Nat. Hazards Earth Syst. Sci. Discuss., 1, C1641–C1651, 2013
www.nat-hazards-earth-syst-sci-discuss.net/1/C1641/2013/

Natural Hazards and Earth System Sciences Discussions
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NHESSD
1, C1641–C1651, 2013

Interactive Comment

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.

R. Kollerud et al.

ruby.kollerud@hotmail.com

Received and published: 6 November 2013

We thank you for the review of our manuscript and all the constructive suggestions.

Response to comments in point 1: Smethurst study and the present study We do not agree that we had done the same as Smethurst et al. 2008 did in their study. Both studies are used the same data on geology, permeability and radiometric data but in a different way.

The aim of our study was to develop a method to assign radon values to unmeasured houses in the Oslo region. To fulfill this purpose we constructed buffers around each

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house and assigned a mean value from indoor radon measurements found in each buffer. We wanted to compare the radon values in each buffer with radiometric data (thorium, uranium and kalium) bedrock geology and permeability around the house. For testing this relationship we used results from a regression model which included the elements previously mentioned. Our aim was not to test the relationship between the elements separately. The method we used in this paper is similar to the method described by Appleton et al. 2011 and Scheib et al., 2006 in UK. Both studies used regressions models with radiometric data, geology and permeability.

Smethurst el al., 2008 presented radon hazards maps with “high” and “moderate” levels. They combined different data-sets for to give one of the two categories to large areas in the Oslo region. They studied the correlation between uranium and percent of dwellings over 200Bq. We tested the correlation between arithmetic mean of thorium, potassium and uranium with geometric mean of radon measurements found within a buffer.

Appleton JD, Miles JC, Young M. Comparison of Northern Ireland radon maps based on indoor radon measurements and geology with maps derived by predictive modelling of airborne radiometric and ground permeability data. Sci Total Environ. 2011 Mar 15;409(8):1572-83

Scheib, C., Appleton, J.D., Jones, D.J. and Hodgkinson, E. Airborne uranium data in support of radon potential mapping in Derbyshire, Central England. In: Radon Investigations in the Czech Republic XI and the Eighth International Workshop on the Geological Aspects of Radon Risk Mapping, Barnet, I., Neznal, M. and Pacherova′, P. (eds). Czech Geological Survey, Prague. 2006.

Response to comment in points 2 and 3 .

Indoor radon measurements We agree that the radon measurements can be described in a better way. We will add the following text:

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Page 3050, line 20

2.2 Data

2.2.1 Indoor radon measurements

Indoor radon measurements have been collected by the Norwegian Radiation Protection Authority (NRPA) as a result of several radon measurement campaigns in the Oslo region during the period 1998-2010 (Figure 1). The programs were largely based on measurements of indoor radon concentrations in dwellings selected at random from the housing stock (Smethurst and Strand, 2008). The measurements were performed according to the recommendations from the NRPA (NRPA, 2008) and Working Group of the effort against radon in Norway (WGR).

Radon concentrations in a home can vary over seasons. WGR recommend that measurements to assess health risks are carried by film tracks for at least two months during the period from October to April (WGR, 2007-2009). 97.5 % of the radon measurements in this study were carried out in between October and April. 82.6 % were carried out during two months or more. A total of 41,515 indoor radon measurements in the Oslo region were obtained from the NRPA radon database. For homes with multiple measurements in several rooms the average was used.

Approximately 2.5% (n=1071) of the radon measurements were lacking address information or lacking radon values and were excluded. The coordinates of the dwelling were obtained from a public registry of cadastral properties, addresses and buildings in Norway (GAB).

2.2.1.1 Type of dwelling and radon measurements

NRPA recommends anyone living in one of the three lowest floors above ground to measure the radon concentration. 98.2 % of the dwellings in the study area (except Oslo) are low-level houses (SSB, 2013). Equivalent present for Oslo are 84.3 %. The most common type of dwelling measured was detached houses with 74.5% of all radon measurements (Table 1).

87.1 % of the radon measurements used in this study was from low-level houses and 2.7% was from the first three floors of apartment buildings.

91.6% of the radon measurements had information on floor level. 99.9% of these were from below third floor. Only 14 radon measurements were made on the third floor and 67 radon measurements were made above third floor. 61 of these were from ground-contact apartments. The radon concentration in ground-contact apartments are similar to those in low-rise residential building located in the same area (Valmari et al., 2012). The 8.4 % lacking information on floor level were included because they were made in low-level houses. 66.7% of the radon measurements missing information on floor level were from Oslo. In 2008/2009 a radon survey was performed in Oslo (Helse- og velferdsetaten, 2009). An invitation letter was sent to 40 000 homeowners living on the first three floors in Oslo inviting them to measure radon in the rooms where they spend most of their time. More than 5100 homeowner participated in this campaign.

The annual average radon concentration for each dwelling was used in this study. The distribution of radon levels in dwellings approximated a log-normal distribution. We analyzed radon values for all municipalities outside Oslo in different dwelling types including underground, first and second floor. For Oslo the annual average concentration for each dwelling was already calculated by averaging the results of the radon measurements.

Since 1970′s it has been popular in Norway to share dwellings, single family house with a basement apartment with it's owns independent entrance. Around 10% of singles and single parents in Norway live in a basement flats (Lappegår and Nordvik, 1998). Lappegår and Nordvik (1998) calculated that around 6.5% of all houses in Norway are basement apartments. 25.5% of the total radon measurements were made in basements. 70.4 % of these were made in main living areas, bedrooms and others places where people spend most of their time. 0.8% of the measurements were made in non-living areas. 28.4 % lacked information on type of room. The mean radon value of measurements lacking information on type room was 181.6 Bqm−3. Since radon mean from main living room areas were 186.2 the results were pooled.

We did not have information on type of house for each dwelling unit in the Oslo region, but we had information on how many dwelling units found in each coordinate point. Coordinates for an address describes the geographic point the address refers to, and will normally specify the access to a building or dwelling.

We categorized the data as follow: if it was one dwelling unit in a coordinate point it was categorized as a detached house, if it was found two dwelling units it was categorized as a semi-detached house. It is possible that some of these dwelling units with two housing units were detached houses with a basement apartment. Coordinate points with three to four dwelling units were categorized as low-level buildings and if it was found five or more dwelling units in a coordinate point it was categorized as an apartment building. Table 2 presents a description of mean radon values according to number of dwelling units in each coordinate point.

Multiple radon value in a XY location In subtitle 2.2.1 we describe the calculation of radon values used in our study. Homes with multiple measurements in several rooms were given the average of all radon measurements made in the house. When there were two or more measured residences sharing the same XY location the radon value from the residence with the highest radon mean value was used. We did not use the highest radon measurement in the house, but the residence with the highest mean radon value. It will be explained in more detail under subtitle 2.3.1 page 3052.

1. All dwellings sharing the same coordinate point as a dwelling with at least one measurement got the same radon value or the mean radon value if the dwelling had more than one measurement. If several dwellings shared the same coordinate point the dwelling with the highest mean value in each coordinate point was used to construct buffers.

Response to comment in points 4. Table 1 is not clear enough We will describe Table 1 and the link between uranium and radium in a better way med following text:

The concentrations of Ra in some common Nordic rocks can be very high. A granitic rock containing uranium might have concentrations of 226Ra between 100 and 600 Bq/Kg. Alum shale from the Middle Cambrian period may have concentrations of 226Ra ranging from 120 to 600 Bq/Kg and alum shale from the Upper Cambrian/Lower Ordovician may have 226Ra concentrations from 600 to 5000 Bq/Kg (NRPA, 2012).

Bedrock geology was coded into four categories according to the uranium content in the different rock types: low (gneiss, mafic intrusives and sediments), moderate (monzonite, latite, syenite and trachytes), high (granite and rhyolite) and very high (alum shale). A more detailed description can be found in Smerthurst et al. (2008). (Table 3).

Response to comment in points 5. Season during indoor radon measurements were done

We will describe this in a better way with follows text: Radon concentrations in a home can vary over seasons. Working Group of the effort against radon in Norway (WGR) recommend that measurements to assess health risks are carried by film tracks for at least two months during the period from October to April (WGR, 2007-2009). 97.5 % of the radon measurements in this study were carried out in between October and April. 82.6 % were carried out during two months or more.

The other points that deserve further attention are described below (P and L mean page and line, respectively):

1) P3046 L3: Please correct “indoor radon concentration measurement”. Avoid this type of jargon throughout the text.

The sentence is changed to “radon concentration values”.

2) P3046 L15-18: This sentence is not clear. Plus a sentence about interest of this manuscript for further studies should be inserted at the end of the abstract.

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The abstract have been modified in the following way:

Radon exposures were assigned to each residential address in the Oslo region using a geographic information system (GIS) that included indoor radon measurements. The results will be used in an epidemiologic study regarding leukemia and brain cancer. The model is based in 6% of measured residential buildings. High density of indoor radon measurements allowed us to develop a buffer model where indoor radon measurements found around each dwelling were used to assign a radon value for homes lacking radon measurement.

Intraclass Correlation Coefficients (ICCs) was used to study agreement between radon values from the buffer method and radon values from indoor radon values from measured houses and from a regression model constructed with radiometric data (eTh, eU)) and bedrock geology. We obtained good agreement for both comparisons with ICC values between 0.54 and 0.68.

GIS offers a useful variety of tools for to study indoor-radon exposure assessment. By using the buffer method it is more likely that geological conditions are similar within the buffer and this may take more into account the variation of radon over short distances. It is also probable that short distance scale correlation pattern express similarities in house styles and living habits. Although the method has certain limitations, we regard it as acceptable for use in epidemiological studies.

3) P3046 L21: I do not used to read or write papers with sentence at present form when presenting previous studies. The sentence is changed to: Norway has some of the highest concentrations of indoor radon in the world (Stigum et al., 2003; Stranden et al., 1986) in homes with an average radon concentration of 88 $Bqm-3$ and 27% of the population is exposed to levels higher than 100 $Bqm-3$.

4) P3047 L9-11: This sentence needs to be rewritten. The other radon isotopes have short half-life and are therefore not regarded as a health issue.

5) P3047 L27-28: Be cautious when dealing with timber. Differences can be observed for instance between coniferous and deciduous woods. Probably you are right. Unfortunately it was not easy to find relevant studies regarding the presence of radon in the wood. For this reason we can comment this on our article. 6) P3050 L6: Please correct “within few meters”.

The sentence is changed to: “within five meters”.

7) P3051 L14-18: I am not sure potassium equivalent concentration exists. Please check.

eK is changed to “K”

8) P3053 L11-14: Please rewrite. Please correct everywhere “measures” with “measurements”.

The word “measures” is replaced with “measurements”.

9) P3053 L15-16: Please be consistent writing “dataset” or “data set”. I would suggest “data-set”.

The word “dataset” or “data set” is replaced with “data-set”.

10) P3053 L22: Please correct “assess”.

The word “asses” was replaced with “assess”.

11) P3053 L23: Please correct “and can be interpreted”. The sentence “can interpreted” is replaced with “can be interpreted”.

12) P3054 L24: Please correct “Pearson”. The word “Person” is replaced with “Pearson”.

13) P3054 L26 to P3055 L4: Please rewrite these sentences. I hope the reader knows the difference between AM and GM: please remove the definition parts. Please correct “these data were closer”.

We think it is important to have some words on the difference between arithmetic and geometric mean. Results from this study probably will be red of others researchers specialist in epidemiology and other disciplines who may don't have the same understanding on these differences.

14) P3055 L16: Space is missing "K and eU". A space between K and eU is given.

15) P3056 L3: I do not understand the adjective "continuous" here as measurements were only punctual in time. We took away the word "continuous" from the sentence.

16) P3057 L4: Please rewrite this part of the sentence. We had modified the sentence to: Miles and Appleton, (2005) also used a kind of buffer method with no predefined limit to get at least 30 indoor radon measurements as basis for calculations of radon values that would be given to the whole square.

17) P3057 L7: Please correct with "percent". The word "present" is replaced with "percent".

18) P3057 L21: Please check the reference. The reference is according with our intention

19) P3058 L24: Please correct "the number of measurements". The sentence "number radon measurements" is replaced with "the number of measurements".

20) P3059 L10: It seems that the extrapolation is only useful when the site is slightly urbanized? Please be cautious with your conclusions here. We found a good agreement in both dense and sparsely populated areas. We noted that in sparsely populated areas ICC was much higher than in dense populated areas. Oslo had the lowest ICC and we tried to find explanations. About Oslo we will add the following text in page3059 L10 The Oslo region is an area with low-level houses, 98.2% of houses in all municipalities (except Oslo) are detached, semi-detached and row houses. Oslo is a large city with mainly apartment building (15.5%). This is a possible explanation why the city of Oslo got some of the lowest ICC values.

21) P3059 L12-18: This paragraph is important but should be inserted before in the methodology section (and should be deepened). Factors that might influence the radon concentration in dwellings are already mentioned in the manuscript in the introduction section.

22) P3059 L20 to P3060 L17: In general a conclusion section is not a simple recall of all the points addressed in the paper. Rather it recalls briefly the main points, present future strategies to improve the current paper and opens perspectives.

We have restructured the conclusion as follows:

Conclusions

The exposure assessment in an epidemiological study often depends of the type of data available. In the Oslo region we had indoor radon measurements in 6% of the residential buildings. We had also information on bedrock geology and radiometric data. This allowed us to develop a buffer model where we used indoor radon measurements found around each dwelling to assign a radon value for homes lacking radon measurement. Radon value from buffers were compared to radon values from a regression model constructed with radiometric data, equivalent concentrations of thorium (eTh), uranium (eU)) and bedrock geology. We found good agreement.

Over 70% of the buffers had a radius between 300 and 500 meters. By using the buffer method it is more likely that geological conditions are similar within the buffer and this may take more into account the variation of radon over short distances. There is probably also that short distance scale correlation pattern in Norway express similar house styles and living habits. Although the method has certain limitations, we regard it as acceptable for use in epidemiological studies.

23) P3060 L22: Please correct with “Smethurst”. Please check carefully the reference list and the paper to remove all the potential typos that may remain. The name “Amethrurst” is replaced with “Smethurst”.

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24) Table 2: Please correct the third line using English words. Table 2. The word "Bedrok is replaced with "bedrock" and "nummer" is replaced with "number"

25) Fig 2: There is no scale/coordinates in this figure. We have included coordinates in Figure 2.

26) Fig 3: I am not sure this flow chart is essential for the understanding of your method. Please also correct the Norwegian words with appropriate English words ("og" with "and" for example). We think it makes it easier for persons not familiar with geology field to understand the method. We have replaced the word "og" with "and". We have also incorporated former figur 5 (the buffer figur). (Figur 3).

27) Fig 5: Please correct 'Percent". This type of plot is not sufficiently clear. We have excluded Figure 5 from the article

28) I suggest inserting other figures as introduced above presenting the indoor radon concentration data-set to strengthen the impact of the manuscript. We have made a figure presenting radon measurements and dwelling density in the Oslo region. (Figure 1).

Please also note the supplement to this comment:
http://www.nat-hazards-earth-syst-sci-discuss.net/1/C1641/2013/nhessd-1-C1641-2013-supplement.pdf

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