A radon mapping exercise within the European MetroRadon project

Valeria Gruber, Sebastian Baumann, Wolfgang Ringer

AGES-Austrian Agency for Health and Food Safety, National Radon Centre, Linz, Austria

& data providers & participants of the exercise
Co-Authors

Thanks to all for your contribution!

- C. Sainz, L. Quindós-Poncela, University of Cantabria, Santander, Spain
- G. Cinelli, European Commission, JRC, Directorate for Nuclear Safety & Security, Ispra, Italy
- J.-L. Gutierrez Villanueva, Radonova Laboratories AB, Uppsala, Sweden
- G. Ciotoli, Italian National Research Council, CNR-IGAG, Rome, Italy
- C. Laubichler, O. Alber, AGES, Graz, Austria
- A. Pereira, F. Domingos, University of Coimbra, Coimbra, Portugal
- E. Petermann, P. Bossew, Bundesamt for Strahlenschutz (BfS), Berlin, Germany
- F. Tondeur, Brussels, Belgium
MetroRADON

Metrology for Radon Monitoring

- European Metrology Programme for Innovation and Research (EMPIR)
- June 2017 – May 2020
- 17 European partners, collaborators
- QA “chain” from primary standards to radon maps
MetroRADON

WP4 - „Radon priority areas“ - Tasks

- Evaluation of the concepts for the definitions of radon priority areas
- Relationship between indoor radon concentration and geogenic radon
- New developments in estimation of radon priority areas
- Harmonisation of radon priority areas across borders

The exercise: "Test existing mapping methods used in various countries with different datasets and evaluate their usability for other countries"

- Find usable datasets and prepare them for the exercise
- Find participants/volunteers
- Participants apply their mapping method and definition of radon priority areas
- Analyse, compare, evaluate results
Data Sets
Austria and Spain
Data Set Austria

Extensive survey in 6 municipalities – IRC (1638 households), soil gas & permeability (~ 150 locations), soil samples, ADR (~ 100 locations)

Additional data from literature (geology, soil map etc.)

All data available in shp-files and tables; georeferenced
Data Set Cantabria

- Measurement data from different surveys (IRC (480), soil gas (260), ADR (80))
- Additional data from literature (geology, karst etc.)
- All data available in shp-files and/or tables; georeferenced

~5.300 km²
## Data Sets – Data extent / quality

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cantabria</th>
<th>Austria</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRC</td>
<td>location approx., low sample density</td>
<td>exact location, high sample density</td>
</tr>
<tr>
<td>Soil air Rn</td>
<td>measured; similar</td>
<td>measured; similar</td>
</tr>
<tr>
<td>Act. conc. in soil</td>
<td>European K, Th, U in soil maps (JRC) 10x10 km grid AM/GM (FOREGS, GEMAS)</td>
<td>40K, 210Pb, 226Ra, 228Ra, 228Th, 238U measurements</td>
</tr>
<tr>
<td>ADR</td>
<td>measured; similar</td>
<td>measured; similar</td>
</tr>
<tr>
<td>Faults</td>
<td>map; similar</td>
<td>map; similar</td>
</tr>
<tr>
<td>Geology</td>
<td>map; similar</td>
<td>map; similar</td>
</tr>
<tr>
<td>Permeability</td>
<td>estimates derived from lithological units</td>
<td>Soil permeability measurements + estimates derived from soil units</td>
</tr>
<tr>
<td>Karst</td>
<td>Binary, derived from lithological units</td>
<td>Questionnaire; at location of IRC</td>
</tr>
<tr>
<td>Building characteristics</td>
<td>-</td>
<td>Soil unit, water conditions, soil depth, ...</td>
</tr>
<tr>
<td>Soil map</td>
<td>-</td>
<td>eU; measured only North region</td>
</tr>
<tr>
<td>Airborne radiometry</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
Mapping Methods

Basic statistics (IRC)

<table>
<thead>
<tr>
<th>Area</th>
<th>AM</th>
<th>GM</th>
<th>Med</th>
<th>% &gt; 300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cantabria</td>
<td>97</td>
<td>54</td>
<td>54</td>
<td>3</td>
</tr>
<tr>
<td>N Mun. 1</td>
<td>289</td>
<td>196</td>
<td>197</td>
<td>31</td>
</tr>
<tr>
<td>N Mun. 2</td>
<td>313</td>
<td>207</td>
<td>213</td>
<td>36</td>
</tr>
<tr>
<td>N Mun. 3</td>
<td>429</td>
<td>273</td>
<td>266</td>
<td>45</td>
</tr>
<tr>
<td>S Mun. 4</td>
<td>289</td>
<td>165</td>
<td>168</td>
<td>28</td>
</tr>
<tr>
<td>S Mun. 5</td>
<td>251</td>
<td>157</td>
<td>144</td>
<td>22</td>
</tr>
<tr>
<td>S Mun. 6</td>
<td>234</td>
<td>146</td>
<td>130</td>
<td>21</td>
</tr>
</tbody>
</table>

![Map of AM Municipality](image)
Mapping Methods

Belgian Radon Mapping software (F. Tondeur)

- Map variation of radon risk within geological units
- Moving average method
- Geological units with significantly different levels of risk – separately
- 500 m x 500 m grid


Mapping Methods

GAMM (AGES, AT)

- Generalised Additive Mixed Model for log(IRC) (Gaussian)
- 5-fold cross validation; stepwise forward selection
- Define relevant variables for model
- Prediction of IRC for location/grid cell/municipality
Mapping Methods

Ordinary kriging OK, Indicator kriging IK & more
(E. Petermann; P. Bossew)

- ANOVA for target variables
- AT: High density of IRC; sufficient for radon risk estimation
- AT: Geogenic covariates as IRC predictor weak; best GRP (Soil radon & perm.)
- ES: No spatial autocorrelation of IRC → OK of soil gas radon; GRP calculated; Correlation between GRP and IRC weak

Variogram of binary coded IRC (AT north) (0 < 300 Bq/m³; 1 ≥ 300 Bq/m³).
Empirical data (crosses), fitted model (solid line).

<table>
<thead>
<tr>
<th>Z</th>
<th>Upper Austria</th>
<th>Styria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rn(soil)</td>
<td>0.5</td>
<td>0.75</td>
</tr>
<tr>
<td>GRP</td>
<td>0.45</td>
<td>0.8</td>
</tr>
<tr>
<td>ADR</td>
<td>0.15</td>
<td>0.35</td>
</tr>
<tr>
<td>$^{40}$K</td>
<td>-</td>
<td>0.6</td>
</tr>
<tr>
<td>$^{226}$Ra</td>
<td>-</td>
<td>0.8</td>
</tr>
<tr>
<td>$^{238}$U</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>eU</td>
<td>0.3</td>
<td>n.a.</td>
</tr>
<tr>
<td>PC1</td>
<td>0.3</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Correlation of variable Z with IRC; AT
Mapping Methods

Empirical Bayesian Kriging Regression EBKR (G. Ciotoli)

- Combines Kriging with regression analysis for more accurate predictions
- Uses response variable (soil gas Rn) and raster layers of the proxies
- GRP map – mainly faulted areas and high permeability areas affect radon in soil air
Geogenic Radon Potential Map – Testing of Correlation between variables and spatial variability

(A. Pereira, F. Domingos)

Mapping Methods

Austria:
• Lack of significance between ADR, eU and other parameters
• No clear spatial correlation for soil gas radon, perm., ADR, soil conc.
• No prediction of GRP possible
• Only AT North: IRC of earthbound rooms show significant differences in soil characteristics, bedrock units, permeability

Spain:
• IRC, ADR, soil gas radon show significant differences in different bedrock units – but no correlation among them
• No clear spatial correlation for IRC and soil gas radon (omnidirectional variograms)
• No prediction of GRP possible
<table>
<thead>
<tr>
<th></th>
<th>AM</th>
<th>GM</th>
<th>Med</th>
<th>% &gt; 300</th>
<th>Med (BE)</th>
<th>% &gt; 300 (BE)</th>
<th>GM GAMM (AT)</th>
<th>OK (DE)</th>
<th>IK % (DE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cant.</td>
<td>97</td>
<td>54</td>
<td>54</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>54</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mun. 1</td>
<td>289</td>
<td>196</td>
<td>197</td>
<td>31</td>
<td>231</td>
<td>40</td>
<td>243</td>
<td>352</td>
<td>86</td>
</tr>
<tr>
<td>Mun. 2</td>
<td>313</td>
<td>207</td>
<td>213</td>
<td>36</td>
<td>240</td>
<td>41</td>
<td>201</td>
<td>360</td>
<td>39</td>
</tr>
<tr>
<td>Mun. 3</td>
<td>429</td>
<td>273</td>
<td>266</td>
<td>45</td>
<td>230</td>
<td>39</td>
<td>208</td>
<td>367</td>
<td>39</td>
</tr>
<tr>
<td>Mun. 4</td>
<td>289</td>
<td>165</td>
<td>168</td>
<td>28</td>
<td>209</td>
<td>38</td>
<td>153</td>
<td>305</td>
<td>26</td>
</tr>
<tr>
<td>Mun. 5</td>
<td>251</td>
<td>157</td>
<td>144</td>
<td>22</td>
<td>183</td>
<td>32</td>
<td>241</td>
<td>300</td>
<td>26</td>
</tr>
<tr>
<td>Mun. 6</td>
<td>234</td>
<td>146</td>
<td>130</td>
<td>21</td>
<td>173</td>
<td>31</td>
<td>310</td>
<td>304</td>
<td>26</td>
</tr>
</tbody>
</table>

RPA: Prob (IRC > 300) > 10%

RPA: AM/GM/Med > 300

RPA: AM/GM/Med > 100
Summary & first conclusions

MetroRn mapping exercise

- Different methods applied; exercise data are challenging
- Not all methods are suitable for all data/areas (depends on data quality, sampling density, heterogeneity of the area, etc.)
- Different mapping methods, but definition of RPA in many countries similar
- Radon-characterisation of areas: different methods deliver similar results, depending on definition of RPA

Next steps:
- Collect more inputs/contributions
- Continue with analysis and evaluation
- MetroRADON report (available at metroradon.eu)
- Peer reviewed paper
This work is supported by the European Metrology Programme for Innovation and Research (EMPIR), JRP-Contract 16ENV10 MetroRADON (www.euramet.org). The EMPIR initiative is co-funded by the European Union’s Horizon 2020 research and innovation programme and the EMPIR Participating States.