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RADON IN A HIGH KARST AREA OF MONTENEGRO – A CASE STUDY

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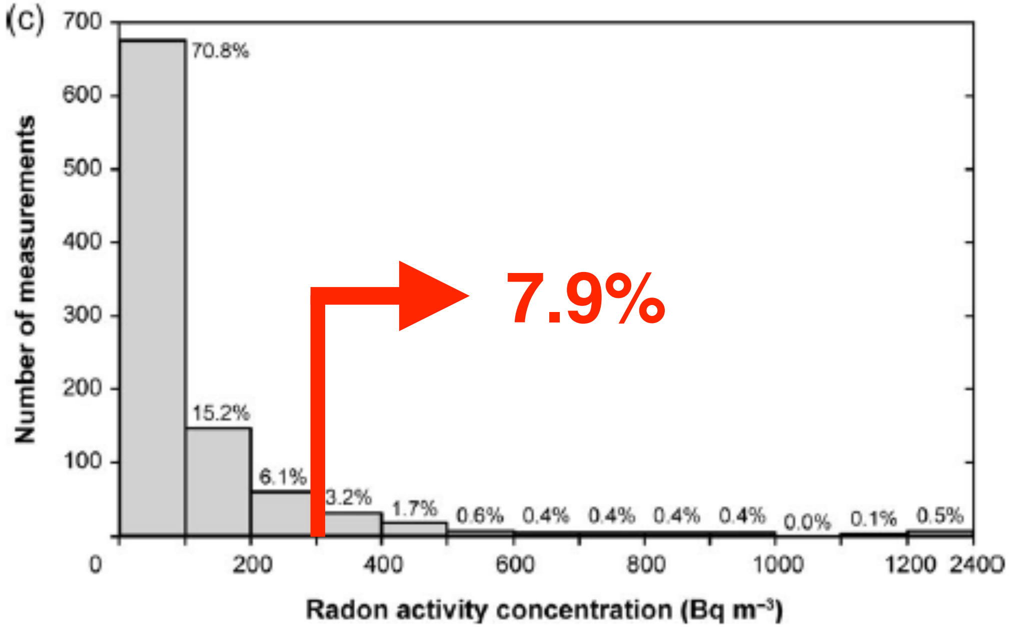
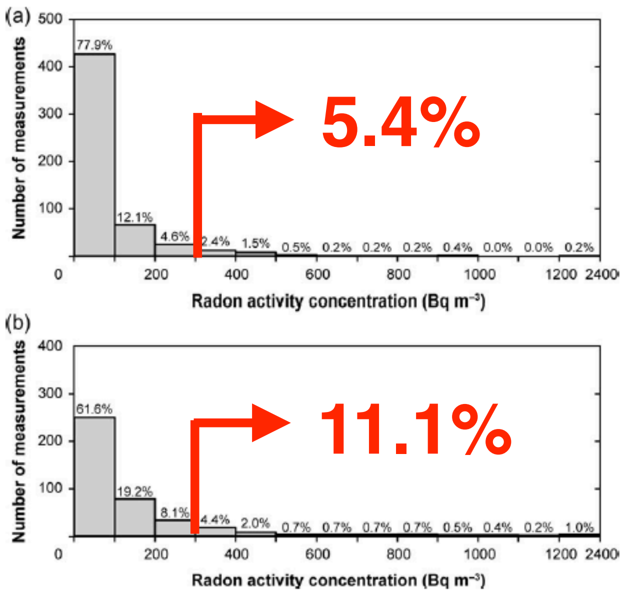
Motivation - Results of indoor radon survey in MNE

Vukotić et al, RPD, 2019, doi: 10.1093/rpd/ncz/022

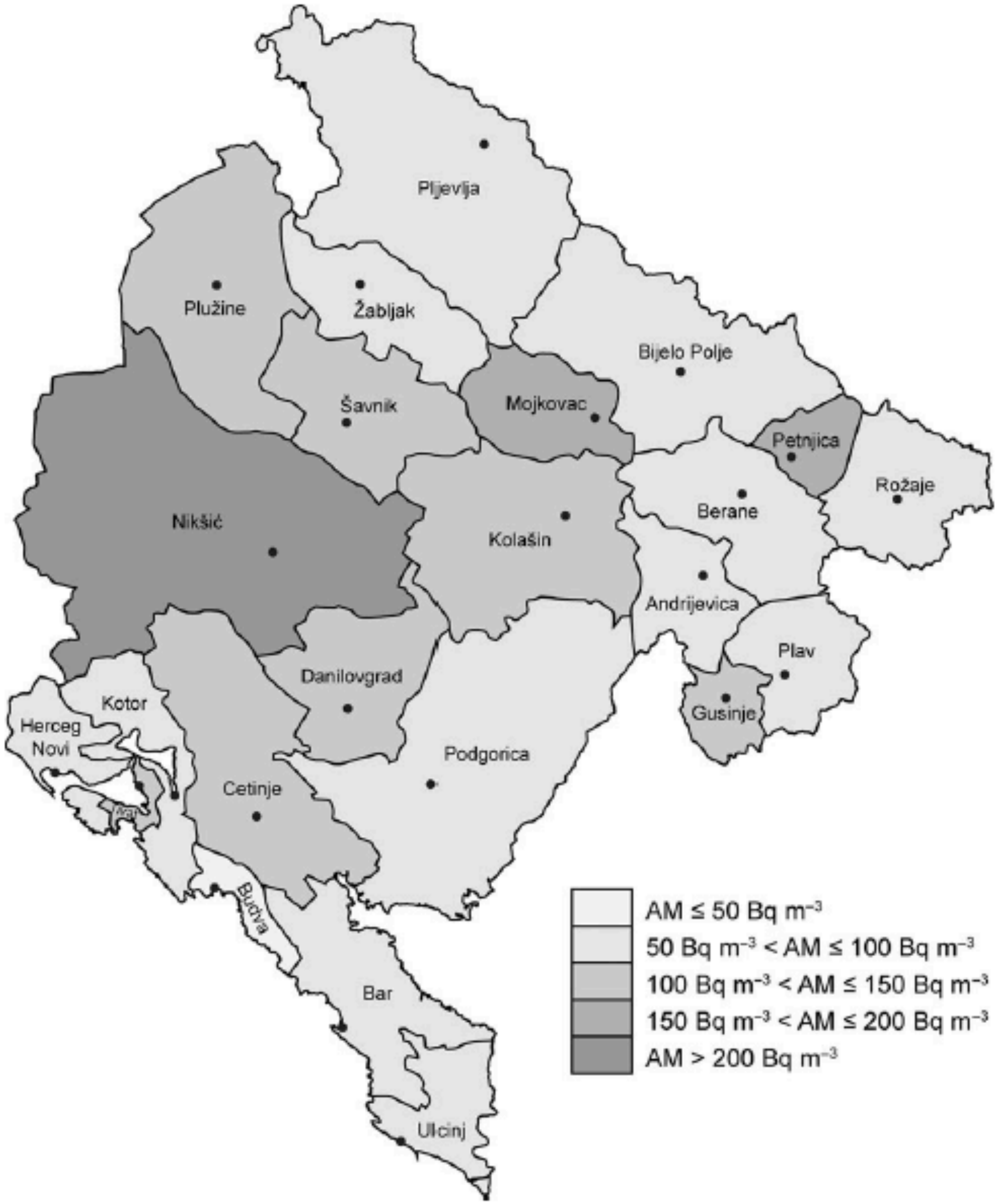
- 2002/03 & 2014/15
- 953 dwellings
- 2x 6-months exposure of CR-39 detectors

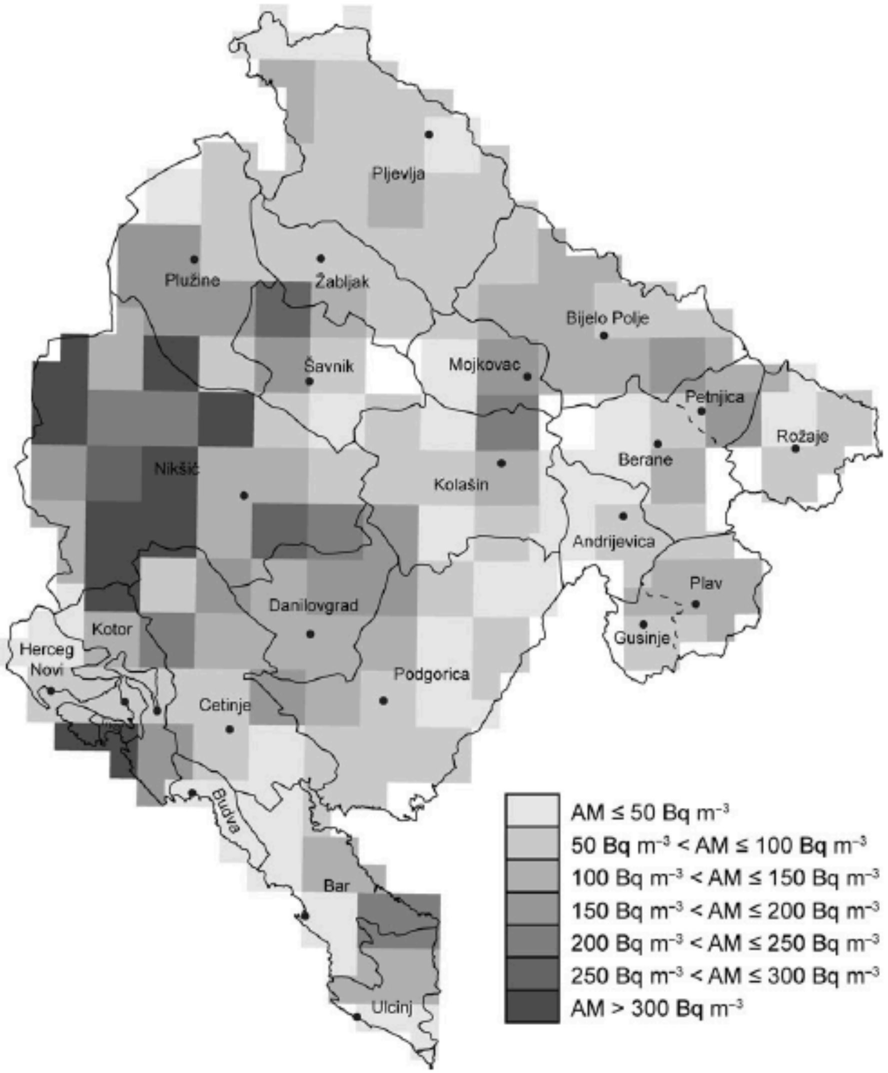
Period	AM (Bq m^{-3})	SD (Bq m^{-3})	MED (Bq m^{-3})	MAX (Bq m^{-3})	GM (Bq m^{-3})	GSD
'summer'	81	126	41	1617	43.2	3.05
'winter'	140	265	58	3798	65.1	3.24
whole year	110	182	52	2321	58.3	2.91





Motivation - Results of indoor radon survey in MNE

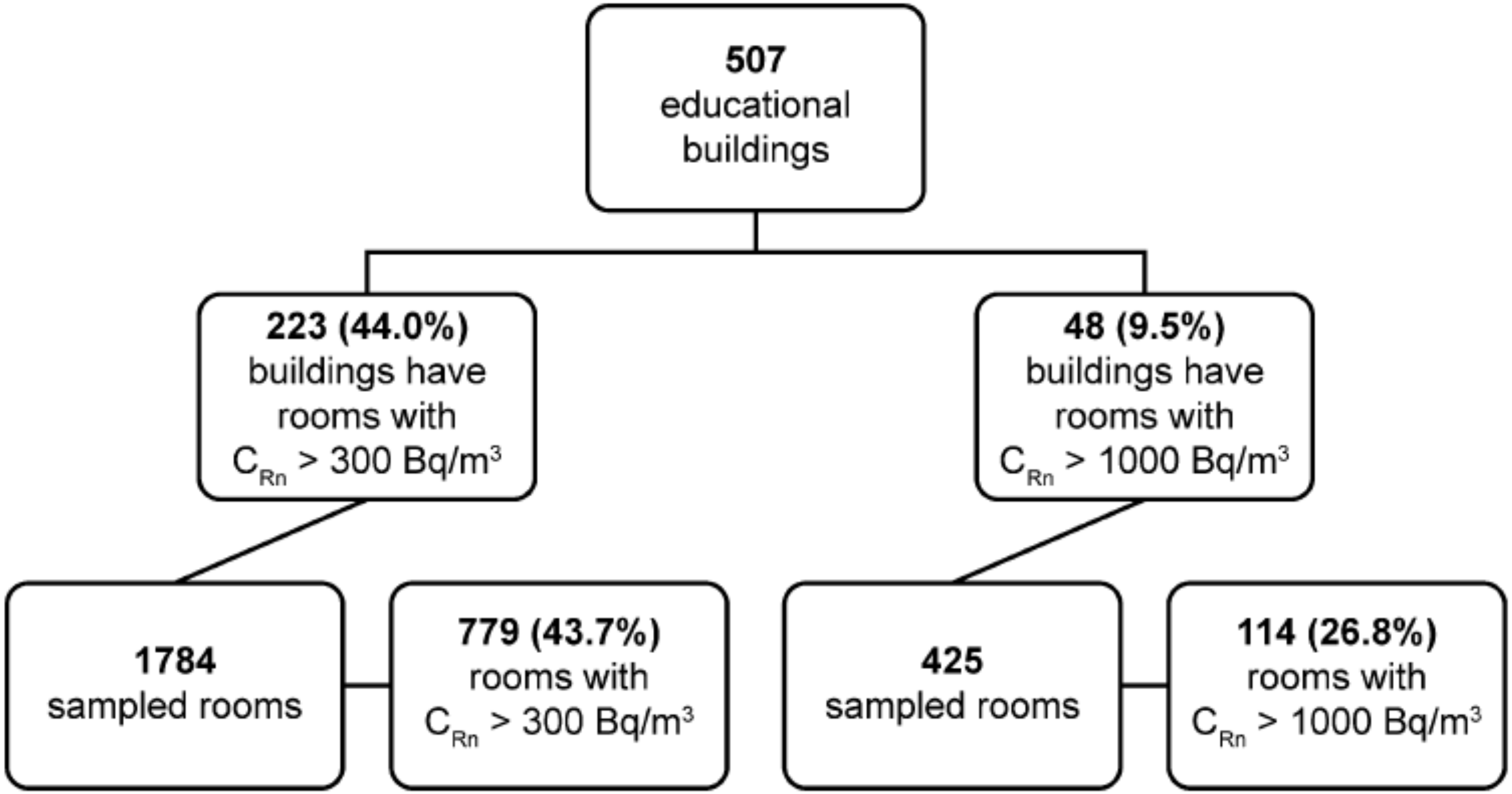




Motivation - indoor radon in S&KG in MNE

Number of rooms	AM (Bq/m^3)	SD (Bq/m^3)	MAX (Bq/m^3)	MED (Bq/m^3)	GM (Bq/m^3)	GSD	$C_{Rn} > 300$ Bq/m^3	$C_{Rn} > 1000$ Bq/m^3
3345	243	345	>3600	129	142	1.09	23.3%	3.4%

AM – arithmetic mean; SD – standard deviation; MAX – the highest radon activity concentration; MED – median; GM – geometric mean; GSD – geometric standard deviation



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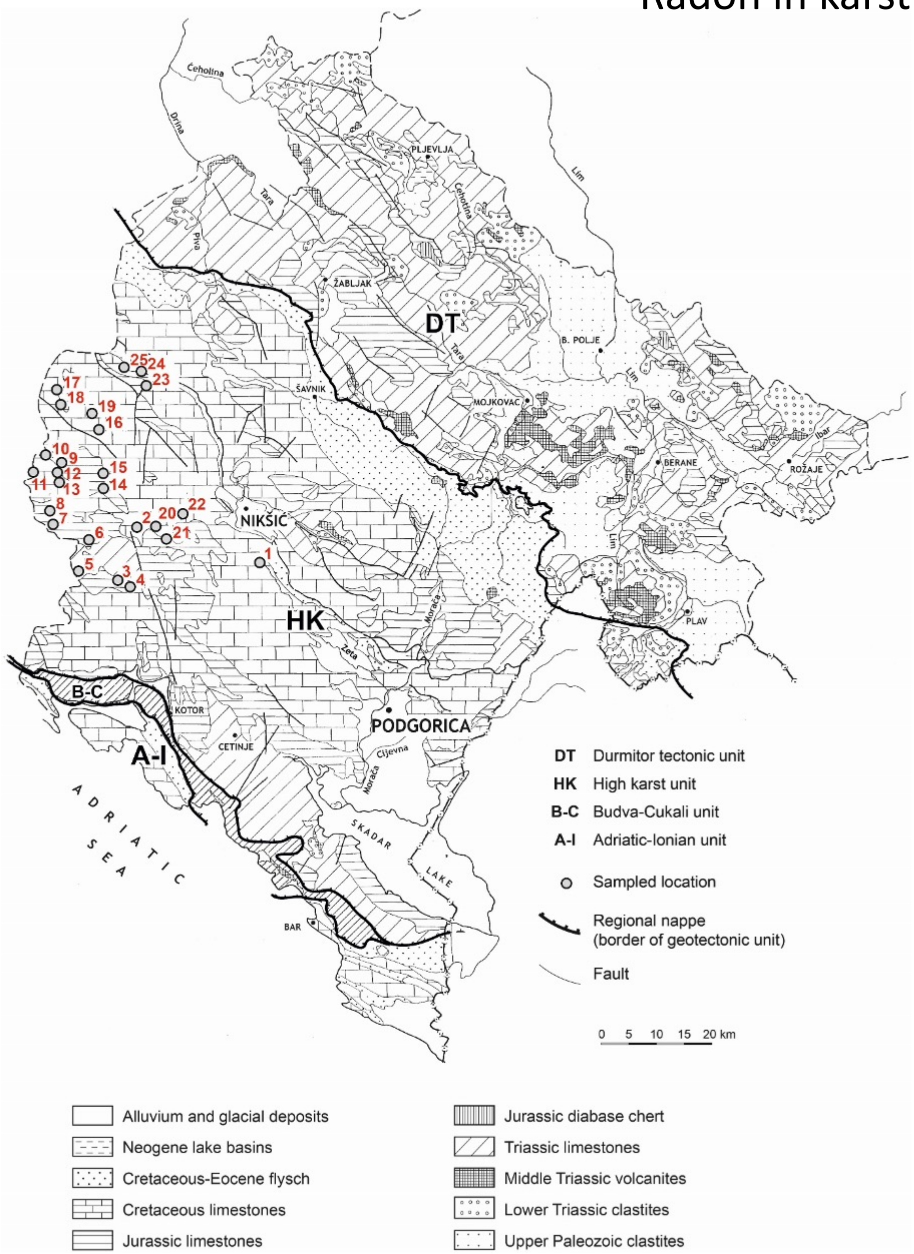
CANU project - 2021/22

Radon in karstic area in the western part of the Nikšić municipality



- 25 locations identified (9 dwellings & 16 S&KG)
- c(Rn): **219 – 2494 Bq/m^3; AM = 977 Bq/m^3**.
- to characterize locations, following parameters were measured:
  - ✓ humidity (*H*),
  - ✓ electrical conductivity (*EC*),
  - ✓ *pH*,
  - ✓ activity concentrations of ^{226}Ra, ^{238}U, ^{235}U, ^{232}Th and ^{40}K,
  - ✓ radon in soil gas activity concentration (*c*),
  - ✓ soil permeability (*k*) for radon gas,
  - ✓ gamma dose rate (*D*) in the air 1 m above the soil.
- GRP is calculated from c & k
- geological and pedological characterization of locations as well as qualitative visual on-site investigation of buildings construction state

GRP

$$GRP = \frac{c_{Rn}}{-log_{10}k - 10}$$

→

GRP < 10 -> LOW

10 < GRP < 35 -> MEDIUM

GRP > 35 -> HIGH

CONDITION	CLASS	DESCRIPTION
GRP < 5	1	VERY LOW
5 ≤ GRP < 10	2	LOW
10 ≤ GRP < 22.5	3	MEDIUM - LOWER
22.5 ≤ GRP < 35	4	MEDIUM - HIGHER
35 ≤ GRP < 60	5	HIGH
60 ≤ GRP < 125	6	VERY HIGH
GRP ≥ 125	7	EXTREME HIGH

Measurement protocol

Results - descriptive statistics of measured variables

Parameter	Range	AM	σ_{AM}	MED
c (kBq/m^3)	8.9 – 390	115	20	77
k (10^{-13} m^2)	3.9 – 180	153	11	180
GRP	11.1 – 419	129	22	99
H (%)	11.8 – 36.9	27.0	1.1	27.7
pH	6.50 – 8.10	7.52	0.08	7.50
EC (μS/cm)	84.8 – 249.0	132.4	8.3	124.5
D (nGy/h)	21 – 80	44.8	3.0	41
^{238}U (Bq/kg)	58.2 – 433	128	15	119
^{226}Ra (Bq/kg)	48.1 – 326	167	14	153
^{235}U (Bq/kg)	3.3 – 20.0	8.3	0.8	7.5
^{232}Th (Bq/kg)	15.3 – 133	66.7	4.6	63
^{40}K (Bq/kg)	145 – 660	378	24	384
$C_{Rn,ind}$ (Bq/m^3)	219 – 2494	977	129	761

Results - correlation matrix

		c	k	GRP	H	pH	EC	^{235}U	^{238}U	^{226}Ra	^{232}Th
c	Spearman	-									
	p-value	-									
k	Spearman	-0,320	-								
	p-value	0,120	-								
GRP	Spearman	**0.906**	-0.035	-							
	p-value	**<0.001**	0.867	-							
H	Spearman	-0.123	-0.029	-0.168	-						
	p-value	0.558	0.891	0.422	-						
pH	Spearman	0.181	**-0.458**	0.049	0.097	-					
	p-value	0.385	**0.021**	0.816	0.644	-					
EC	Spearman	-0.442	**0.614**	-0.267	-0.299	-0.278	-				
	p-value	0.027	**0.001**	0.196	0.147	0.178	-				
^{235}U	Spearman	**0.465**	-0.055	0.342	0.318	-0.092	-0.305	-			
	p-value	**0.019**	0.793	0.094	0.122	0.662	0.138	-			
^{238}U	Spearman	**0.400**	0.007	0.367	-0.006	-0.331	-0.042	**0.708**	-		
	p-value	**0.048**	0.975	0.071	0.977	0.106	0.841	**<0.001**	-		
^{226}Ra	Spearman	**0.521**	0.014	**0,475**	0.183	-0.282	-0.293	**0.764**	**0.707**	-	
	p-value	**0.008**	0.947	**0,016**	0.38	0.172	0.155	**<0.001**	**<0.001**	-	
^{232}Th	Spearman	-0.254	0.200	-0.299	-0.037	-0.463	-0.008	0.204	0.136	0.275	-
	p-value	0.220	0.339	0.147	0.859	0.020	0.972	0.328	0,517	0.184	-
^{40}K	Spearman	-0,458	0,296	-0,451	0,212	-0,391	0,077	-0,102	-0,167	-0,006	0,657
	p-value	0,021	0,150	0,024	0,310	0,053	0,715	0,626	0,426	0,975	<0.001
D	Spearman	**0,517**	-0,284	0,388	0,019	-0,040	-0,438	**0,615**	**0,426**	**0,719**	0,117
	p-value	**0,008**	0,168	0,055	0,926	0,848	0,029	**0,001**	**0,034**	**<0.001**	0,576
$C_{Rn,ind}$	Spearman	-0.084	0.359	-0.02	0.171	0.086	0.068	0.078	0.017	0.09	-0.068
	p-value	0.689	0.078	0.924	0.414	0.681	0.746	0.711	0.936	0.67	0.746

Conclusion related to correlation matrix

- In investigated area high values of:
  - **c – (8.9 – 390) kBq/m^3, AM = 115 kBq/m^3;**
  - ***k* – (3.9 – 180) · 10^{-13} m^2, AM = 153 · 10^{-13} m^2;**
  - ***GRP* – (11 – 419), AM = 129.**
  - **^{226}Ra – (48 – 326) Bq/kg, AM = 167 Bq/kg,**

- **9/25** locations have a **radon index** (*RI*) which is categorized as ***extremely high***, and the other **9/25** locations have ***very high RI***.

- **Spearman correlation** -> a **strong relationship** between ***c*** and ***GRP*** ($r_s = 0.906$, $p < 0.001$), **moderate relationships** of ***c*** with *D* ($r_s = 0.517$, $p < 0.008$) and **^{226}Ra** ($r_s = 0.521$, $p < 0.008$),

- **Pearson correlation** -> **positive linear relationships** of **gamma dose rate** (*D*) with **radium** and **radon concentration** (*c*) in soil and with *GRP* of the location -> *D* could be used at karstic terrains as the first, although rough indicator of radium content in the soil, and geogenic radon potential at the location as well

GRP - results

Location*	c (kBq/m^3)	k (10^{-13}m^2)	GRP	RI (Czech)	RI (Croatian)	$C_{Rn,ind}$ (Bq/m^3)
Bogetići – S	30.8	180	41.4	High	High	2400
Podbožur – H	11.1	180	14.9	Medium	Lower medium	2208
Grahovo – S	186.3	160	234.5	High	Extremely high	847
Bare (Grahovo) – H	109.3	7.58	51.6	High	High	658
Nudo – S	24.9	142	29.4	Medium	Higher medium	679
Vilusi – S	8.9	157	11.1	Medium	Lower medium	364
Broćanac – S	284.0	180	381.3	High	Extremely high	1270
Petrovići – S	247.0	3.89	102.5	High	Very high	361
Pilatovci – S	312.3	180	419.4	High	Extremely high	1070
Pilatovci – H	20.7	180	27.8	Medium	Higher medium	964
Vraćenovići 1 – S	73.7	180	99.0	High	Very high	1356
Vraćenovići 2 – S	128.0	180	171.9	High	Extremely high	1284
Jošovina – H	77.0	180	103.3	High	Very high	290
Velimlje – H	60.1	180	80.7	High	Very high	330
Velimlje – S	98.7	180	132.6	High	Extremely high	2040
Crni Kuk – S	158.3	180	212.6	High	Extremely high	583
Vukotino Polje – H	389.7	66.2	330.5	High	Extremely high	1210
Donje Crkvice – S	194.3	74.3	172.2	High	Extremely high	219
Donja Somina – S	107.0	156	132.4	High	Extremely high	481
Rudine – S	45.4	180	61.0	High	Very high	2494
Rudine – H	81.4	180	109.3	High	Very high	761
Kruščice – H	73.7	180	99.0	High	Very high	677
Javljen – H	37.0	180	49.6	High	High	330
Javljen – S	50.1	180	67.3	High	Very high	1178
Krstac – S	68.2	180	91.6	High	Very high	372

Results of inspection

Location	Number of floors	Filling, F (m)	Material of outer walls, MOW	Foundation slab, FS (cm)	Floor slab quality, FSQ	Window frames, WF	Period of constructio , PoC
Bogetići – S	1	0.3-1.5	stone, concr., brick	≤ 5	Very perm.	Al	before 190
Podbožur – H	2	0.1-0.9	stone	≤ 5	Very perm.	PVC	1900-44
Grahovo – S	2	0	concrete	> 5	Low perm.	PVC	1980-99
Bare – H	1	0.6	concrete block	> 5	Very perm.	PVC	1980-99
Nudo – S	2	0.9	concrete	> 5	Very perm.	Al	1980-99
Vilusi – S	1	0.3-1.0	stone	≤ 5	Very perm.	wood	1945-63
Broćanac – S	1	0.1-0.9	stone	≤ 5	Very perm.	wood	1945-63
Petrovići – S	2	0.3-1.0	concrete block	> 5	Low perm.	wood	1980-99
Pilatovci – S	1	0	stone	≤ 5	Permeable	PVC	1945-63
Pilatovci – H	2	0.1-0.6	concrete block	≤ 5	Very perm.	PVC	1980-99
Vraćenovići 1 – S	1	0	stone	≤ 5	Very perm.	PVC	1900-44
Vraćenovići 2 – S	1	0.1-0.6	stone	≤ 5	Very perm.	PVC	1945-63
Jošovina – H	1	0	stone	≤ 5	Very perm.	PVC	1945-63
Velimlje – H	1	0	stone	≤ 5	Permeable	wood	1900-44
Velimlje – S	2	0.6-1.2	stone	> 5	Very perm.	wood	1945-63
Crni Kuk – S	2	0-1.0	concrete block	> 5	Low perm.	PVC	1980-99
Vukotino Polje – H	1	0	stone	≤ 5	Permeable	wood	1964-79
Donje Crkvice – S	1	0.2-1.2	stone	≤ 5	Very perm.	wood	1945-63
Donja Somina – S	2	0	stone	≤ 5	Permeable	wood	1945-63
Rudine – S	1	0.3-1.6	stone	≤ 5	Very perm.	wood	1964-79
Rudine – H	2	0	stone	≤ 5	Permeable	PVC	1900-44
Kruščice – H	1	0	stone	≤ 5	Very perm.	wood	1964-79
Javljen – H	1	0	stone	≤ 5	Permeable	wood	1964-79
Javljen – S	1	0	stone	≤ 5	Permeable	Al	1964-79
Krstac – S	2	0	stone	> 5	Low perm.	Al	1945-63

Conclusion - Regression analysis

- The regression analysis was used to determine the relationship between the dependent variable (**$C_{Rn,ind}$**) and independent variables of geogenic origin **(U, Ra, c, k, GRP, D)** as well as those related to humans and their way of construction, use and maintenance of buildings **(F, MOW, FS, FSQ, WF, PoC).**

- The best linear regression model includes the following variables: **$C_{Rn,ind}$ = $C_{Rn,ind}$ (FSQ, c, k, GRP, ^{238}U)**

- **29.1**% of the variance of indoor radon concentrations can be explained by these five predictor variables.

- **the applied regression model** as a whole is **statistically significant** at the significance level of 95% (F=2.9678, p=0.0381, df = 24).

THANK YOU FOR YOUR ATTENTION!

QUESTIONS AND COMMENTS ARE WELCOMED