characterized due to the lack of data. The aim of our work was to obtain more precise estimates of the spatial variability of indoor terrestrial gamma dose rates in France by using a more recent and complete data base and geostatistics. The study was based on the exploitation of 97 595 measurements results distributed in 17 404 locations covering all of France. Measurements were done by the Institute for Radioprotection and Nuclear Safety (IRSN) using RPL (Radio Photo Luminescent) dosimeters, exposed during several months between years 2011 and 2012 in French dentist surgeries and veterinary clinics. The data used came from dosimeters which were not exposed to anthropic sources. After removing the cosmic rays contribution in order to study only the telluric gamma radiation, it was decided to work with the arithmetic means of the time-series measurements, weighted by the time-exposure of the dosimeters, for each location. The values varied between 13 and 349 nSv/h, with an arithmetic mean of 76 nSv/h. The observed statistical distribution of the gamma dose rates was skewed to the right. Firstly, ordinary kriging was performed in order to predict the gamma dose rate on cells of 1*1 km^2, all over the domain. The second step of the study was to use an auxiliary variable in estimates. The IRSN achieved in 2010 a classification of the French geological formations, characterizing their uranium potential on the bases of geology and local measurement results of rocks uranium content. This information is georeferenced in a map at the scale 1:1 000 000. The geological uranium potential (GUP) was classified in 5 qualitative categories. As telluric gamma rays mostly come from the progenies of the ^{238}Uranium series present in rocks, this information, which is exhaustive throughout France, could help in estimating the telluric gamma dose rates. Such an approach is possible using multivariate geostatistics and cokriging. Multi-collocated cokriging has been performed on 1*1 km^2 cells over the domain. This model used gamma dose rate measurement results and GUP classes. Our results provide useful information on the variability of the natural terrestrial gamma radiation in France ('natural background') and exposure data for epidemiological studies and risk assessment from low dose chronic exposures.

Abbreviations: GUP, Geological uranium potential; TGDR, Indoor telluric gamma dose rates; LMC, Linear model of coregionalization; MCCK, Multi-collocated cokriging; OK, Ordinary kriging; WMM, Arithmetic mean of measurements at the same location, weighted by the time exposure of the dosimeters.

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1. Introduction

Natural sources account for most of the population exposure to ionizing radiation. In particular, radon decay products and gamma rays emitted by terrestrial natural radionuclides found in the soil and in building materials contribute heavily to the dose. In France, natural sources that account for exposure to environmental radiation include radon (43%), terrestrial gamma rays (14%), cosmic rays (8%), and water and food (7%) (Rannou et al., 2006). The exposure is variable due to geographic location, housing characteristics, season, etc.

Terrestrial gamma radiation is emitted from naturally occurring radioisotopes, such as ^{40}K and the radionuclides from the ^{238}U and ^{232}Th series and their decay products. The levels of terrestrial gamma radiation are related to geology and uranium, thorium and potassium content of the rock from which the soils originate in each area. Indoor gamma dose rates may vary with geology, building materials, housing type and building period (Hatakka et al., 1998; Lyogi et al., 2002; Idrish Miah, 2001, 2004; Quindós Poncela et al., 2004, Rannou et al., 1984; Sundal and Strand, 2004; Szegvary et al., 2007).

In France, the study of Billon et al. (2005) allowed estimates of the French population's true exposure to natural ionizing radiation. The study provided a statistical description of the exposure and maps of arithmetic means of indoor radon concentrations, indoor and outdoor terrestrial gamma dose rates, and effective doses due to cosmic radiation, by “departement” (French district). The exposure indicators were corrected to reduce their variations due to several factors that influence measurements. In that study, 8737 indoor terrestrial gamma dose rate measurements yielded an average dose rate of 55 nSv/h (SD, 18 nSv/h), which ranged from 23 to 96 nSv/h over the 59 districts. There were also 5294 outdoor terrestrial gamma dose rate measurements with an average dose rate of 46 nSv/h (SD, 15 nSv/h), which ranged from 25 to 85 nSv/h over the 38 districts. These results provided useful exposure indicators of French population and allowed identifying areas with important variations. Nevertheless, numerous areas could not be characterized due to the lack of data (measurements available for only two-thirds of the country) and precise estimation of the spatial variability of indoor terrestrial gamma dose rates could not be obtained.

The spatial interpolation methods, including geostatistics, have been developed for and applied to various disciplines. Ordinary kriging and cokriging are two geostatistical techniques used to create continuous maps of spatially autocorrelated attributes. These techniques have been commonly used in environmental sciences, soils sciences, medical/health sciences and have been sometimes compared for spatial interpolation of data (Carter et al., 2011; Goovaerts, 1999, 2011; Knotters et al., 1995; Liu et al., 2006; Moral, 2010; Oliver et al., 1998). These geostatistical techniques can also be applied to map natural or artificial radioactivity (Baume et al., 2011; Buttafuoco et al., 2010; Caro et al., 2013; Dubois et al., 2007; Guagliardi et al., 2013; Guastaldi et al., 2013; Mabit and Bernard, 2007; O'Dea and Dowdall, 1999; Sanusi et al., 2014; Szegvary et al., 2007). Ordinary kriging (Sanusi et al., 2014; Szegvary et al., 2007) and more rarely cokriging (Guastaldi et al., 2013) have been used in recent studies for interpolating gamma radiation levels.

The aim of our work was to obtain better indicators of the spatial variability of indoor terrestrial gamma dose rates in France by using more recent and complete data, and geostatistics. The study was based on 97,595 measurement results distributed in 17,404 locations covering the whole French territory. Measurements were done by the Institute for Radioprotection and Nuclear Safety (IRSN) using RPL (Radio Photo Luminescent) passive dosimeters, exposed during several months between 2011 and 2012, in French dental surgeries and veterinary clinics. The results used came from dosimeters which were not exposed to anthropic sources. Moreover, the IRSN developed in 2010 a map of the uranium potential of French geological formations, on the basis of geology and local measurement results of rocks uranium content. The geological uranium potential (GUP) was classified in 5 qualitative categories. As telluric gamma rays mostly come from the progenies of the ^{238}U series present in rocks, this information, which is exhaustive throughout France, has also been used for estimating the telluric gamma dose rates.

2. Materials and methods

2.1. Data source: results of indoor gamma dose rate measurements

For this study, data has been provided by the LDI (Laboratoire de Dosimétrie de l'IRSN). The data were collected between 2011 and 2012, as part of the routine monitoring of French dentist surgeries and veterinary clinics. The dosimeters were not exposed to anthropic radioactive sources and thus reflect the background of the gamma radiations in buildings. The dosimeters were the RPL technology (Radio Photo Luminescent) where RPL refers to the luminescence arising through interaction with ionizing radiation and induced to emission by the action of ultraviolet light. The detector is a silver-doped glass of phosphate. The luminescent properties of the glass derived from a very small concentration of doping agents (silver ions) where Ag + acts as traps for both electrons and positive holes. These traps are metastable, so that stimulation with ultraviolet light causes the electrons in the traps to move to an energy level above their state and to return to it with the release of luminescence in visible range. The intensity of this luminescence is directly proportional to the dose received. A combined system of 5 different filters allows to compare doses from beta, X and gamma radiation. The principal advantage comes from the fact that since the traps are metastable, the signal is not erased by the read-out procedure but remains indefinitely, allowing the measurement to be reproduced. It has very low fading and low sensitivity to the environmental temperature. Nanto et al. (2011) and Ranogajec-Komor et al. (2008) indicate that RPL dosimeters, commonly used for personal monitoring, are also suitable for monitoring environmental and ambient radiation. After reading and processing with a special algorithm, measurements count the absorbed dose of gamma radiation received during the total time exposure of the detector with an accuracy of 20%.

LDI data are usually related to monthly and quarterly measurements which correspond to the workers chronological follow-up. In order to harmonize those measurements and study a gamma dose rate, all the data have been divided by the corresponding time exposure which lies between 20 and 180 days. The data base counts 98 858 measurements distributed at 17 420 locations in France (Fig. 1). The density of measurement sites is variable, with clusters of measurements in the biggest cities. Areas where few measurements are available correspond to the areas with the lowest population density. All locations do not have the same number of measurements (the number varies between 1 and 29). More than 90% of the data is constituted of quarterly measurements and on average there are 6 measurement results per location.

2.2. Auxiliary information: uranium potential of geological formations

The IRSN achieved in 2010 a classification of French geological formations, characterizing a uranium potential on the bases of several criteria such as geology and local means of uranium content