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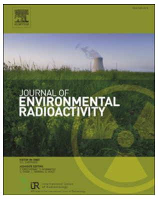

Homogenity of geological units with respect to the radon risk in the Walloon region of Belgium

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ABSTRACT

In the process of mapping indoor radon risk, an important step is to define geological units well-correlated with indoor radon. The present paper examines this question for the Walloon region of Belgium, using a database of more than 18,000 indoor radon measurements. With a few exceptions like the Carboniferous (to be divided into Tournaisian, Visean and Namurian-Westphalian) and the Tertiary (in which all Series may be treated together), the Series/Epoch stratigraphic level is found to be the most appropriate geological unit to classify the radon risk. A further division according to the geological massif or region is necessary to define units with a reasonable uniformity of the radon risk. In particular, Paleozoic series from Cambrian to Devonian show strong differences between different massifs. Local hot-spots are also observed in the Brabant massif. Finally, 35 geological units are defined according to their radon risk, 6 of which still present a clear weak homogeneity. In the case of 4 of these units (Jurassic, Middle Devonian of Condroz and of Fagne-Famenne, Ordovician of the Stavelot massif) homogeneity is moderate, but the data are strongly inhomogeneous for Visean in Condroz and in the Brabant massif. The 35 geological units are used in an ANOVA analysis, to evaluate the part of indoor radon variability which can be attributed to geology. The result (15.4–17.7%) agrees with the values observed in the UK.

1. Introduction

Indoor radon is recognised as one of the major indoor pollutants, the second cause of lung cancer (WHO, 2009). The presence of radon in the indoor atmosphere is highly variable from one house to the other, and it must be considered as a random variable to be studied with statistical tools. Kemski et al. (2009) point out two factor groups known to predispose houses to elevated indoor radon levels. They consist of (1) the territorial situation characterized by regional geology, geomorphology and soil type, and (2) the regionally collocated building and housing conditions. The multivariate analysis conducted on a large number of data in the United Kingdom (Appleton and Miles, 2010), showed that more than 50% of the variance of indoor radon concentrations cannot be related to the variability of known factors. Only two factors were found to be strongly correlated with radon: the geological context and the geographical localisation. Altogether, the factors related to the building accounted for not more than 10%.

This result shows that radon risk mapping should be an essential component of information on the radon risk conveyed to the authorities and the general public. It also justifies the mapping methodology adopted in the UK, considering separately each geological unit, and mapping the variations of the risk indicator within each unit (Miles and Appleton, 2005). The same approach was followed in a previous work for the Walloon region of Belgium (Cinelli et al., 2010).

The definition of the considered geological units is obviously an essential step in this methodology. The goal of the geological division is to clearly display in the radon risk map the borders between adjacent areas with significantly different levels of risk. But there is also a clear advantage not to distinguish between geological units having similar levels of risk, in order to improve statistics and to simplify the map. We previously used units defined purely by their Age/Stage, or sometimes their Period/System when their outcropping extent is limited. The present work will re-examine

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this question, showing that many of these units are not homogenous for the radon risk, suggesting a further division on a geographical basis, but also the possibility of grouping several Stages.

2. Materials and methods

2.1. Radon risk indicator

Existing radon maps look very different in many aspects: in terms of the displayed variable, the spatial resolution, the type of interpolation (or not), and the selection of levels displayed for the variables (Dubois and Bossew, 2006; Dubois, 2005). Some European countries built maps based on measured indoor radon levels, giving estimates of the mean radon levels in buildings by area, or the predicted percentage of buildings above a chosen reference level as Denmark (Andersen et al., 2001), Italy (Bochicchio et al., 2005), Belgium (Cinelli et al., 2010) and UK (Miles and Appleton, 2005). Other countries instead used indirect indicators of indoor radon to derive maps of radon prone areas based on soil properties and measurements as Germany (Kemski et al., 2009), Czech Republic (Mikšova and Barnet, 2002), Spain (García-Tavalera et al., 2013; Quindos et al., 2008) and France (Demoury et al., 2013). The indicators include parameters such as concentration of radium or radon in the ground, and soil permeability.

Belgian radon risk maps use as the risk indicator the percentage of houses above the reference level used in the country (presently 400 Bq/m^3), predicted from ground floor measurements (Cinelli et al., 2010). However, the goal of the present work is not to produce a revised risk map, but to compare the radon risk levels associated to different geological units. For simplicity, we shall rather use the geometrical mean radon concentration (GM) as the quantity representative of the risk. As shown in Cinelli et al. (2009), long-term and short-term data can be mixed for the calculation of the GM.

Affected areas, defined as areas where more than 1% of dwellings bypass the reference level of 400 Bq/m^3, typically show a GM higher than 67 Bq/m^3 (Gerardy and Tondeur, 2002). If the new EC reference level of 300 Bq/m^3 (EC, 2013) is applied in this definition, a threshold GM $\approx$ 50 Bq/m^3 must be considered. As the geometrical standard deviation is very roughly constant, the accuracy of the GM is basically determined by the number of data. Assuming GSD $\approx$ 2.2, the accuracy of the GM is roughly $1\sigma < 20\%$ for the subgroups with >20 data, $1\sigma < 10\%$ for >70 data and $1\sigma < 5\%$ for >260 data.

Throughout this paper, the GM will be expressed in Bq/m^3. For simplicity, this unit will often be omitted in the tables and in the discussion.

2.2. Indoor radon database

We use two databases of indoor radon measurements coming from the south of Belgium, the Walloon region. The two data sets used have been collected by the Federal Agency for Nuclear Control (FANC-AFCN) on the one hand and by the Institut Supérieur Industriel de Bruxelles (ISIB) on the other hand. The ISIB data, about 5092, are short-term (ST) measurements collected in houses with charcoal canisters exposed during 3–4 days in every season except summer; radon is measured in equilibrium with its short-lived progeny by gamma-spectrometry with NaI(Tl) detector. Only ground floor data will be analysed hereafter. The FANC data, about 13,680, are long-term (LT) indoor radon data collected using track-etch detectors exposed during 3 months on ground floor level mostly during spring or autumn.

The area of the region is 16,844 km^2, and the average sampling density is thus slightly above 1 data/km^2.

For each house for which a radon measurement is available, the database includes the geographical coordinates (Belgian Lambert system 1972), the radon concentration on the ground floor, and the local geological unit determined with the digital geological map (GSB). This map is known as the “old” map, being more than one century old. A new geological map is under development (GSW) but not yet fully available. The new map was only used till now to correct the geological unit in case of anomalies (e.g. high radon level on a presumably low-risk unit).

Loess, a quaternary aeolian deposit, is considered as a separate unit, which is not the case in the old geological map, where loess is presented as a local cover above the underlying geological unit, with no indication of the limits of loess covered areas. However, loess plays a special role in the indoor radon pollution (Tondeur et al., 1996), which justifies that it is considered separately.

The radon hazard of a geological unit is determined by its composition, structure, permeability, formation, deformation and tectonic history, and local cover or position. Due to their strong variation in space, not all of this information is available from geological maps, and it is clear that treating radon data as homogeneous populations over defined geological units derived from geological maps is only a generalising approach taking into account only part (and not always the same) of these determining parameters. For these reasons, parameters such as lithology and structure are not included in the database, but treated as being relatively homogeneous (with respect to radon risk) on the scale of the defined geological unit (GU).

2.3. Geological units used in the previous work

Table 1 recalls the list of geological units used in (Cinelli et al., 2010).

A very significant geographical variability of the radon risk was observed within several geological units, indicating that they are not homogeneous groups, but with only little effect on risk mapping. For example, Cambrian includes data from the Stavelot massif (high radon risk) and from the Rocroi massif (rather low risk) but they do not interfere in the mapping process because of the distance between the two massifs.

However, there is a strong interest in defining more homogenous units, for “fundamental” reasons (e.g. study of log-normality, or study of the correlation between indoor radon and several risk indicators like gamma background (García-Tavalera et al., 2013), soil radon (Barnet et al., 2008), radiogeochemical data (Drolet et al., 2013, 2014) …) as well as for very practical reasons (e.g. communication about affected areas). Such homogeneous units could also be used as a basis of a geogenic radon map which is under development at European level (Gruber et al., 2013). This map aims to display a quantity closer to geogenic hazard, i.e. which measures “what earth delivers” in term of radon irrespective of anthropogenic factors and temporally constant over a geological timescale.

2.4. Methodology for building more homogenous units

The process of building the new geological units (GU) includes a first step of subdivision, followed by a step of fusion of contiguous similar units.

The initial units are divided according to the province (Hainaut, Brabant, Namur, Liège, Luxembourg), and according to the roughly S–N division in geographical regions (Gaume, Ardenne region, Fagne-Famenne, Condroz, Haine-Sambre-Meuse, middle Belgium), with a complementary zone (NE of the province of Liege, ‘Herve’). The “Haut-Pays” in the South of Borinage was first considered