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The relation between radon in schools and in dwellings: A case study in a rural region of Southern Serbia

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ABSTRACT

Recognized as a significant health hazard, radon (Rn) has been given increasing attention for years. Surveys of different kinds have been performed in many countries to assess the intensity and the geographical extent of possible Rn problems. Common surveys cover mainly dwellings, the indoor place with highest occupancy, and schools, where people spend a large fraction of their lifetime and which can also be considered exemplary for Rn exposure at workplaces; it has however been observed that relating them is difficult. It was unclear whether residential Rn at a location, or in a region, can be predicted by Rn at a school of that location, or vice versa. To current knowledge, no general rule seems applicable, as few models to describe the relationship between Rn in dwellings and in schools have been developed.

In Southern Serbia, a Rn survey in a predominantly rural region was based on measurements in primary schools. The question arose whether or to which degree the results can be considered as indicative or even representative for residential Rn concentrations. To answer the question an additional survey of indoor Rn concentrations in dwellings was initiated, designed and performed in Sokobanja district in 2010–2012 in a manner to be able to detect a relationship if it exists. In the study region, 108 dwellings in 12 villages and towns were selected, with one primary school each.

In this paper, we investigate how a relation between Rn in schools and dwellings could be identified and quantified, by developing a model and using experimental data from both the above main and additional surveys. The key criterion is the hypothesis that the relation dwellings – schools, if it exists, is stronger for dwellings closer to a school than for those dwellings further away. We propose methods to test the hypothesis.

As result, the hypothesis is corroborated at 95% significance level. More specifically, on town level (typical size about 1 km), the Rn concentration ratio dwelling/school is about 0.8 (geometrical mean), with geometrical standard deviation (GSD) about 1.9. For dwelling and school hypothetically in the same location, the ratio is estimated about 0.7 with GSD about 1.5.

We think that the methodology can be applied to structurally similar problems. The results could be used to create "conditional maps" of Rn concentration in dwellings, i.e., for example a map of probabilities that indoor Rn concentrations in dwellings exceed 100 Bq/m^3, as function of Rn concentration in the local school.

1. Introduction

Radon is almost unanimously considered to be a major health hazard (WHO, 2009 and references therein) and therefore increasingly subject to regulation. In Europe, the latest step was

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within the European Council Directive "laying down basic safety standards (BSS) for protection against the dangers arising from exposure to ionising radiation" (EC, 2014) which have to be implemented as national law by EU Member States. Among other, the BSS require establishing reference levels for long-term indoor Rn concentration, not exceeding 300 Bq/m^3 for both dwellings and workplaces, and development of a national radon action plan. Rn studies, whether required by the action plan following the BSS or in addition, include assessment of the Rn levels, identification of regions with a significant number of buildings with elevated Rn concentration exceeding reference levels,[1] including investigation of the influence of regionally predominant building characteristics and living habits. An important tool is a Rn survey, which usually consist of measurements in a representative sample of dwellings or – increasingly frequently – of soil Rn in a geographical region, commonly defined by administrative units.

The first radon survey of a larger region of Southern Serbia has been based on primary schools. There were various reasons for this choice:

- A full residential Rn survey would include several thousands of measurements for which the means were not available;
- The logistic and administrative effort is comparatively small for a school Rn survey; given the rural character and the remoteness of parts of the region, as well as the sociological reality, representative sampling of dwellings would be very complicated;
- Practically every village has a primary school; building characteristics of village schools are quite uniform;
- Previous school surveys in other countries showed that meaningful results can be obtained (for an overview see table 4 in Bochicchio et al., 2014 and the one in Annex 1);
- Schools are workplaces that are subject to Rn regulations.

The school Rn survey covered three districts (Serbian term: *oblasti*) of South Serbia by the end of 2010 (the time when the present study was in course), covering about 4.5% of the population and 7.5% of the area of Serbia (Kosovo excluded). Specific methodology has been developed and presented, together with results, in several workshops performed in the region and published in a number of articles and international conference contributions (among others, Žunić et al., 2010, 2012, 2013; Carpentieri et al., 2011; Bochicchio et al., 2014; Bossew et al., 2014).

Naturally, the question emerged whether, or to which extent, school Rn can be regarded as indicative or representative for residential Rn. One cannot assume that mean indoor Rn concentrations observed in schools and dwellings are equal, even if the buildings are located over the same geogenic radon potential. Similarly, one cannot anticipate that Rn in a school is a valid estimate for the average residential Rn in a village or town. Possible reasons are (1) that the geogenic Rn potential of the location of the school is not representative for the residential area (e.g. if the schools are located outside or on locations which are topographically untypical, which seems to be the case sometimes in the studied region), and (2) systematically different construction styles of schools and dwellings, different occupation, usage and air exchange patterns (See also discussion in Žunić et al., 2010, and in Clouvas et al., 2011.).

Some studies tried to deal with this issue, usually by comparing radon concentration measurement results in schools and dwellings located in the same towns and accounting for some factors such as occupancy or the floor level, but usually without developing a model attempting to describe the relationship. A list (probably not complete) of such studies is given in the table in annex 1, highlighting the main conclusions about the relationship. As a summary, it seems that no general rule on the local correlation between school and residential Rn can be found, although in most cases no or weak correlation was observed. However, some authors report correlation between the spatially aggregated variables (e.g. Gaidolfi et al., 1998). Some studies find or suspect correlation of school Rn with geology or external dose rate (see annex 1).

A "satellite project" was therefore designed in 2010 and performed in 2011–2012, aimed to investigate through a specifically developed model a possible local relation between school and residential Rn concentration; "local" means, whether on a defined local scale (same village or in a hypothetic house on the same location as a school) one can infer from observed school Rn to expected Rn in dwellings. Thus, the objective of this study is finding out whether an estimate of Rn concentrations in dwellings, given Rn in schools, is possible.

One non-trivial problem in investigating such a relationship is the fact that school and residential data are not spatially "collocated", i.e. not measured at the same location. Locations separated by a distance may not be comparable because of the spatial variability of the geogenic control. If means over regions are compared, as some investigators do, one cannot be sure whether schools and dwellings are spatially uniformly or randomly distributed within the region without clustering, otherwise the consequence may be a biased mean. The design of the study presented here, nicknamed "onion" design, was chosen according to a spatial scheme and accounting for the problem addressed above, aimed to reveal such a relationship.

A larger scale survey of indoor Rn in Serbian dwellings is currently under way as part of the country's effort to implement a National Radon Action Plan in compliance with the EU-BSS, Udovičić et al. (2016). In the future, comparing the results of that large survey with those predicted by the school survey in this study, might help to decide to which degree Rn exposure deduced from school Rn measurements can be considered representative for exposure in dwellings or for overall Rn exposure.

The article is organized as follows. In Section 2, the experimental design, sampling and measurement will be described. Methods of statistical analysis will be described only in the results Section 3 because we thought that this allows following them more easily. (Explanation of certain non-standard statistical procedures has been left to a technical annex.) Section 3 starts with showing how the targeted design has been implemented (3.1), followed by univariate exploratory analysis (3.2). In the subsequent sections, the hypothesis will be tested in different ways, which motivated this study, namely, that statistical association between Rn in schools and in dwellings decreases, in tendency, with distance between their locations. Bivariate analysis (dwellings ~ schools) starts in Section 3.3 with applying logistic regression to model conditional exceedance probability of indoor Rn concentration. In Section 3.4 the covariability of Rn in schools and dwellings will be explored using cross-variogram analysis; significance tests for the cross-variogram and its shape are proposed. Another statistical test for the hypothesis underlying the "onion" design will be presented in Section 3.5. Finally, in Section 3.6, the possibility of generating a conditional risk map of Rn in dwellings in Southern Serbia is presented, derived from the previously published "school Rn" map (Bossew et al., 2014).

2. Design, materials and methods

2.1. Spatial study design and implementation in Sokobanja district

As we had to anticipate, given previous experiences of a number of authors, that a relation between school and residential Rn, if

[1] Such areas are sometimes called Rn prone areas or high-Rn areas; in view of the practical consequences, the term radon priority area has been recently proposed. The BSS (article 103, par. 3) do not provide a specific term.