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Geographical distribution of the annual mean radon concentrations in primary schools of Southern Serbia – application of geostatistical methods

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ABSTRACT

Between 2008 and 2011 a survey of radon (^{222}Rn) was performed in schools of several districts of Southern Serbia. Some results have been published previously (Žunić et al., 2010; Carpentieri et al., 2011; Žunić et al., 2013). This article concentrates on the geographical distribution of the measured Rn concentrations. Applying geostatistical methods we generate "school radon maps" of expected concentrations and of estimated probabilities that a concentration threshold is exceeded. The resulting maps show a clearly structured spatial pattern which appears related to the geological background. In particular in areas with vulcanite and granitoid rocks, elevated radon (Rn) concentrations can be expected. The "school radon map" can therefore be considered as proxy to a map of the geogenic radon potential, and allows identification of radon-prone areas, i.e. areas in which higher Rn radon concentrations can be expected for natural reasons.

It must be stressed that the "radon hazard", or potential risk, estimated this way, has to be distinguished from the actual radon risk, which is a function of exposure. This in turn may require (depending on the target variable which is supposed to measure risk) considering demographic and sociological reality, i.e. population density, distribution of building styles and living habits.

1. Introduction

1.1. The Serbian school radon survey

The Serbian indoor radon survey is based on measurements made in primary schools, performed in the framework of a research project by the Ministry of Education, Science and Technological Development of the Republic of Serbia. The first phase started in August 2008 and has so far included 340 schools in three districts (Districts of Jablanica, Districts of Pčinja and Districts of Zaječar) in South Serbia (Fig. 1).

The field activity of this phase was completed by the end of 2010. The assumptions which support the choice of schools as indicators of geographical distribution of indoor Rn are:

(1) Geographical distribution of schools reasonably is related – at least in rural regions – with distribution of the population;
(2) For the same location, Rn exposure in schools is indicative of (but not necessarily equal to) indoor Rn exposure in buildings where people spend most of their time, in general.

Apart from this, knowing Rn levels to which school children and teachers are exposed is by itself important information. Furthermore, schools are workplaces (for teachers) with public access (children) which will be subject to the forthcoming new Euratom Directive on Basic Safety Standards being approved by the European Union (European Commission, 2012).

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Fig. 1. Administrative map of Serbia; grey: regions discussed in this article. Italic: neighbouring countries.

The rationale and design of the survey and preliminary results of the indoor radon measurements in schools were published (Žunić et al., 2010; Carpentieri et al., 2011; Žunić et al., 2013) and presented at several scientific meetings[1] The radon concentration measurements have been carried out in cooperation with an Italian research team led by the Italian National Institute of Health, Rome.

A high number of primary schools, some of them very small with only few pupils, are distributed fairly uniformly over the country. This gives the chance to evaluate spatially the quantity "annual mean Rn concentration", which may be considered as realization of continuous spatial random field, in statistical terminology, and which makes it a good candidate for estimation by geostatistical methods. Applying them we generate "school radon maps" of expected mean Rn concentrations and of estimated probabilities that a concentration threshold is exceeded. On the other hand, it must be stressed that the "radon hazard", or potential risk, estimated this way, has to be distinguished from the actual radon risk, which is a function of exposure.

In several countries over the world surveys of Rn in schools have been performed (Vaupotič, 2011; for an overview see Bochicchio et al., accepted). The primary reason is of course to assess the Rn burden to which pupils and teachers are exposed. Since schools are logistically easier to access for measurements than private homes, school surveys may also give hints to the geographical distribution of Rn in general.

1.2. Factors which control indoor radon

Factors which control indoor Rn can be divided into two classes: factors related to the Rn sources and ones related to Rn infiltration and accumulation. Rn sources are geogenic Rn – in most cases the most important one – and building materials, tap water, outdoor Rn and natural gas. The extent to which *geogenic* Rn, quantified by the geogenic radon potential can contribute to indoor Rn depends on *anthropogenic* factors, related to construction of the house (mainly isolation against the ground, tightness of windows), the floor level on which the monitored room is located (the higher the floor level the lower Rn concentration in most cases) and living habits (time spent at home, frequency of opening windows etc.) Some of the anthropogenic factors are clearly related to climate, others to sociological and socio-economic factors. In short, geogenic radon represents the *hazard* which can become a *risk* under circumstances represented by anthropogenic factors.

1.3. School Rn – 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; Clouvas et al., 2011).

The relationship school Rn – residential Rn, if exists at all, it is not easy to identify. One non-trivial problem in investigating such 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.

In order to investigate whether a relationship exists in the investigated region of Southern Serbia, and whether it can be used for estimating local mean residential Rn from school Rn, a small additional project was started in 2010 in one of the investigated districts (Sokobanja Spa, District of Zajecar). Its design was chosen according to a spatial scheme and accounting for the problem addressed above, aimed to reveal such relationship. The spatial variability of controlling geogenic Rn potential is tentatively accounted for by allocating the dwellings in concentric circular zones around the schools (hence its nickname "onion design"). First, very preliminary results based on a few measurements indicate the existence of a relationship, but significance is yet poor. More robust results are expected later in 2013.

2. Methods

2.1. Experimental procedure

In all primary schools of 13 municipalities in the three districts, Rn detectors were deployed between 2008 and 2010. For details on measuring technique applied in this project, see Carpentieri et al. (2011). Further details can be found in Bochicchio et al. (accepted). In most cases Rn was measured two consecutive

[1] "Radon in Environment 2009", 10–14 May, 2009, Zakopane, Poland; 6th Conference on "Protection Against Radon at Home and Work", 13–17 September 2010, Prague, Czech Republic; Third and Forth ECE workshops, Sokobanja 5–7 July 2010 and 30 Oct – 2 Nov 2011 University of Kragujevac, Serbia, and others.