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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Prediction of indoor radon concentrations in dwellings in the Oslo region – a model based on geographical information systems" *by* R. Kollerud et al.

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We thank you for the careful review of our manuscript and all the constructive suggestions. We agree in your suggestions and will alter the manuscript as explained below.

Specific comments

Page 3049 Line 11-12 : Stated purpose a little ambitious as mentioned above. Substitute "estimate" with "assign" ?

The purpose of the study will be modified to: "The purpose of this study was to develop a best possible method for assigning inside radon concentration values to each

dwelling in the Oslo region, Norway".

I miss some basic and important information about the health issues related to radon: the only well-established risk is that of lung-cancer, so this risk should at least be mentioned.

We will include the following information regarding the risk: "Radon is an established human lung carcinogen based on experimental evidence of mutagenesis studies in cell culture and laboratory animals (Hussain et al., 1997 ; Weaver et al., 1997), and epidemiologic cohort studies among uranium miners and case-control studies in the general public (International Agency for Research on Cancer (IARC)). The International Agency for Research on Cancer considered that there is sufficient evidence of the carcinogenicity of radon and its decay products to humans (IARC, 2001 , WHO handbook, 2009) ."

Page 3047 Line 4: Correct first sentence. Only the radon isotope Rn-222 (called radon) can be considered one of the main sources for background radiation as correctly stated further down.

The first sentence will be corrected to: "222Rn is the main source of background radiation exposing humans. This is a naturally occurring radioactive gas resulting from the decay of 238U which is the most common naturally occurring uranium isotope."

Furthermore, the other important sources to ionizing radiation should be mentioned (external gamma background radiation, perhaps also ingestion of radioactivity in food and drink, medical diagnostic exposures etc.)

We will include the following regarding other important sources to ionizing radiation: "Humans are exposed to many different sources of ionizing radiation, both natural and human-made. Natural background radiation emerges from three sources: cosmic radiation, terrestrial radiation and internal radiation. Cosmic radiation comes from the sun and into the atmosphere. Terrestrial radiation is originated from radioactive materials

found in soil. The major isotopes of concern for terrestrial radiation are uranium and the decay products of uranium, such as thorium, radium, and radon. Trace amounts of radioactive minerals can be transferred to both food and drinking water. For instance, vegetables can typically be cultivated on soil containing radioactive minerals. Once ingested, these minerals result in internal exposure. In addition all people have radioactive potassium-40, carbon-14, lead-210 and other isotopes inside their bodies from birth. By far, the most significant source of man-made radiation exposure to the public is from medical procedures, such as diagnostic X-rays, nuclear medicine, and radiation therapy. Recent studies have showed an increased risk of childhood leukemia associated with natural background gamma-ray exposure (Kendall, 2013)."

Page 3049 Line 11-12 : Stated purpose a little ambitious as mentioned above. Substitute "estimate" with "assign" ? We agree and will substitute the word "estimate" with "assign".

The relevance of including maps of K-40 and thorium concentrations in the analysis are not explained. These nuclides do not have a direct causal relationship to radon concentration, as opposed to uranium-238. Ref. Scheib notes that K-40 is a good indicator for clay content and permeability, but the relevance of thorium is not explained.

We will explain the relevance of including maps of 40K and thorium as follows: "The speciïňĄc levels of terrestrial environmental radiation are related to the geological composition of each lithologically separated area, and to the content in thorium (Th), uranium (U) and potassium (K) of the rock from which the soils originate in each area. In terms of natural radioactivity, igneous rocks of granitic composition may be strongly enriched in Th and U (on an average 15 μg g-1 of Th and 5 μg g-1 1of U), compared to rocks of basaltic or ultramaïňĄc composition (<1 μg g-1 of U) (Faure, 1986 ; Me'nager et al., 1993). For that reason, higher radiation levels are associated with igneous rocks and lower levels with sedimentary rocks. A study of the presence of alum shale in the central eastern parts of Norway showed a correlation between rock type and indoor radon concentration (Smethurst et al., 2011). 10% of the homes built on alum shale

had indoor radon concentrations above 1000 $Bqm-3$. Similar studies from the UK also showed a correlation between the geology of the soil and radon concentrations in indoor air (Miles and Appleton, 2005).

Airborne radiometric data of eU, eTh and eK have been used for improving the accuracy of maps of indoor radon. Appleton et al., 2008 found good agreement between radon maps modeled from airborne radiometric data on both eU, eTh and eK and soil geochemical data compared with radon maps produced by conventional mapping, based solely on geochemical and indoor radon data. Maps modeled with airborne data on eU, eTh and eK identified some additional areas where radon risk appear to be relatively high compared to conventional radon maps. Scheib et al., 2006 report eK as a good indicator of the clay content and permeability of bedrock."

Page 3053 Line 3: Explain very briefly how the fraction of radon measurements above 200 Bq/m3 was calculated. Analyses ware made with buffers containing 20 and 30 radon measurements as is mentioned in page 3055. We will explain this further on page 3053: "In addition the percentage of radon measurements above 200 Bq/m3 in each buffer was estimated based on the procedure described in sect. 2.3.1. Buffers with 20 or more and 30 or more radon measurement was used for the analysis. A total of 6901 buffer had 20 or more measurements, 3235 buffer had 30 or more radon measurements."

Line 5-6: bedrock and eU is probably correlated, and perhaps not fully independent, does this influence analysis results? Yes, they are correlated and not fully independent, but high correlation between covariates leading to possible collinearity is not a problem in prediction models. Line 1-2: A correlation between indoor radon and uranium concentrations from airborne gamma measurements in this area was established in an earlier publication by Smethurst et al 2008. I suggest the reference to this is included here. I assume this sentence refers to analysis in the present study; this should be clarified/explained clearly.

You are right and the reference will be added. The first sentence in 4.1 will be altered to: “In this study a positive correlation was found between indoor radon concentration, bedrock geology, and airborne gamma measurements. Although this observation is consistent with previous findings (Smethurst et al., 2008; Scheib et al., 2006), the use of detailed information in our dataset allowed us to characterize, to our knowledge for the first time, the association between predicted indoor radon concentrations in each dwelling, in a region with a population size of nearly two million, and radiometric measurements of bedrock and superficial geology at the same location.”

Page 3059 Line 14-18 I suggest that radon in household water is also included on the list of factors that might affect indoor radon levels.

We will add household water in the last sentence in 4.2.: “We also lacked information regarding other factors as level of radon in household water, floor material and ventilation that also might affect the radon concentration in Norwegian dwellings.”

Technical corrections We will include all suggested corrections in the manuscript. We are sorry that we forgot to include NRPA in the acknowledgements.

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., 1, 3045, 2013.