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FIRST STEP TOWARDS THE GEOGRAPHICAL DISTRIBUTION OF INDOOR RADON IN DWELLINGS IN ALBANIA

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The realisation of the geographical distribution of the indoor radon concentrations in dwellings represents a valuable tool necessary for assessing the public exposure. In this work are reported the results of the indoor radon obtained in the first stage of the survey involving 247 measurements. From the preliminary information on ~10 % of the territory, covering the biggest cities in Albania results on indoor radon concentrations ranging from 14 to 1238 Bq m^{-3} with an arithmetic mean of 120 ± 67 Bq m^{-3}. The population-weighted average indoor radon concentration was calculated to be 101 Bq m^{-3}. The adopted survey strategy highlighted the necessity for the future stages to spread the measurements in order to cover the entire territory of Albania, instead of remaining focused only on the demographic criteria.

INTRODUCTION

Radon exposure contributes significantly to the annual dose (~50 %) received by the population due to natural radiation sources (2.4 mSv y^{-1})[(1)] and is recognised to be the second cause of lung cancer, after smoking[(2)]. As reported to the recent European basic safety standards[(3)], epidemiological studies have shown an increase of lung cancer from prolonged exposure to indoor radon at levels of the order of 100 Bq m^{-3}. In the last decades, there has been an increased concern in many countries regarding the establishment of national legislations on indoor radon concentration in dwellings. According to the legislative framework in Albania[(4)], the reference levels for indoor radon concentration are established to be 200 Bq m^{-3} for new buildings and 400 Bq m^{-3} for old buildings (respectively, before and after 2000). However, the choice of appropriate action reference levels as well as the decision criteria when to carry out radon mitigation actions has to be revised. In this context, the national survey plans are a priority for reducing the population exposure to indoor radon in dwellings.

The first results of national indoor radon concentration (173 indoor radon measurements) in dwellings, schools and working places are reported in Bode *et al.*[(5)] Moreover, several studies regarding soil gas radon and indoor radon concentrations are performed in different areas of the country[(6–8)]. In this study discussed are the first steps for the realisation of the national action plan in order to address long-term risk from radon exposure in dwellings. Solid-state nuclear track detectors (SSNTD) CR 39 are used for indoor radon measurements. A total of 247 indoor radon measurements in dwellings are recorded both during the first survey Bode *et al.*[(5)] and from the more recent measurement campaign. The results obtained are spatially represented considering a regular grid with cells of 10 km × 10 km resolution, and the relationships with the geological information are discussed.

MATERIALS AND METHODS

Study area and indoor radon survey strategy

Albania is located in the western part of the Balkan Peninsula and has a surface of 28.748 km^2. From the geological point of view, the Albanian territory, characterised by a complex geological structure, is part of the Alpine Mediterranean orogenic belt. The several geological units of Palaeozoic through Mesozoic to Neogene age can be grouped into two main domains: inner units characterised by the presence of intensely deformed ophiolitic and metamorphic rocks and outer units composed by regional thrusts involving triassic and pliocenic sedimentary rocks[(9)]. The principal types of rocks that characterise the geotectonic units are shown in Figure 1.

Based on 2011 census results[(10)], the total population of Albania is ~2.8 million inhabitants. This survey aims to gather operational information by investigating the indoor radon concentrations in the dwellings of the most populated cities located in 10 of the 12 regions of Albania. The first stage of the national indoor radon survey includes the design of a regular grid with ~345 cells of 10 × 10 km resolution that covers the whole territory of the Republic of Albania. First, the authors identified the number of cells without buildings, corresponding mainly cells located in the national borders. Moreover, the choice of the type of dwelling was based on data obtained by INSTAT[(10)], where the total number of buildings in Albania is $\sim 6 \times 10^5$ (where ~50 % are built before the year 2000), only 4 % of them are flats and the rest are residential houses.

A total of 247 indoor radon concentration measurements (covering 36 grid cells) are performed generally on ground floor involving the inhabited rooms (kitchen, bedroom and living rooms). Randomly, the authors chose to investigate the basement and the higher floors of the buildings, in order to study the effect of the height above the ground on indoor radon concentration. Every participant was asked to fill up forms containing personal information, address, general characteristics of the building and the room where the detector was placed. To each detector was assigned an identification code and the geographical coordinates in order to allow the georeferenciation using geographical information system. Figure 1 shows the location of indoor radon measurements. The first results on indoor radon measurements indicate the necessity that future survey stages must follow not only the demographic criteria, but in second grade, attention must be paid to cover the

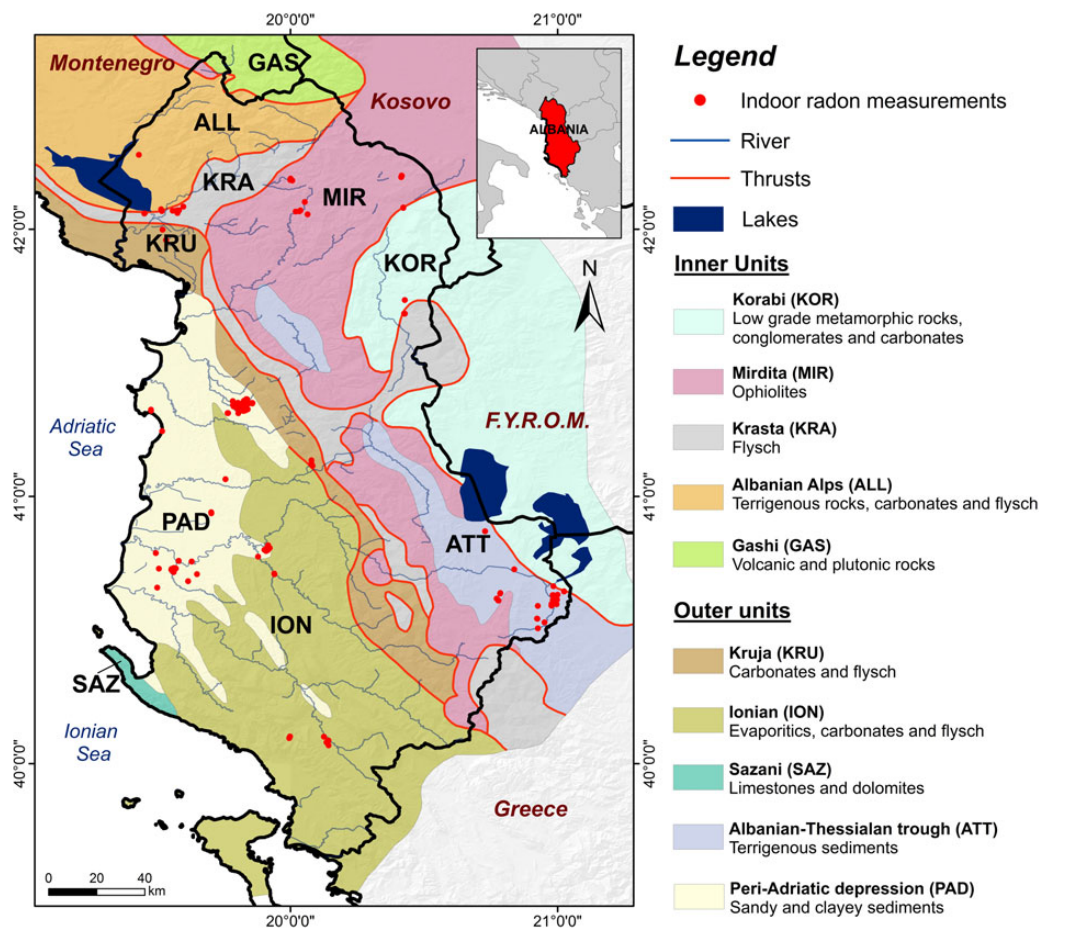

Figure 1. Simplified geotectonic map of Albania after Havancsák *et al.*[(11)] The circles show the location of indoor radon measurements.

entire territory of Albania according to IAEA recommendations[12].

Measurements of indoor radon concentration

The indoor radon concentrations are measured by passive detectors based on SSNTD Radtrak, consisting of track etch detectors made of CR 39 plastic films contained in an antistatic holder (NRPB/SSI type). Radon enters the container by diffusion and decays by emitting alpha particles, which leave invisible tracks in the detector. Detectors are placed in the inhabited rooms of the dwelling at approximately between 1 and 2 m height from the floor and as far as possible from windows and doors in order to avoid air currents. Each detector is exposed for ~3 months either in the period 1999–2014 mainly during summer and winter seasons. For quality control purposes, duplicate detectors were placed in randomly selected dwellings.

After exposure, the CR39 films are etched for ~14 h in NaOH (6 M) solution at a temperature controlled bath ranging from 70°C to 80°C[13]. The etched tracks are counted using digital optical microscope readings (×150) based on random screening of 20 areas (field of view of the microscope) of 0.76 mm^2. The indoor radon concentration (in Bq m^{-3}) is calculated from the superficial track density using the following equation:

$$\mathrm{Rn}^{\mathrm{indoor}} = \frac{N - N_{\mathrm{bckg}}}{\mathrm{CF} \times t}, \tag{1}$$

where N and N_{bckg} are, respectively, the gross and background track densities per unit area (track m^{-2}), CF is the calibration factor [track cm^{-2} (Bq h $m^{-3})^{-1}$] and t is the exposure time (h). The recent intercomparison organised at Lurisia Spa, Italy, showed a good agreement with reference values and an excellent constancy between duplicate detectors used for this test. In order to obtain an estimate of the annual average, the carried out measurements are corrected for seasonal variations. The correction factors are obtained by studying the variations in indoor radon concentration observed in summer and winter seasons with respect to the entire year in randomly selected dwellings located in different geographical regions. The minimum detection indoor radon concentration is ~12 Bq m^{-3} for a 3-month exposure time.

RESULTS AND DISCUSSIONS

Indoor radon concentrations

The indoor radon survey is conducted from 2009 to 2014, in 10 regions (18 districts) of Albania, where

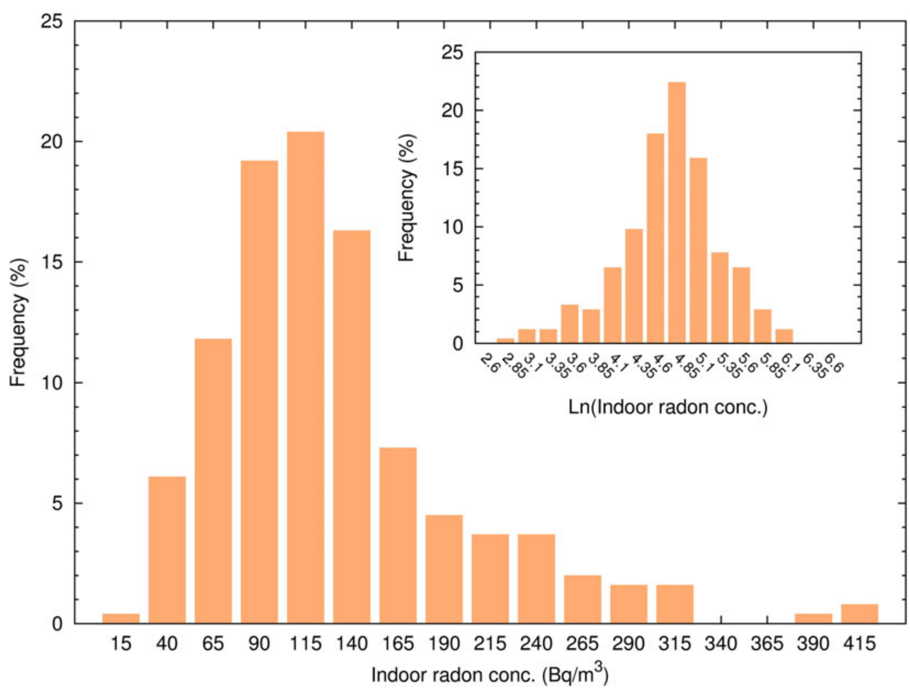

Figure 2. The frequency distribution of indoor radon concentration in dwellings (excluding the outliers). The inset figure shows the frequency distribution of the logarithmic transformation.

247 dwellings are investigated by means of SSNTD CR 39. The distribution of indoor radon concentrations ranges between 14 and 1238 Bq m^{-3}. It was observed that the indoor radon concentrations follow a lognormal distribution (Figure 2), checked by the Kolmogorov–Smirnov test ($P > 0.05$)[12, 14]. The geometrical mean (GM) is found to be $103^{+80}-45$ Bq m^{-3} (at 1σ uncertainty calculated from the geometric standard deviation (GSD) equal to 1.8). The arithmetic mean (AM) is found to be 120 ± 67 Bq m^{-3}. Less than 1 % of the records (two records) are found to be outliers (i.e. exceeding the median +1.5 Inter Quartile Range) using the graphical box-plot and are rejected from the statistical analysis. The authors note that outliers correspond to radon measured in basements with low occupancy. The overall results show that the indoor radon concentrations in ~13 % of dwellings exceed the reference level of 200 Bq m^{-3}, whereas <1 % of dwellings are >400 Bq m^{-3} [according to V.K.M. 591[4]]. However, the indoor radon concentrations (AM) are relatively higher compared with Spain, 80.3 Bq m^{-3} (AM)[15]; most of Italian Regions, 25–99 Bq m^{-3} (AM) (except for Lombardia and Lazio, respectively, 111 and 119 Bq m^{-3})[16] and Turkey, 81 Bq m^{-3} (AM)[17].

The preliminary results of the indoor radon survey in different types of dwellings in Albania are summarised in Table 1. Over 80 % of the measurements are performed in ground floor either in flats or in houses. The construction characteristics of dwellings seem not to affect the indoor radon concentrations; in fact for the ground floor in flats, a GM of $102^{+61}-38$ Bq m^{-3} is observed with respect to houses where the GM is $106^{+74}-44$ Bq m^{-3}. As it may be expected, a decrease of indoor radon concentrations can be observed in the order basement > ground floor > first floor > highest floors, with AM values ranging from 275 ± 180 to 64 ± 28 Bq m^{-3}. It can be noted that the number of measurements is fundamental for correctly evaluating the GM and reducing the effect of outliers and the first type uncertainties; therefore, future stages of measurements are necessary to improve the quality of the dataset (Table 2).

In Figure 3, the authors report the AM and SD of indoor radon concentrations associated with the geological units identified in the simplified geological map of Figure 1. For the ALL and KOR units, characterised by only two records, the maximum semi-dispersion is reported instead. As it may be expected, the classification according to the simplified geological map seems not to give a clear relationship within the reported SD. This is reasonable since indoor radon concentrations depend not only from the radon emanation from soils or underlying rocks but also building materials and dwelling construction characteristics[12]. However, the authors notice that ATT unit, which is characterised by terrigenous sediments underlined by flysch, limestone and dolomite rocks, shows frequently relatively high radon concentration (160 ± 68 Bq m^{-3}). Relatively high concentration in dwellings characterised by underlying rocks of limestone and dolomite is reported in other studies[18, 19]. This is also observed in KRA and ION units; however, this evidence is very weak due to the high variability and low statistics. The other geologic units show a similar concentration, but characterised by high variability in particular for the PAD unit, which is characterised by heterogeneous sandy and clayey sediments. A more extended survey, on the base of more detailed geological maps, is necessary to support with more statistics these preliminary indications.

In Figures 4 and 5, the spatial distribution at 10 × 10 km cell grid is reported with graduated colours on the base of the number of measurements and of the

Table 1. The GM of indoor radon concentrations (in Bq m^{-3}) and the GSD is reported together with the arithmetic mean (AM) and SD for different type of dwellings investigated at different floors.

Dwelling type	N°	GM (Bq m^{-3})	GSD	AM ± SD (Bq m^{-3})	Floor level	N°	GM (Bq m^{-3})	GSD	AM ± SD (Bq m^{-3})
Flats	84	90	1.6	100 ± 46	Basement	—	—	—	—
					Ground floor	59	102	1.6	112 ± 46
					First floor	13	75	1.6	83 ± 33
					Higher floors	12	58	1.6	64 ± 28
Houses	163	111	1.8	130 ± 74	Basement	18	245	1.3	275 ± 180
					Ground floor	143	106	1.7	127 ± 113
					First floor	2	—	—	25 ± 11[a]
					Higher floors	—	—	—	—
Total	247	103	1.8	120 ± 67	Basement	18	245	1.3	275 ± 180
					Ground floor	202	105	1.7	122 ± 98
					First floor	15	64	1.9	75 ± 37
					Higher floors	12	58	1.6	64 ± 28

[a]Maximum semi-dispersion is reported.

Table 2. The GM of indoor radon concentrations (in Bq m^{-3}) and the GSD is reported together with the arithmetic mean (AM) and SD for the investigated regions.

Region	Districts	Population	N°	% dwellings (>200 Bq m^{-3})	Indoor radon concentrations		
					GM (Bq m^{-3})	GSD	AM ± SD (Bq m^{-3})
Korçë	Korçë, Pogradec, Devoll	220 357	73	25	148	1.5	160 ± 68
Dibër	Peshkopi	137 047	8	13	123	1.5	138 ± 54
Kukës	Kukës, Has	85 292	11	9	100	1.5	123 ± 53
Gjirokastër	Gjirokastër	72 176	10	10	116	1.4	119 ± 42
Tiranë	Tiranë, Kavajë	749 365	65	14	96	2.0	112 ± 83
Shkodër	Shkodër, Pukë	215 347	30	—	89	1.8	93 ± 39
Berat	Berat, Kuçovë	141 944	16	—	92	1.3	93 ± 22
Fier	Fier, Lushnjë	310 331	25	—	84	1.3	90 ± 21
Elbasan	Elbasan, Peqin	295 827	7	—	82	2.2	75 ± 49
Durrës	Durrës	262 785	2	—	—	—	46 ± 5[a]

[a]Maximum semi-dispersion is reported.

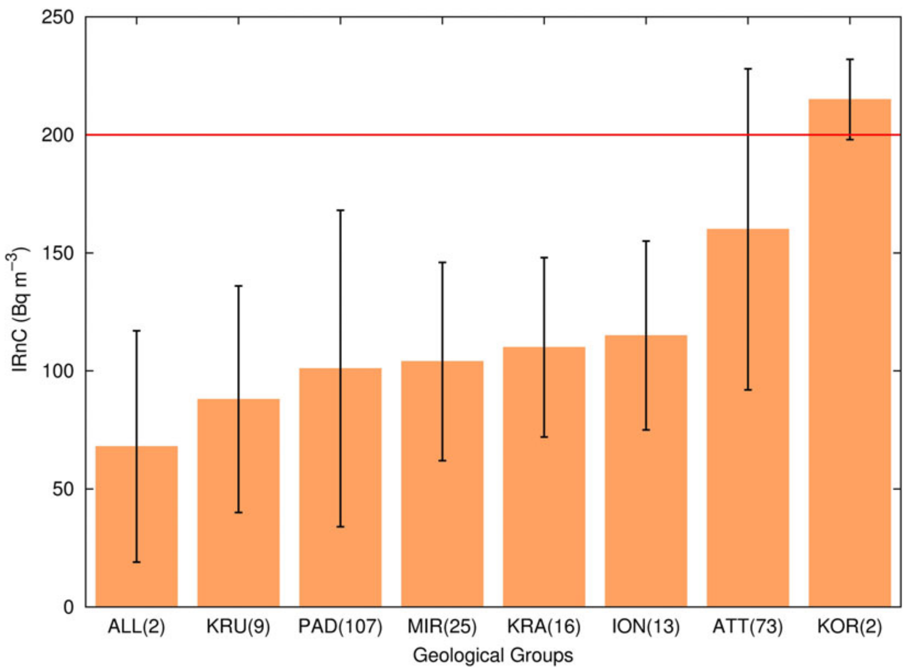

Figure 3. Classification of AM indoor radon concentrations (in Bq m^{-3}) according to the simplified geological map (Fig. 1). In parentheses, the authors give the number of measurements. The error bars show the SD at 1σ level (with exception of geological units with only two records where the maximum semi-dispersion is shown).

AM of indoor radon concentrations, respectively. The authors choose to represent the AM in order to be homogeneous and comparable with other studies[20]. The first results give preliminary information on indoor radon concentrations for ~10 % of the territory of Albania. However, the authors notice that the regions of Vlora and Lezha are still not investigated and are the priority of the next phases of the survey.

In Figure 5, the authors observe a pattern of high concentration in the Korça region with AM ranging from 150 up to 280 Bq m^{-3}. In this region, as well as in Gjirokastër region, are indicated outliers of radon

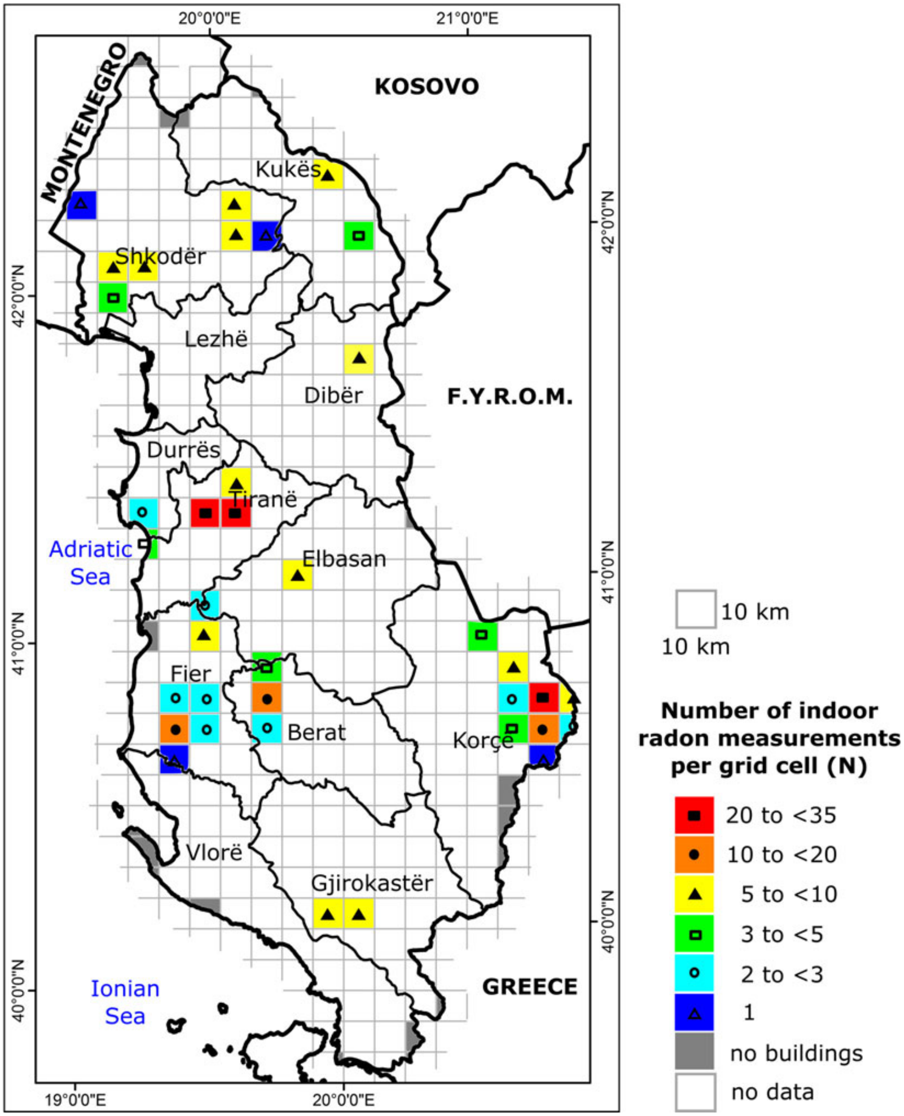

Figure 4. Number of measurements per 10 × 10 km cell grid. Data obtained from the survey 2009 to 2014.

concentration (up to 1240 Bq m^{-3}) observed in the case of measurements when detectors are placed in basements. The indoor radon concentrations in the regions of Durres, Fier, Tirana, and partially Berat interested principally by PAD unit are generally characterised by relatively low values from 20 to 150 Bq m^{-3}. In Tirana, relatively high concentrations of uranium in soils are reported in Dogjani *et al.*[6] with a large variation from 3.5 to 8.4 μg g^{-1}. This large variation is also confirmed by some unpublished results; however, the concentrations are found to be relatively lower, ranging from 1.5 to 5.2 μg g^{-1}. While, in the region of Fier and partially Berat, the concentration of uranium in soil varies from 1.0 to 2.6 μg g^{-1}[21]. The high variability of uranium concentration in the rocks of the PAD unit enforces the need of an extensive investigation, since it is one of the most inhabited areas in Albania.

CONCLUSIONS

The first step towards the geographical distribution of indoor radon concentration in dwellings based on a regular grid with cells of 10 × 10 km resolution is reported. The preliminary results, involving 247 measurements, which cover ~10 % of the territory, are

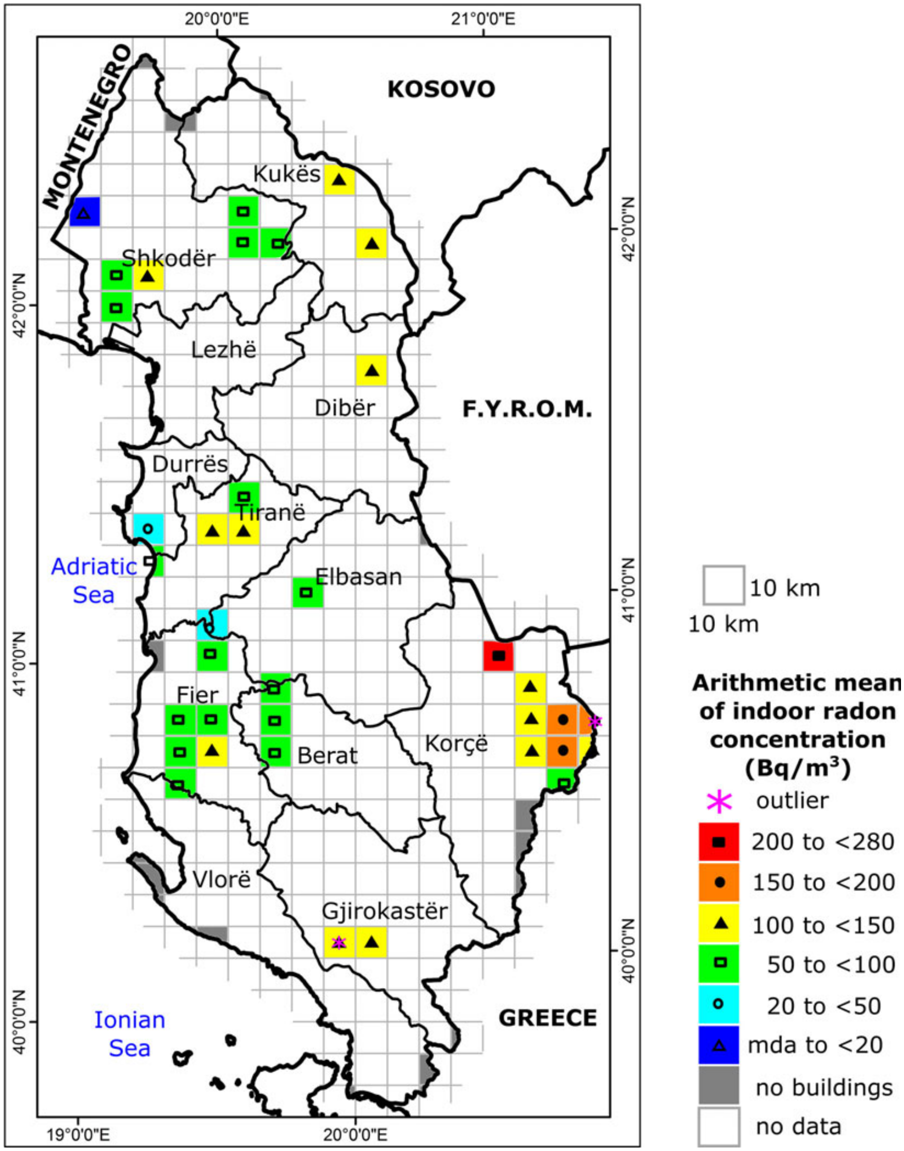

Figure 5. The AM of indoor radon concentrations (Bq m^{-3}) over a 10 × 10 km cells. Data obtained from the survey 2009 to 2014.

presented in order to discuss the criteria adopted for the national survey strategy. The type of construction either flats or houses seems not to affect the indoor radon concentration in the dwelling, whereas the authors observe a decrease of indoor radon concentrations in the order basement > ground floor > first floor > highest floors. The geology seems to have a moderated influence on geogenic radon, but higher statistics and more detailed geological maps are needed to support this statement. The AM of indoor radon concentration was 120 ± 67 Bq m^{-3}, whereas only 13 % of dwellings exceeds the reference level of 200 Bq m^{-3}. The population-weighted annual indoor radon concentration was found to be 101 Bq m^{-3}. Indeed, the geographical distribution of indoor radon concentration gives indication of high radon-level areas in Albania and can be used as a solid criterion for foreseeing radon mitigation actions included in the national technical building code and planning of integrated epidemiological studies by the Public Health Institute. For this purpose, the future stages of indoor radon survey must aim to increase the statistics per cell and cover the entire territory in order to enhance the significance of this information.

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