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Major influencing factors of indoor radon concentrations in Switzerland

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ABSTRACT

Purpose: In Switzerland, nationwide large-scale radon surveys have been conducted since the early 1980s to establish the distribution of indoor radon concentrations (IRC). The aim of this work was to study the factors influencing IRC in Switzerland using univariate analyses that take into account biases caused by spatial irregularities of sampling.

Methods: About 212,000 IRC measurements carried out in more than 136,000 dwellings were available for this study. A probability map to assess risk of exceeding an IRC of 300 Bq/m^3 was produced using basic geostatistical techniques. Univariate analyses of IRC for different variables, namely the type of radon detector, various building characteristics such as foundation type, year of construction and building type, as well as the altitude, the average outdoor temperature during measurement and the lithology, were performed comparing 95% confidence intervals among classes of each variable. Furthermore, a map showing the spatial aggregation of the number of measurements was generated for each class of variable in order to assess biases due to spatially irregular sampling.

Results: IRC measurements carried out with electret detectors were 35% higher than measurements performed with track detectors. Regarding building characteristics, the IRC of apartments are significantly lower than individual houses. Furthermore, buildings with concrete foundations have the lowest IRC. A significant decrease in IRC was found in buildings constructed after 1900 and again after 1970. Moreover, IRC decreases at higher outdoor temperatures. There is also a tendency to have higher IRC with altitude. Regarding lithology, carbonate rock in the Jura Mountains produces significantly higher IRC, almost by a factor of 2, than carbonate rock in the Alps. Sedimentary rock and sediment produce the lowest IRC while carbonate rock from the Jura Mountains and igneous rock produce the highest IRC. Potential biases due to spatially unbalanced sampling of measurements were identified for several influencing factors.

Conclusions: Significant associations were found between IRC and all variables under study. However, we showed that the spatial distribution of samples strongly affected the relevance of those associations. Therefore, future methods to estimate local radon hazards should take the multidimensionality of the process of IRC into account.

1. Introduction

Radon is a naturally occurring radioactive noble gas that is a decay product of uranium. The decay products of radon are known to cause lung cancer through their accumulation in the lungs. In outdoor air, radon is strongly diluted (Vaupotic et al., 2010). However, in environments with low air exchange, such as buildings, radon concentrations are generally higher and can lead to a considerable health threat. In Switzerland, about 230 cancer deaths per year are attributable to radon (Menzler et al., 2008).

Radon concentrations in houses originate from the underlying geology, building materials and domestic water supplies. The geological parameters controlling IRC are mainly the uranium content of the ground and its permeability (Johner and Surbeck, 2001). In Switzerland, three main different geological areas are generally considered. The Alps in the south of Switzerland are

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dominated by granites and gneisses. Some of the variants of these rocks are known to be rich in uranium (Schön, 2004). In northwest Switzerland, the landscape is formed by the Jura Mountains, which are characterized by a high abundance of carbonate rock. Carbonate rock is subject to strong weathering, also called karstification. The karstification of carbonate rock results in a highly permeable cave system, which facilitates the transport of radon gas. Karstic regions are therefore known to be radon prone areas (Vaupotic et al., 2001). The Swiss Plateau is the lower part of the country. This area is located between the Jura Mountains and the Alps, is covered mainly by quaternary sediments containing partially glacial deposits originating from the Alps and is not considered an area with high radon potential. Those quaternary deposits overlay the molasse sedimentary rock (mainly detrital sediments, sandstones, shales, etc.) (Trümpy, 1980). Most of Switzerland's population resides along the Swiss Plateau.

Apart from geology, IRC are subject to several other variables, a reality which has made it difficult to develop reliable predictive models up to now. These variables can be grouped into 3 categories: spatial variability (geology, lithology, pedology) (Bossew et al., 2008; Cinelli et al., 2011; Friedmann and Bossew, 2010; Ielsch et al., 2010; Kemski et al., 2009; Miles and Appleton, 2005; Tapia et al., 2006), temporal variability (meteorology, anthropogenic influences) (Bossew and Lettner, 2007; Burke et al., 2010; Denman et al., 2007; Groves-Kirkby et al., 2006; Miles, 2001) and architectural characteristics of the structures concerned (building age, floor level, foundation, building material, building type, room type of measurement) (Friedmann, 2005; Friedmann and Groeller, 2010; Girault and Perrier, 2012; Kemski et al., 2009).

The aim of this work was to identify the relevant factors influencing IRC in Switzerland. For this purpose, univariate analyses of IRC were performed for each variable under study and maps showing the density of IRC measurement were computed for each class of variable in order to account for potential spatial biases. Using univariate analyses, we explore separately the effect of each variable on IRC while it is known that many variables may contribute to determine IRC. However, univariate analyses are more easily interpretable and may help to understand the major controls of IRC.

2. Data and methods

2.1. Data

The IRC data used in this study originates from the radon database of the Swiss Federal Office of Public Health (FOPH). The database consists of 211,714 measurements carried out in 136,401 Swiss dwellings.

The sampling strategy of the IRC data used in this study changed over the last 30 years. Initially the criterion was to obtain a minimal number of randomly measured buildings in each municipality. This strategy changed towards sampling of houses with potentially high IRC values. However, cantons with radon-prone areas tended to be more active with respect to IRC sampling.

2.1.1. Measurement characteristics

The measurements were taken with passive electret or alpha track detectors (Kotrappa et al., 1990; Nikolaev and Ilić, 1999). The detectors were sent to homeowners, who then set them out to expose them over a time period of about 3 months. Homeowners were asked to fill in a questionnaire containing details about the concerned building and the measurement conditions. We chose only those measurements which were taken in the basement, the ground-, the first- and the second floor. It was further recorded whether the room where the measurement was taken was inhabited during the measurement period. Finally, starting and ending date of the radon detector exposition were indicated. All measurements were taken between 1981 and 2012.

2.1.2. Building characteristics

The questionnaire also asked for information about the building characteristics. The relevant variables are the geographical coordinates in the Swiss geographical coordinate system (CH1903) and the building type. The database contains 9 different types of building. For convenience, we grouped them into four major types: "Apartment", "Detached House", "Farm" and "School". Furthermore, the database contains information about the type of foundation of the corresponding building. We limited our analysis to cases in which the type of foundation was uniquely indicated, which results in the three following types: "Concreted", "Concreted afterwards" and "Earth foundation". Finally, we analyzed IRC with respect to the year of the building's construction.

2.1.3. Outdoor temperature data

The Federal Office of Meteorology and Climatology "MeteoSwiss" provides access to the daily mean outdoor temperatures at 125 stations evenly distributed over Switzerland for the last decades. We downloaded the daily mean outdoor temperatures for the last 30 years (MeteoSwiss, 2013).

2.1.4. Lithological data

The lithological data we used in this study originate from the map "Lithologisch-petrografische Karte der Schweiz-Lithologie-Hauptgruppen 1:500,000" (SGTK, 2000). The map is vectorized, on a scale of 1:500,000 and consists of 70 lithological classes.

2.2. Data preprocessing

2.2.1. Coordinate corrections

The geographical coordinates of each building in the radon database of the FOPH were often not reliably indicated by the building-owners. Most of the buildings are registered in the central database of the Swiss Federal Statistical Office (FSO). This building registry provides a unique building ID with which the exact coordinate of each building can be determined. For those analyses for which the spatial distributions of the measurements were relevant we included all buildings for which this building ID was available. The altitude above sea level of each building was sampled from the digital elevation model "DHM25" which is provided by the Federal Office of Topography Swisstopo. This digital elevation model has a resolution of 25 m.

2.2.2. Random declustering and fractal dimension

Due to different cantonal sampling strategies and local differences of population density in Switzerland, the measurements of IRC in the database of the FOPH exhibit a strong spatial clustering. This leads to biased estimates especially in the estimation of IRC characteristics of geological units. To reduce this bias, we applied random declustering (Kanevski and Maignan, 2004) by creating a grid of 500 m $\times$ 500 m over all of Switzerland and by randomly sampling 6 houses in each grid cell. The degree of clustering of the point set was measured by its fractal dimension resulting from sandbox counting (Kanevski and Maignan, 2004).

2.2.3. Attribution of IRC to buildings

In about 87% of the considered houses one measurement was taken in inhabited rooms. 2 measurements of inhabited rooms were available in 10% of the houses. With the exception of the floor level analysis, we chose the maximum IRC in inhabited rooms as the unique IRC for each house. This resulted in a total of 32,151 measurements. When certain variables were unknown (e.g.