A national radon hazard map of Norway based on geology and indoor radon

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12th International Workshop on the Geological Aspects of Radon Risk Mapping, 16-18 September 2014, Prague

1. NGU (Geological Survey of Norway)
2. Avalonia Geophysics and University of Exeter
3. NRPA (Norwegian Radiation Protection Authority)
AIMS:
• study relationship between geology and radon
• produce national map

Issues in Norway
• lack of national datasets for eU, soil-gas
• sparse population, indoor radon

⇒ characterise geology using indoor radon
⇒ project this to areas without indoor radon data
1. Background - previous studies
2. Datasets – geology + indoor
3. Statistical analysis
4. Map creation
5. Future work – airborne eU
Radon hazard in Norway

Å 300 deaths per year  
Å 200 Bq/m$^3$ maximum level, 100 Bq/m$^3$ action level  
Å average in Norway ca 90 Bq/m$^3$

Radon hazard map 2008, Oslo region

Possible data sources:

- Indoor radon concentrations
- Bedrock geology
- Drift geology
- Airborne Gamma Ray Spectrometry
- Soil gas, permeability
- Chemical
- Groundwater
Airborne radiometric surveys in Norway

Radiométriques sur vol et hélicoptère en Norvège
Dataset: Indoor Radon

Year average indoor radon concentrations (NRPA)

- 34563 geo-referenced measurements
- ground floor living rooms and ground floor bedrooms
Norwegian contribution to the European Indoor Radon Map
July 2014

10 km grid based on 34563 annual average radon concentration measurements from ground floor living rooms and ground floor bedrooms (GRISO Lambert Azimuthal Equal Area projection)

Number of data in each grid cell:
1 - 58
59 - 176
177 - 381
382 - 705
707 - 1468
Norwegian contribution to the European Indoor Radon Map
July 2014

10 km grid based on 34563 annual average radon concentration measurements from ground floor living rooms and ground floor bedrooms (EPSG Lambert Azimuthal Equal Area projection)

Geometric mean radon concentration
Bq/m³

- Blue: 1 - 14
- Light blue: 15 - 46
- Light green: 47 - 72
- Yellow: 73 - 117
- Orange: 118 - 2380

Statenstilsvevet
Bedrock geology
1:250,000
Drift geology

1: 1M
1: 250,000
1: 50,000
Thick and continuous drift deposits
Analysis

- Form union of bedrock/drift datasets
  - 838995 polygons
  - Use combined bedrock / drift geology as class

- Use ANOVA to study the influence of geology classes on the variance in radon
## Analysis

<table>
<thead>
<tr>
<th>Dataset</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedrock geology</td>
<td>31697</td>
</tr>
<tr>
<td>Drift geology</td>
<td>616761</td>
</tr>
<tr>
<td>Combined bedrock and drift geology</td>
<td>838995</td>
</tr>
<tr>
<td>Units with at least one indoor radon measurement ($nR_{unit} \geq 0$)</td>
<td>5714</td>
</tr>
<tr>
<td>Units with at least 10 indoor radon measurements ($nR_{unit} \geq 10$)</td>
<td>696</td>
</tr>
</tbody>
</table>

**Terminology:**
- **Unit**: polygon formed by union of bedrock and drift geology
- **Class**: bedrock/drift type of a particular *unit*
- **$R$**: annual average radon concentration for a given dwelling (room)
- **$P_{200}$**: proportion of dwellings in a *unit* that have $R > 200$ Bq/m³
- **$nR_{unit}$**: number of $R$ measurements for a given *unit*
- **$nR_{class}$**: number of *units* for a given *class*
Analysis

• **ANOVA:**
  - Proportion of variance explained by geology:
    • Combined bedrock/drift categories
    • Bedrock categories
    • Drift categories
  - More detailed drift and bedrock classifications explain more of the variation
### Analysis

#### ANOVA:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Indoor radon measure</th>
<th>Proportion of variance(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_{\text{R}_{\text{unit}}} \geq 10$</td>
<td>$\ln(R)$</td>
<td>20.0</td>
</tr>
<tr>
<td>$n_{\text{R}<em>{\text{unit}}} \geq 10$, and $n</em>{\text{R}_{\text{class}}} \geq 10$</td>
<td>$\ln(P)$</td>
<td>39.5</td>
</tr>
</tbody>
</table>

- 20% of indoor radon explained by geology
- 40% of ($P>200$) for polygon explained by geology
• For each unit, aim to calculate a proportion $P$ of dwellings in unit which have $R > 200$ Bq/m$^3$

• For units where we have sufficient $R$ measurements:
  – use data from unit.

• For units with insufficient $R$ measurements:
  – use data from *national average* for class of that unit

• If
  – $P \geq 0.2$ Particularly radon-prone
  – $P < 0.2$ Not particularly radon-prone
### Determination of $P$

<table>
<thead>
<tr>
<th>$nR_{\text{unit}}$</th>
<th>$nR_{\text{class}}$</th>
<th><strong>Determination of $P$</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\geq 30$</td>
<td></td>
<td>Determine $P$ from geological unit</td>
</tr>
<tr>
<td>$&lt; 30$</td>
<td>$\geq 30$</td>
<td>Determine $P$ from geological class</td>
</tr>
<tr>
<td>$&lt; 30$</td>
<td>$&lt; 30$</td>
<td>Insufficient data to determine $P$</td>
</tr>
</tbody>
</table>
Wilson score for confidence in proportion:


Generate $C_H$ and $C_L$ for desired intervals

Intervals 95%, 80% and 70%
<table>
<thead>
<tr>
<th>Confidence limits</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>C95_L &gt;= P_0</td>
<td>95% confidence of being particularly radon-prone</td>
</tr>
<tr>
<td>C95_L &lt; P_0 &lt;= C80_L</td>
<td>80% confidence of being particularly radon-prone</td>
</tr>
<tr>
<td>C80_L &lt; P_0 &lt;= C70_L</td>
<td>70% confidence of being particularly radon-prone</td>
</tr>
<tr>
<td>C70_L &lt; P_0 &lt;= C70_H</td>
<td>May or may not be particularly radon-prone</td>
</tr>
<tr>
<td>C70_H &lt; P_0 &lt;= C80_H</td>
<td>70% confidence of not being particularly radon-prone</td>
</tr>
<tr>
<td>C80_H &lt; P_0 &lt;= C95_H</td>
<td>80% confidence of not being particularly radon-prone</td>
</tr>
<tr>
<td>C95_H &gt;= P_0</td>
<td>95% confidence of not being particularly radon-prone</td>
</tr>
</tbody>
</table>

\[ \bar{P}_0 = 0.2 \]
Naive Bayes Classifier

- 142 instances (geological units)
- 2 categorical features: Bedrock (37 categories), Drift (22 categories)
- 2 output classes:
  - Based on GM of indoor radon in geological unit
  - Percent over 200 Bq/m³
  - LOW (0-20 %)
  - HIGH (> 20%)
Naive Bayes Classifier

5-fold cross-validation:

<table>
<thead>
<tr>
<th>Actual class</th>
<th>Predicted class</th>
<th>HIGH</th>
<th>LOW</th>
<th>Total</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIGH</td>
<td>HIGH</td>
<td>27</td>
<td>13</td>
<td>40</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>LOW</td>
<td>41</td>
<td>61</td>
<td>102</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>68</td>
<td>74</td>
<td>142</td>
<td></td>
</tr>
<tr>
<td>Predictive value</td>
<td></td>
<td>0.40</td>
<td>0.82</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Classifier accuracy CA: 0.62
Matthews Correlation Coefficient MCC: 0.25
CONCLUSIONS

• Examined relationships between geological categories and indoor radon

• Geological factors explain around:
  – 20% of variance of ln(R)
  – 40% of variance of ln(P_{200})

• Can produce national radon probability maps from geology-based classifier trained on indoor concentrations
  – assumes geological properties for given class are the same nationally
  – does not take account of inhomogeneities inside geological units

• Other classification methods being investigated

• No AGRS data included at present – study using eU underway

THANK YOU!