Relationships between geogenic radon potential and gamma ray maps with indoor radon levels at Caprarola municipality (central Italy).

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The LIFE-Respire partnership

RESPIRE
Radon real time monitoring system

DURATION:

Start date 01/09/2017 End date 31/08/2020

Centro di Ricerca, Previsione, Prevenzione e Controllo dei Rischi Geologici, Sapienza Università di Roma, Rome – Italy (project leader)

Istituto di Geologia Ambientale e Geoingegneria, Consiglio Nazionale delle Ricerche, Rome - Italy

Istituto Nazionale di Geofisica e Vulcanologia, Rome - Italy

Federal Agency for Nuclear Control, Brussels, Belgium

Research Institutes

Elica S.p.A., Fabriano (AN), Italy

Industry

The LIFE-Respire project objectives

Radon r**E**al time monitoring **S**ystem and **P**roactive **I**ndoor **Re**mediation

1. To demonstrate in 4 significant areas, with different GRP in Italy and Belgium, a cost-effective and eco-friendly solution for Rn real-time measurement and remediation **to keep indoor Rn levels below 300 Bq/m^3 level** (as indicated in European Directive 2013/59/EURATOM).

2. To realize and install an intelligent and adaptable hybrid Rn remediation system composed by sensors, an Air Quality Balancer (called SNAP) and an external additional fan-system (eolian and/or electric) working on positive pressure method.

3. To construct a real time LIFE-RESPIRE geodatabase of collected continuous Rn measurements, coupled with other geological and geochemical data, as well as building characteristics.

4. To provide local authorities with Rn hazard guidelines, i.e., guidance about Indoor Radon Abatement Acts, and about the risk, measurement and remediation of radon in workplaces and schools; **and real-time WebGis radon maps** for land use planning and health risk assessment, helping to prepare relevant national action plans (Articles 54, 74 and 103 in 2013/59/EURATOM).

RESPIRE
Radon real time monitoring system

Respire project activities

Preparatory actions

- A1 Caprarola Site Characterization
- A2 Permissions for Demonstration cases implementation

Implementation actions

- B1 Prototype assembly and tests
- B2 Implementation of demonstration cases including remediation measures
- B3 Monitoring and WebGis
- B4 Replicability potential evaluation and demonstrative case in Belgium

Monitoring of the impact of the project actions

- C1 Monitoring of project impact indicators and LCA
- C2 Socio-economic impact assessment

E Management

Public awareness and dissemination of results

- D1 Dissemination planning and execution
- D2 Networking

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Radon real time monitoring system

Objectives

1. To construct the geogenic radon potential (GRP) map of the Caprarola municipality (northern Lazio, central Italy) by using multivariate regression model (Empirical Bayesian Kriging Regression, EBKR)

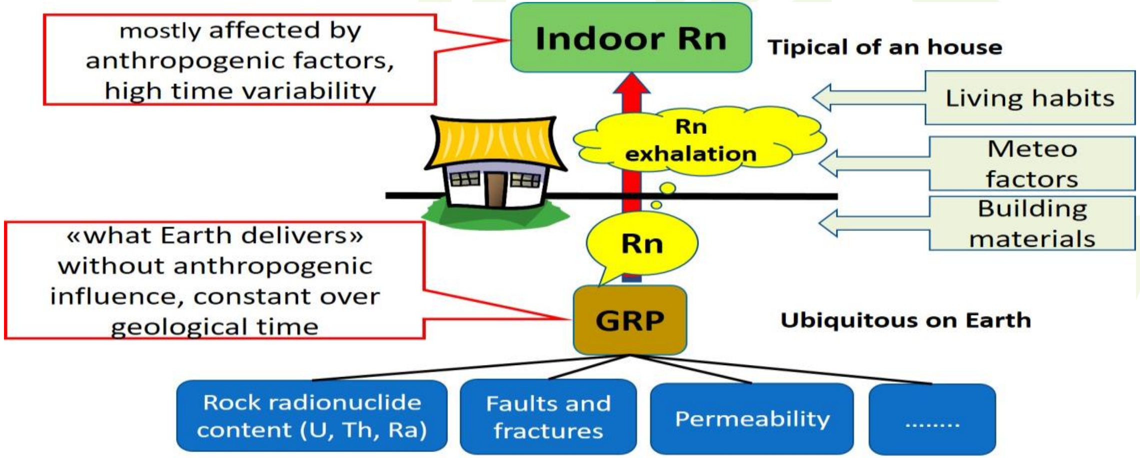
2. To study the relationships between:

- GRP and Rn indoor
- Terrestrial gamma dose rate and Rn indoor
- Indoor gamma dose rate and Rn indoor.

Rationale

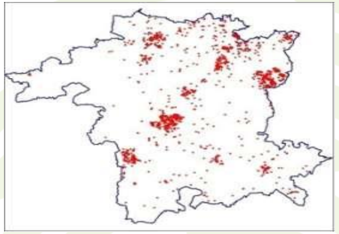
- The Geogenic Radon Potential (GRP) defines the availability of radon generated in the ground for surface exhalation or infiltration into buildings.
- **<u>GRP of an area is directly measurable in the field by the Rn concentrations in the soil pores.</u>** These quantities actually are available only regionally and/or locally.

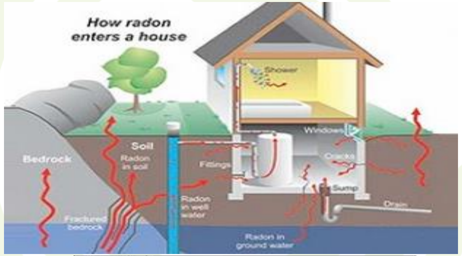
- Other factors control the GRP of a region: the source and the transport in the ground.
- The transport is additionally affected directly/indirectly by factors related to tectonics, and geodynamic features i.e., active faults, seismicity, geothermal activity and volcanism.

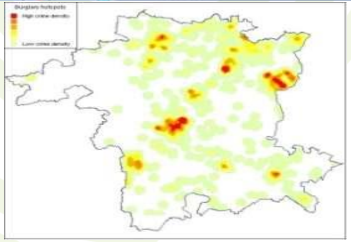


The indoor radon mapping problem

- The spatial distribution of indoor Rn samples at large scale is often clustered
- Indoor Rn usually shows strong variability at least on short geographic scale (i.e., non-autocorrelated and non-stationary spatial behavior) because of its multifactorial dependence (i.e., physical, meteorological and anthropic parameters)
- The direct interpolation of indoor Rn values beyond the boundary of an urban area could be a difficult and non-robust procedure to accomplish







The radon mapping problem

- Alternative approaches consider the costruction of Geogenic Radon Potential (GRP) maps by using available geological and geochemical information (i.e., rock permeability, faults, radionuclide content, etc.), calibrated by using soil gas radon.
- These data are more suitable to construct GRP maps because they are characterised by:

- higher spatial autocorrelation
- lower variability
- not depend by anthropogenic factors

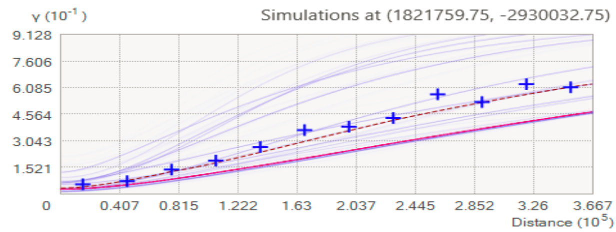
Methods

How Empirical Bayesian Kriging Regression works

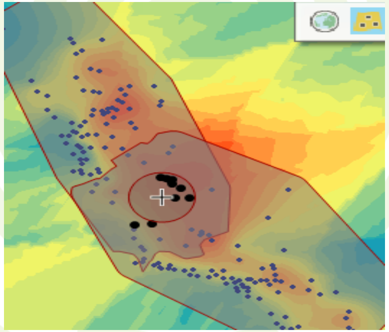
- Empirical Bayesian Kriging Regression (EBKR) combines ordinary least square (OLS) regression and simple kriging to provide accurate predictions of moderately non-stationary data at a local level. It accounts for these local effects by dividing the input data into subsets of a given size before doing any modeling.

- EBKR estimates the semivariogram through a process of subsetting and repeated simulations and transforms the proxy variables into their principal components, that are used as the explanatory variables in the regression model. The PCs transformation also solves the problem of multicollinearity because each PC is uncorrelated with the others.

- Each principal component captures a certain proportion of the total variability of the explanatory variables; (in general few principal components up to 70% of the total variability).



Simulated semivariograms. Empirical semivariances fall in the middle of the spectrum



Prediction with subsets

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Methods
Empirical Bayesian Kriging Regression

Advantages of EBKR

- Requires minimal interactive modelling
- Allows accurate predictions of non-stationary data
- Uses **local models** to capture small scale effects
- More accurate than other kriging methods for small datasets

Disadvantages of EBKR

- Processing is slower than other kriging methods
- Anisotropy is unavailable

Hengl T., Heuvelink G.B.M.,Rossiter D.G. (2007). **About regression-kriging: From equations to case studies.** **Computers & Geosciences**, 33 (10),1301-1315

The study area
Caprarola municipality (central Italy)

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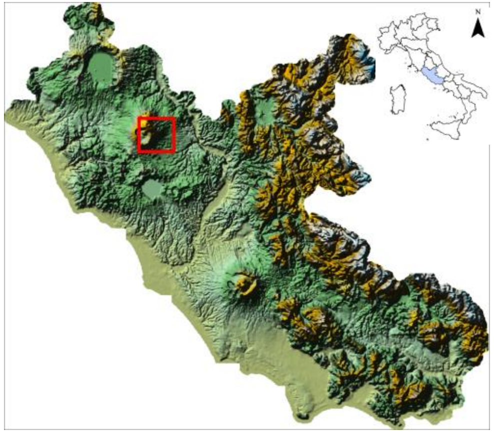
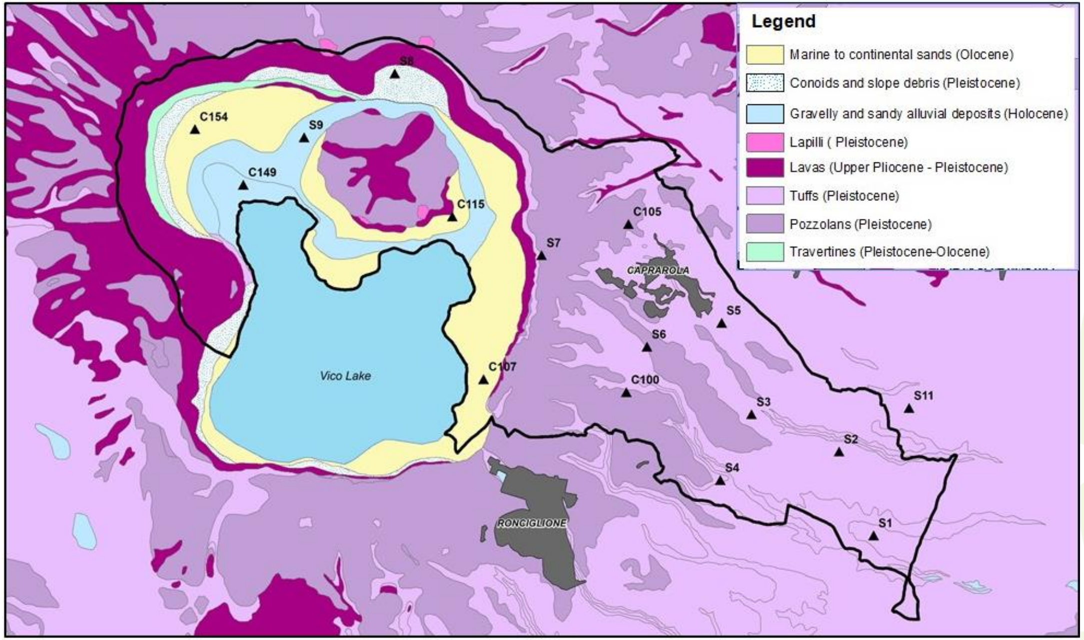
The study area is located about 100 km N of Rome, in central Italy.



Methods
Geological setting



Simplified geology of the Caprarola municipality modified after the Geological Map of the Lazio Region (scale 1:25000) (Cosentino and Pasquali, 2012).

- volcanic rocks (tuffs and lavas), outcropping in whole area.
- sedimentary rocks (recent and lake deposits, mainly outcropping in the Western sector of the area.

- The volcanic products are particularly enriched on natural radionuclides, and they were traditionally used as building materials in the old center of the Caprarola village.

▲ Soil samples

Methods
The Proxy variables

- **Radionuclide content in Bq/kg (226Ra, 238U, 232Th, 40K) averaged on lithological types.** 16 samples (high-resolution gamma spectrometer equipped with a low-background HPGe coaxial detector, GEM – EG&G ORTEC)
- **EMAN =** Emanation coefficient, averaged on lithology →

$$\eta = \frac{Rn_{cp}}{Rn_{tot}} = \frac{Rn\ amount\ in\ connected\ pores}{total\ Rn\ amount}$$

(Sasaki et al., 2004)

- **Diffusive RnFLUX** from the soil, averaged on lithology and calculated by →

$$J = \eta\rho_p(1-\varphi)\ 226Ra\sqrt{\lambda D_0\, e^{-\left(6\varphi R_s + 6R_s^{14\varphi}\right)}}$$

(Voltaggio et al., 2006)

- **GAMMA = Terrestrial gamma dose rate** → 187 samples

(NaI γ-ray portable scintillometer Scintrex GRS-500) Ordinary Kriging

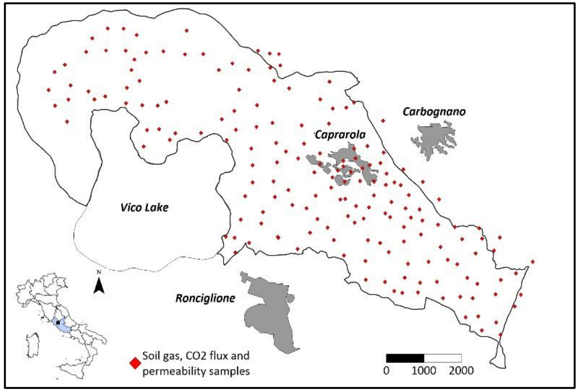
- **CO2 =** soil-gas CO_2 concentration → 178 samples (Draeger X-am 7000) Ordinary Kriging
- **Perm** = Permeability of soil/rocks → (measured in then field at the soil gas sampling points)

Results

Response variable: Soil gas radon

Soil gas radon sampling

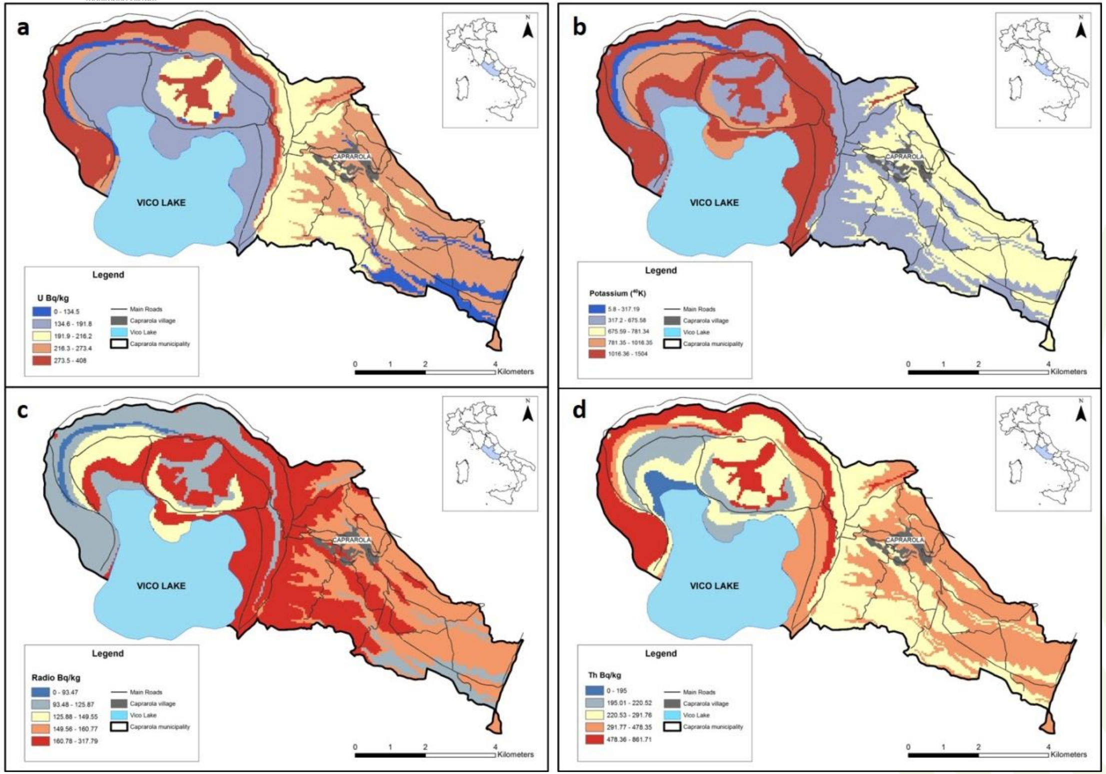
Soil gas and permeability measurements



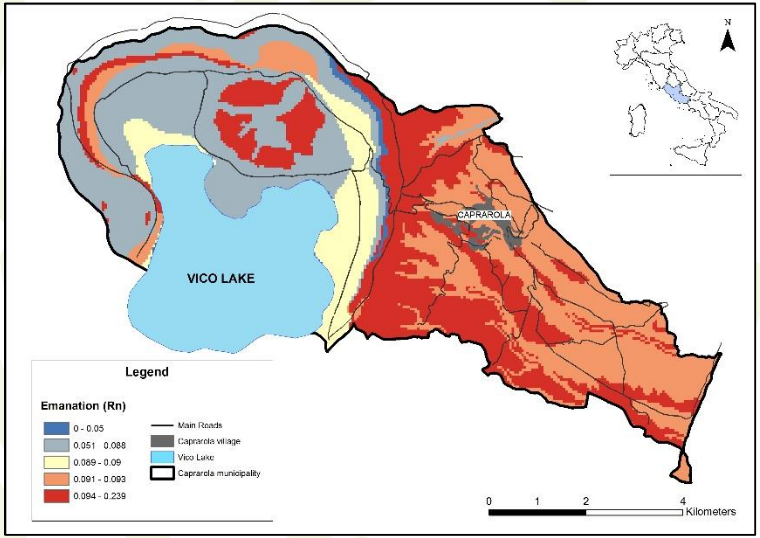
Mainstatistics	N	Mean (95% CI)	GM (95% CI)	Min	Max	St.dev
^{222}Rn (kBq/m^3)	**180**	**157(143-172)**	**130 (118-143)**	**17**	**865**	**99.2**
^{220}Rn (kBq/m^3)	**180**	**314(286-341)**	**259 (235-286)**	**34**	**>1000**	**183**
CO_2 (%, v/v)	178	0.68 (0.61-0.65)	0.55 (0.49-0.61)	0.06	3.1	0.47
K (m^2)	157	1.19E-11		4.13E-13	1.12E-10	1.4E-11
TGDR (µS/h)	187	0.36 (0.34-0.38)	0.34 (0.33-0.36)	0.15	0.97	0.11
^{226}Ra (Bq/kg)	16	149 (120-179)		79	318	57
^{238}U (Bq/kg)	16	181 (142-219)		85	369	18
^{232}Th (Bq/kg)	16	253 (200-307)		23	481	104
^{40}K (Bq/kg)	16	744 (611-877)		317	1236	249
^{222}Rn Emanation	16	0.087 (0.076-0.099)		0.046	0.14	0.021
^{222}Rn flux (Bq/m^2/day)	16	7291 (6209-8373)		3730	11482	2030

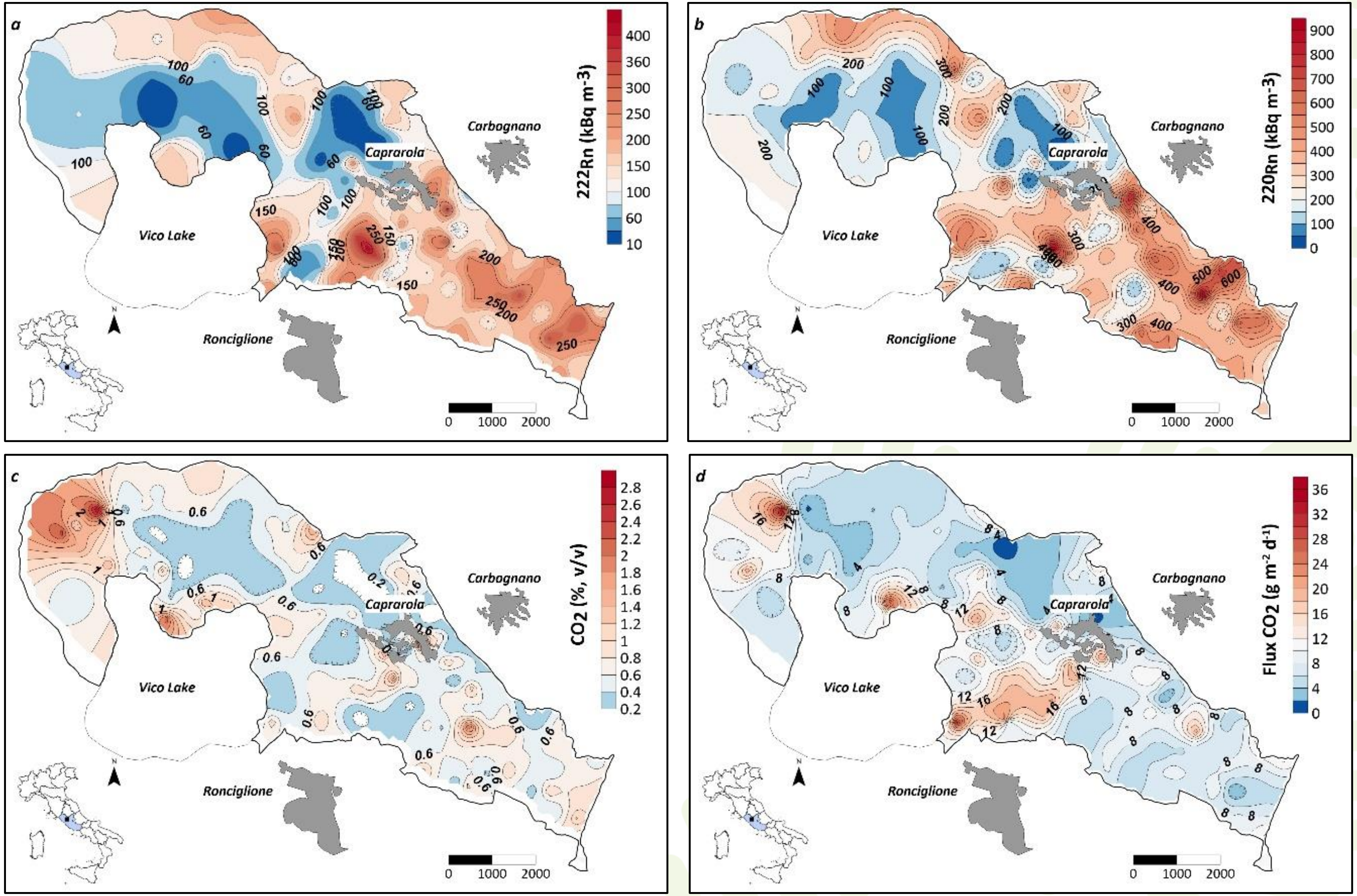
Results - Proxy variable maps

Radionuclide content (U, K, Ra, Th)



Emanation coefficient

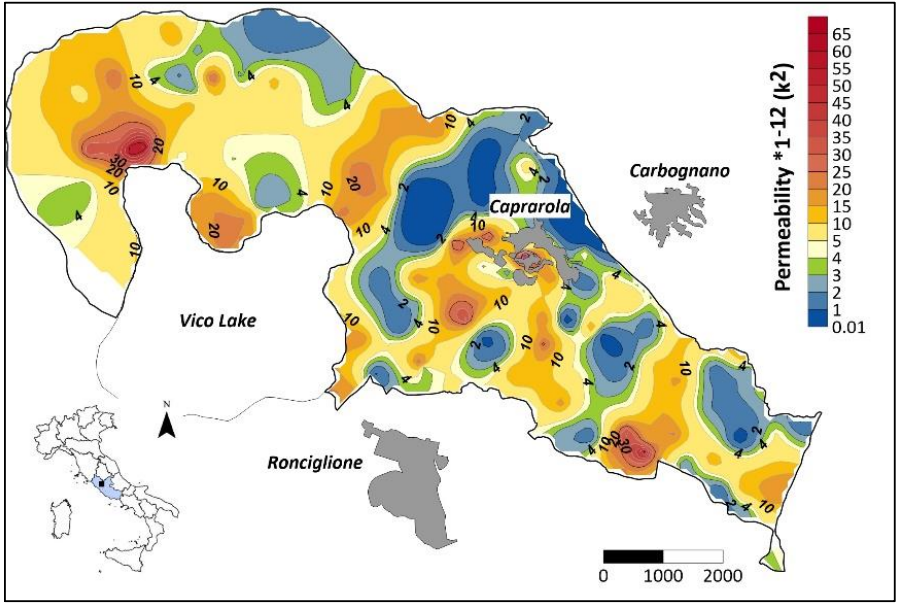


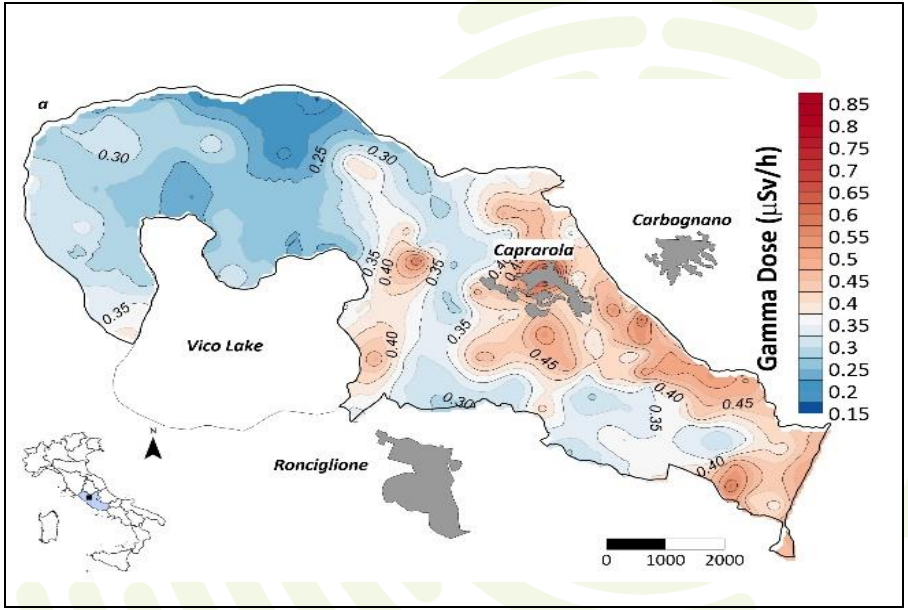


14th INTERNATIONAL WORKSHOP – GARRM, September 18th – 20th(21nd), 2018, Prague, Czech Republic

Results

Permeability – Terrestrial gamma dose rate





Results - Empirical Bayesian Kriging Regression

Cross validation results

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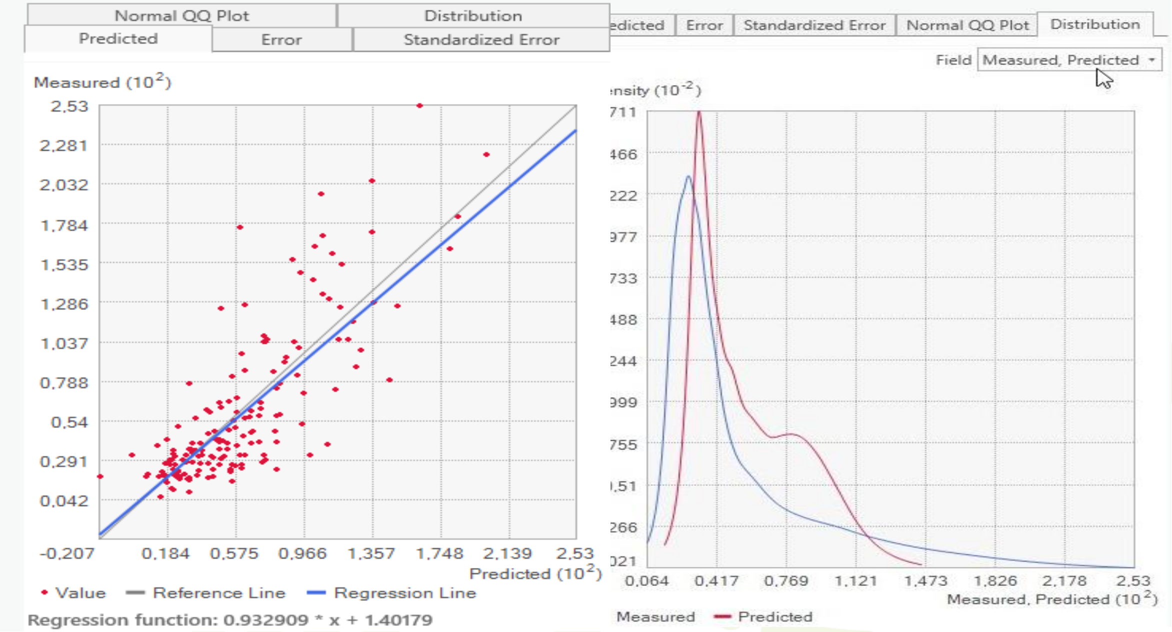
Parameter	
Inside 90 Percent Interval	90.740
Inside 95 Percent Interval	95.061
Mean Error	-0.543
Root-Mean-Square (RMS) Error	29.248
Mean Standardized Error	-0.007
RMS Standardized Error	**0.956**

Root Mean Square Standardized Error: This value should be close to 1



Results - Map of the GWR Rn estimates

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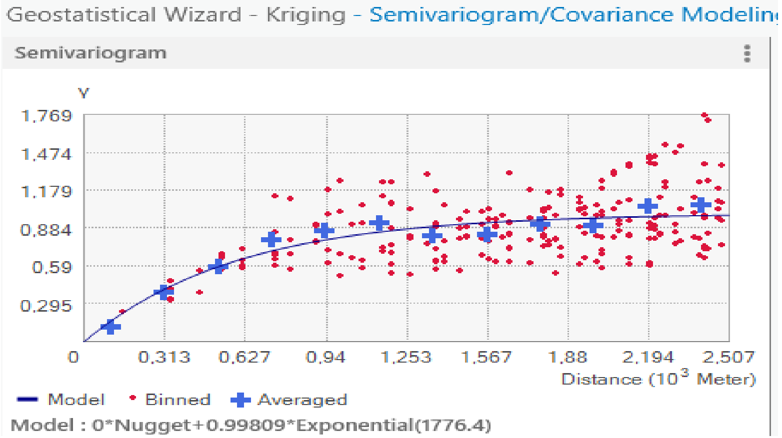
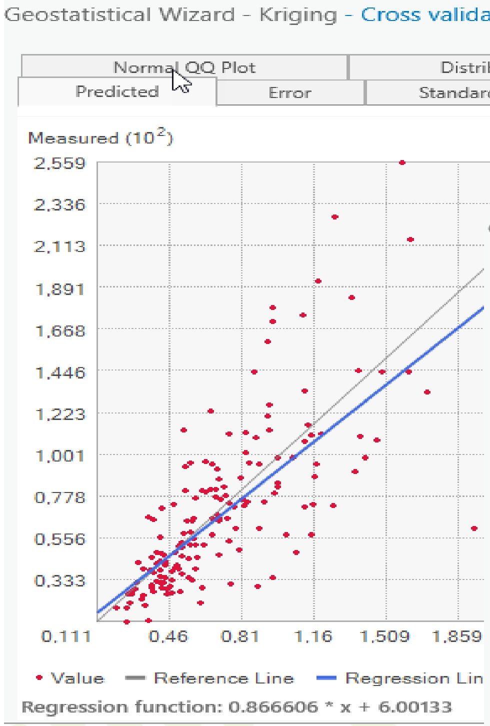
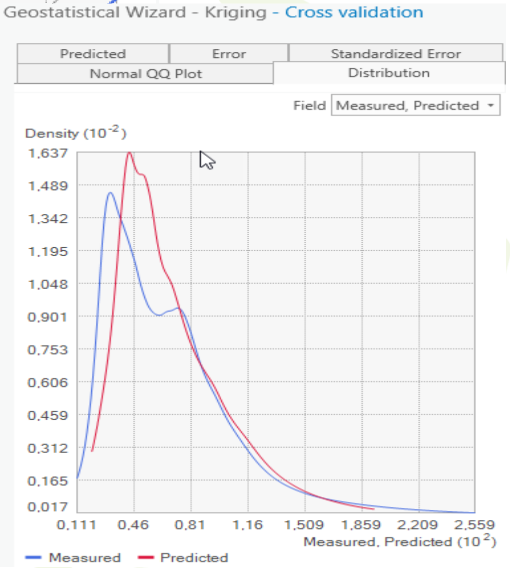
- Simple Kriging have been applied to map the estimated values by GWR.

Parameter	
Mean Error	0.200
RootMeanSquare (RMS)	29.84
RMS Standardised	**0.900**
Average Standard Error	29.02

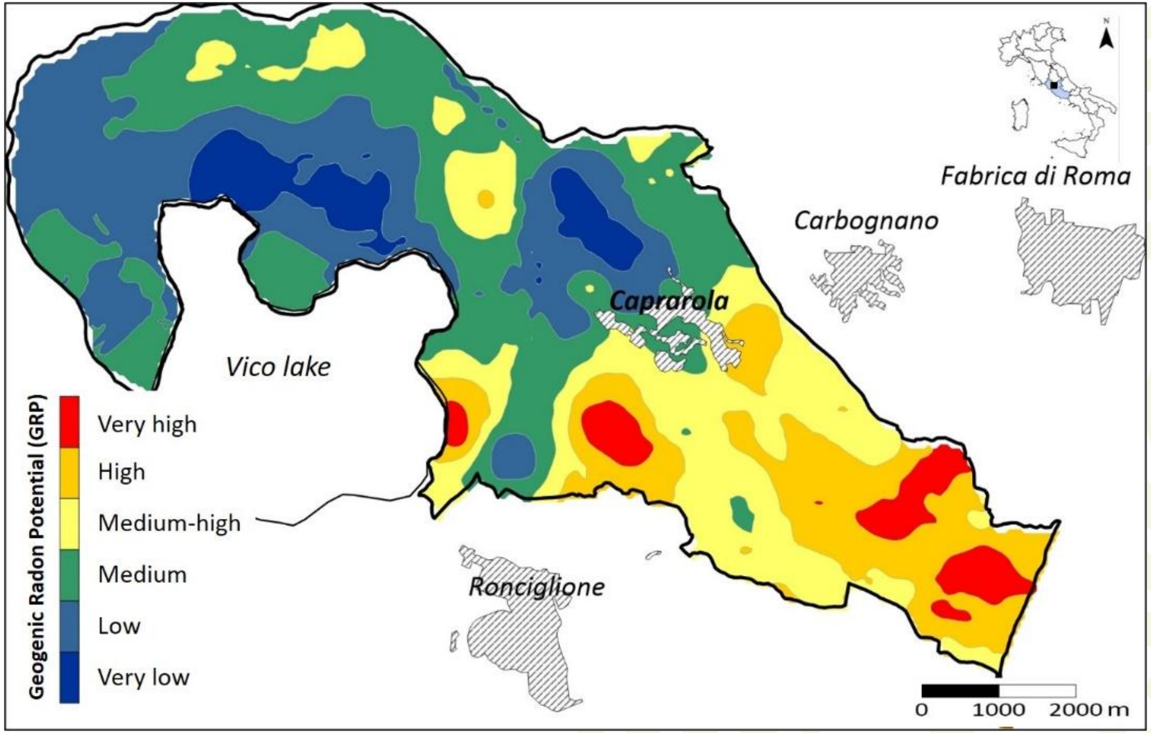






Results

Geogenic Radon Potential



Results – Radon Indoor Survey

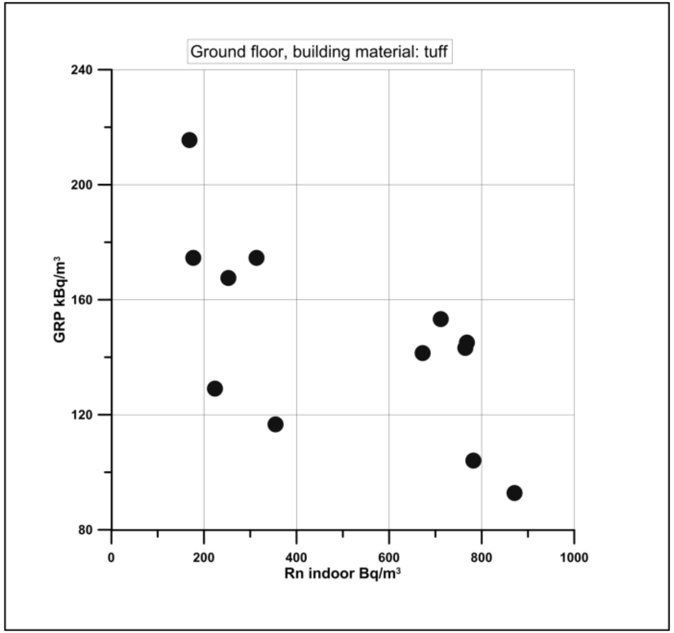
Preliminary and short-time indoor radon measurement surveys were carried out in the Municipality of Caprarola by using charcoal canisters, in order to select buildings in which integrated seasonal radon measurements (in winter and summer) will be conducted

Caprarola	N	AM (95% CI)	GM(95% CI)	Median	Min	Max	Std.Dev.
Indoor Rn Bq/m^3	82	677(491-863)	405(320-512)	364	14	5800	835

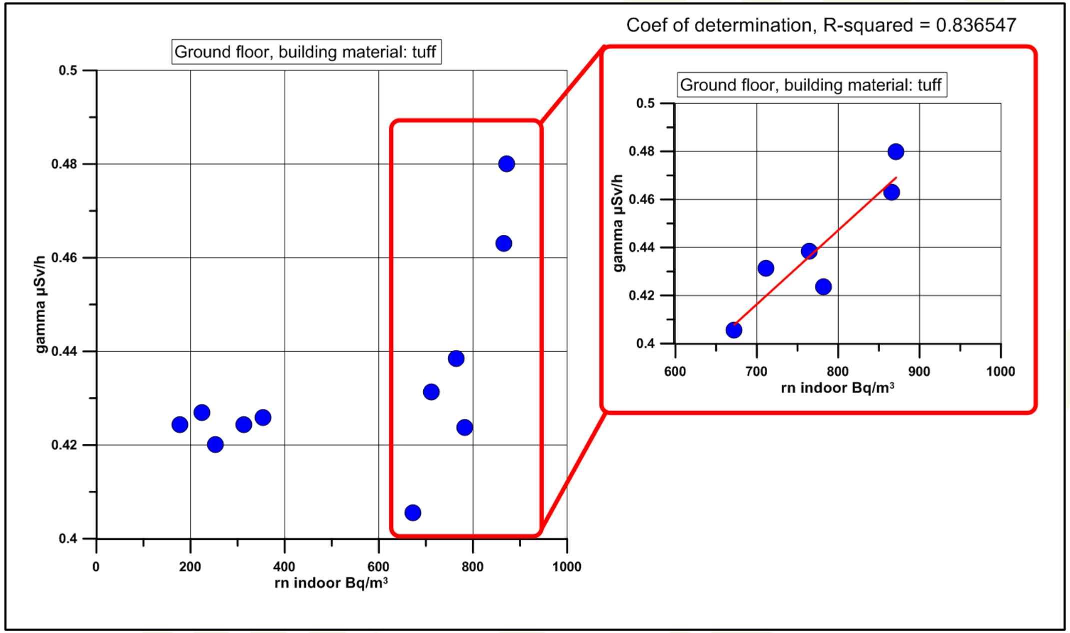
About 65% of the measured buindings are above the limit indicated in European Directive 2013/59/EURATOM

Results (preliminary indoor radon survey)

GRP vs Indoor Rn

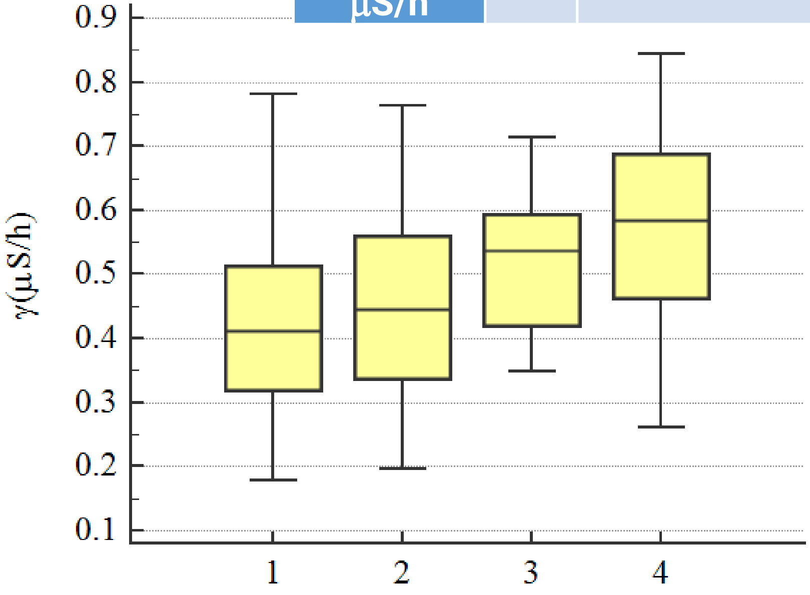


TGDR vs Indoor Rn



Results – Indoor Gamma Dose Rate

Caprarola	N	AM (95% CI)	GM (95% CI)	Median	Min	Max	Std.Dev.
IGDR µS/h	116	0.48 (0.45-0.51)	0.46(0.43-0.49)	0.49	0.18	0.84	0.16



1 = center of the room, on the floor

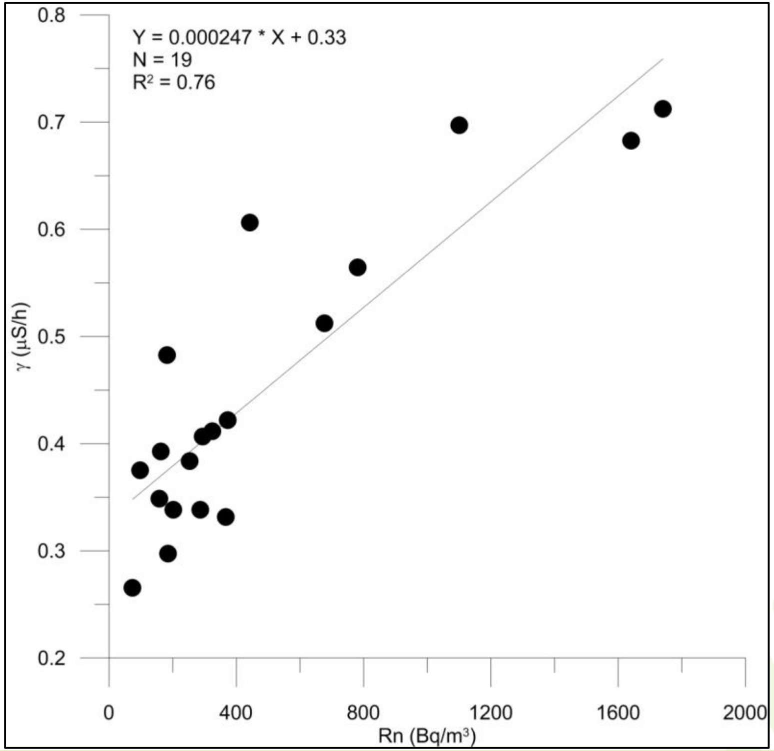
2 = center of the room, 1 mt above the floor

3 = 1.5 mt from the walls

4 = on the walls

Results (preliminary indoor radon survey)

IGDR vs Indoor Rn



The graph shows a good relationship between indoor gamma dose rate and indoor radon concentrations, thus confirming the contribution of the building materials for the Caprarola site.

Conclusions

- The application of multivariable spatial techniques seems to be more appropriate to construct maps of the radon potential. The EBKR model has proven to be the best spatial regression model among the other classical (OLS) and spatial (GWR) model estimation.
- GRP values estimated in correspondence of IR mesurements at ground floors and cellars do not show a clear correlation with the IRC. However, IRC above 600Bq/m^3 show a positive correlation with the terrestrial gamma dose values thus suggesting that in this case IRC could be mainly due to the radon emanation from the building materials (mainly tuff) rather than the geogenic potential of the soil and outcropping rocks.
- The good relationship between indoor gamma dose rate and IRC confirms the contribution of the building materials for the Caprarola site.

THANK YOU FOR THE ATTENTION!!

www.liferespire.it www.liferespire.eu

Principal Component Analysis Results

Factor Loadings (Varimax raw) (Rn_SpatialRegression) Extraction: Principal components (Marked loadings are >.700000)

	Factor - 1	Factor - 2	Factor - 3
40-K	0.738	-0.292	0.337
EmanationCoeff	-0.762	0.277	-0.032
Pemeability	-0.168	-0.503	-0.259
226-Ra	0.273	-0.194	0.794
Rn in the Pore	0.036	0.144	0.859
232-Th	0.778	0.218	0.176
220-Rn	-0.054	0.873	0.085
238-U	0.638	0.500	-0.020
DTM	0.105	-0.760	0.216
Cumulative Expl.Var (%)	30.3	56.7	66.8