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FIRST MAP OF RESIDENTIAL INDOOR RADON MEASUREMENTS IN AZERBAIJAN

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This article describes results of the first measurements of indoor radon concentrations in Azerbaijan, including description of the methodology and the mathematical and statistical processing of the results obtained. Measured radon concentrations varied considerably: from almost radon-free houses to around 1100 Bq m^{-3}. However, only ~7% of the total number of measurements exceeded the maximum permissible concentrations. Based on these data, maps of the distribution of volumetric activity and elevated indoor radon concentrations in Azerbaijan were created. These maps reflect a mosaic character of distribution of radon and enhanced values that are confined to seismically active areas at the intersection of an active West Caspian fault with sub-latitudinal faults along the Great and Lesser Caucasus and the Talysh mountains. Spatial correlation of radon and temperature behavior is also described. The data gathered on residential indoor radon have been integrated into the European Indoor Radon Map.

INTRODUCTION

According to the World Health Organization (WHO), radon is one of the most toxic and radioactive gases (WHO Fact Sheet No. 291: http://www.who.int/mediacentre/factsheets/fs291/en/). According to data from the International Commission on Radiological Protection, radon and its daughters account for 50–90% of collective radiation exposure. This gas is odorless, tasteless and colorless; for these reasons it is impossible to detect without special equipment. Radon, produced by the decay of radium in the soil, decays into products called radon progeny. During decay, these radon daughters produce radioactive alpha particles and stick to aerosols, dust particles and other elements present in the air. Based on experimental and epidemiological studies, in 1987 the International Agency for Research on Cancer classified radon and its daughters as human carcinogens.

Lung cancer is caused by inhaled, short-lived radon progeny. Large-scale studies in Western Europe and the USA showed that radon is the second most important cause of lung cancer after smoking.

According to observations in 1 million houses in the USA, radon exposure ranges from several units to over 1000 Bq m^{-3}; in 2% of the buildings, indoor radiation exposure is comparable to the exposure experienced by residents of the Ukrainian city of Pripyat (now completely evacuated) as a result of the Chernobyl Nuclear Plant accident in April 1986.

In the year 2006, the Joint Research Centre (JRC) of the European Commission launched a project with the aim of mapping radon at the European level (https://rem.jrc.ec.europa.eu), which represents a part of the European Atlas of Natural Radiation, starting with the European Indoor Radon Map (EIRM)(1). At the International Workshop on the European Atlas of Natural Radiation in late 2015 (Verbania, Italy), it was decided to include the data-set measured in Azerbaijan within the framework of a joint collaboration between the Institute of Geology and Geophysics of the Azerbaijan National Academy of Science (GIA) and the Radon Competence Center (RCC) of the University of Applied Sciences and Arts of Southern Switzerland (SUPSI). At that time, the EIRM already included 30 countries.

The problem of radon is addressed in countries where the environmental situation is considered to be favorable. For example, Sweden was the first country where researchers paid attention to the growth of oncological diseases (including lung cancer) among people who live on the first or second floor in several areas of the country. It was found that radon gas is emitted from underlying rocks into the basements and living areas of the buildings located in these areas.

In Germany, the level of radon in 1% of residential buildings is over 250 Bq m^{-3}, and in 0.1% of buildings it exceeds 600 Bq m^{-3}. (Radiation protection experts of the European Union (EU) have determined that the annual average activity concentration in air for residential buildings should not exceed 300 Bq m^{-3})(2).

In Slovenia, 730 kindergartens and 890 schools were examined between 1990 and 1994 within the framework of the National Radon Program. Radon exposure exceeded the maximum acceptable level of 400 Bq m^{-3} in 47 kindergartens (6.4%) and in 77 schools (8.7%)[3]. Radon concentrations and mitigation activities were also studied in other European countries.

For national health authorities who seek to design proper policies to prevent any possible impact of radon on the health of the population, it is essential to know the distribution of radon within the country. A radon map is such an instrument, allowing public health authorities to have an overview of the situation. Azerbaijan is an upper-middle-income country according to the Development Co-operation Directorate of the Organization for European Economic Co-operation (OECD-DAC1) list of recipients, which shows all countries and territories eligible to receive Official Development Assistance (ODA). The list is based on the gross national income per capita as published by the World Bank, with the exception of G8 members, EU members and countries with a firm accession date for entry into the EU (OECD homepage: http://www.oecd.org/dac/stats/daclistofodarecipients.htm). Radon is usually not a health priority issue for countries in this category, and for that reason there still exists a lack of indoor radon measurements on a national level.

Studies of radon concentrations in Azerbaijan were based on the Swiss cadaster experience and carried out for the first time in 2010–11. Between 1994 and 2004, the Swiss Federal Office of Public Health generated a countrywide indoor radon cadaster in order to define high, medium and low radon-prone areas. More than 4000 passive radon dosemeters were randomly distributed in all Swiss municipalities. The same strategy has been adopted for the generation of the Azerbaijan radon cadaster. Those results are discussed in this article. The studies were carried out jointly by the RCC of the SUPSI and the GIA of the National Academy of Sciences.

Azerbaijan is located on the western shore of the Caspian Sea (at the east extremity of the G. Caucasus, L. Kura depression and Talysh Mountain) and has a population of ~9.3 million people (2012). Four physical features dominate Azerbaijan: the Caspian Sea in the east; the Greater Caucasus mountain range in the north; the Lesser Caucasus and Talysh Mountains in the south; and the extensive flatlands (Kura Valley) at the country's center. Azerbaijan has a total land area of ~86 600 km^2. It is bordered on the north by Russia, on the west by Armenia, on the northwest by Georgia, on the southwest by Turkey and on the south by Iran (Figure 1).

A wide stratigraphic range of sedimentary, metamorphic and magmatic formations comprise the geological structure of Azerbaijan. The Greater and Lesser Caucasus ranges are represented by sedimentary and volcanic-sedimentary formations of Jurassic, Cretaceous and Paleogene age. Within the Kura intermountain depression, younger Neogene–Quaternary rocks have settled.

Results of radiometric studies carried out since 1949 have shown that natural radiation fields in the territory of Azerbaijan remain within the range typical for rocks and soils of the earth and hover around 6–8 μR h^{-1}. At the same time, a relationship between natural radiation fields and the geological structure of the territory has been discovered.[4]

MATERIAL AND METHODS

Dosimetry

Since the measurements ultimately had to be integrated into the EIRM and have statistical significance, some 2500 passive radon dosemeters of the Gammadata–Landauer type were delivered to GIA with the support of the Swiss National Science Foundation and the RCC.

These passive radon dosemeters were placed randomly in different regions of the country, mainly in residential but in some cases in industrial buildings, during the period of November–December 2010. The exposure time did not exceed 2 months because the cold season in Azerbaijan is short. Several (~50) dosemeters were installed in oil fields of the Absheron peninsula and kept there from March to April 2011. An allocation map of dosemeters within the territory and the density of measurement points for different administrative regions are shown in Figures 2 and 3.

Sampling of data: data collection

When the dosemeters were placed, data sheets were compiled for each one containing specific information such as the code of the instrument, date-time of installation and removal, exact address, coordinates, floor, type and material of the measured building (see Table 1).

For accreditation purposes, the level of uncertainty for each single dosemeter is around 15%, according to the supplier, Gammadata–Landauer and our laboratory, with another 1% error resulting from problems in transport. In previous indoor radon studies, a total uncertainty of 12% has been estimated.

RESULTS

Distribution of concentrations

Measured indoor radon concentrations varied in a wide range: from 0 to above 1100 Bq m^{-3}. Out of the 2404 measured houses, 169 were above 200 Bq m^{-3} and 418 remained between 100 and 200 Bq m^{-3}.

Figure 1. Geographical location of Azerbaijan.

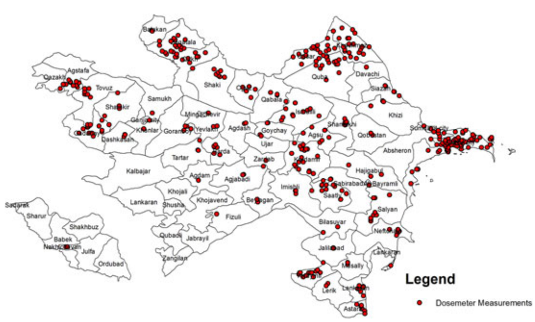

Figure 2. Geographic distribution of measurements.

Figure 3. Number of radon measurement points per district.

The obtained data were processed using purely statistical methods since no geological or soil measurements (usually a radon source indicator) were available.

The frequency distribution of the measured radon concentrations is shown in Figure 4, indicating a log-normal character with a median of 58 Bq m^{-3} and a mean of 84 Bq m^{-3}. The upper background limit calculated as twice the median amounted to around 116 Bq m^{-3}.

All of the above values can be considered as statistically elevated, but compared with the maximum

Table 1. Radon concentrations in buildings built of different materials.

Building material	No. of houses	Radon concentration ($Bq\,m^{-3}$)			
		Max.	Min.	Median	Mean
Adobe brick (air-dried)	355	796	0	65	89
Ashlar	9	664	20	97	190
Brick	88	1109	6	62	94
Concrete	40	253	13	37	52
Lime stone (cube)	1420	1014	0	54	79
Natural stone	12	328	52	104	114
River rocks	342	834	0	73	100
Timber (wood)	15	216	14	47	72
n/a	123	339	1	54	75
Total	2404				

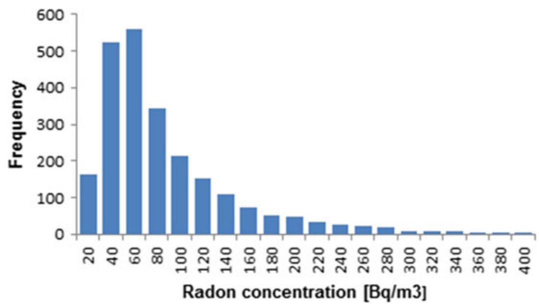

Figure 4. Frequency distribution of the indoor radon concentration.

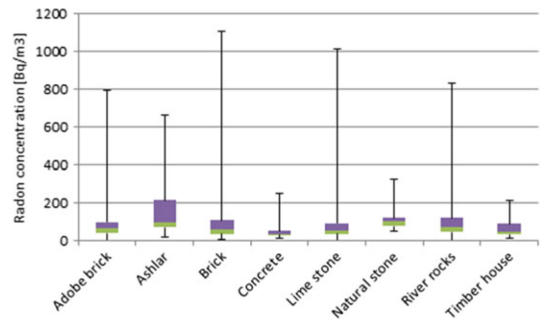

Figure 5. Box plot of the obtained data.

allowable concentration (MAC) for indoor radon in Azerbaijan, which is 200 $Bq\,m^{-3}$, only the buildings with radon concentrations exceeding the MAC are interesting from a public health point of view.

For a more detailed analysis, a closer look at the building materials of the measured houses is shown in Table 1.

A box plot of radon concentration as a function of the building materials is shown in Figure 5. The calculated whiskers, which indicate the variability outside the upper and lower quartiles of the data-set, show a long-tail behavior above the third quartile (heavy-tailed distribution), which represents the values between the median and the highest obtained value and includes 25% of the data.

Based upon these results, buildings constructed with ashlar are statistically the most radon-contaminated cases, followed by houses constructed with natural stone and river rock.

Only in the case of ashlar does the upper quartile touch the MAC of 200 $Bq\,m^{-3}$ for radon in Azerbaijan.

An analysis of concentrations on the floor levels of the 2030 houses was carried out and showed a normal behavior: the higher the floor, the lower the mean radon concentration. Small differences between concentrations on the first and the second floors have been found (Table 2).

Comparison between Switzerland and Azerbaijan

Analysis of the resulting map shows that the spatial distribution of radon in Azerbaijan is heterogeneous and forms a mosaic. The areas with elevated radon concentrations are confined to the mountainous and the folded massifs of the Great and Lesser Caucasus and the Talysh range, which lies on the border with Iran. The lower concentrations are confined to lowland zones, basically semi-desert and riverbed areas. These results suggest that high concentrations are associated with relatively ancient and dislocated rocks.

The spatial distribution in Switzerland is also heterogeneous, with higher values in the southern part of the Alps and the western mountains of the Jura (Figure 6).

Geological aspects

Considering the impact of other geological factors on the distribution of radon, it is necessary to note that radon is an admixture component; it is

Table 2. Radon concentration at different buildings floors.

Floor	No. of houses	Radon concentration (Bq m^{-3})			
		Max.	Min.	Median	Mean
1	1562	1109	0	62	90
2	438	547	1	52	69
3	15	68	0	24	25
4	6	45	0	23	24
5	1	19	19	19	19
n/a	374				
Total	2404				

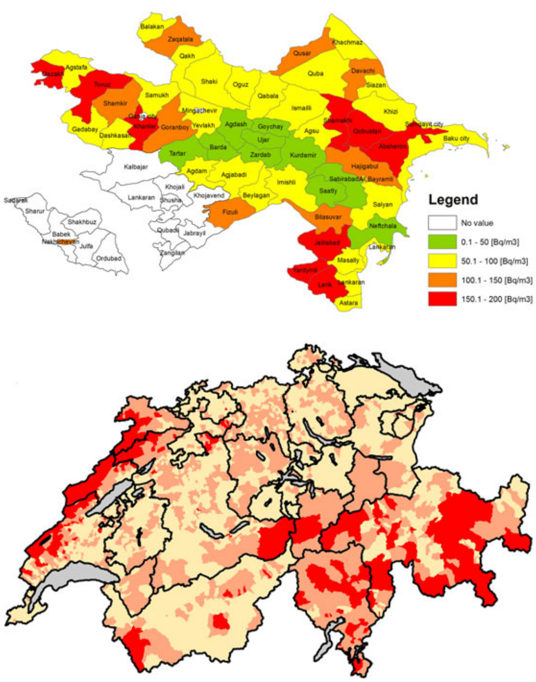

Figure 6. Comparison of the spatial indoor radon distributions in Azerbaijan and Switzerland. (Source: Swiss Federal Office of Public Heath 2013, SwissBoundaries2012©Swisstopo)

produced from the subsoil and released at the surface in the presence of hydrocarbon, nitrogen and carbon dioxide gas streams. Prevalent routes of vertical migrations are highly permeable zones of deep faults that usually are expressed by high thermal flow. The seismic activity intensifies fluid flows[5, 6]. It is an interesting fact that indoor radon measurements are able to reflect the geological impact of radon occurrence at this statistical scale.

The first map of indoor radon concentrations in Azerbaijan was made based on the results of completed studies. This map identifies areas where radon concentrations exceed MAC and can be dangerous for the health of the population.

The relationships between radon fields and geological conditions consist of the following:

- The highest radon activity is confined to the areas of intersection of the deep faults of the Caucasus in line with active N-S faults.
- A mosaic association of radon anomalies with seismically active zones of the Great and Lesser Caucasus and Talysh ranges and its coupling with the Kura Depression has been observed.
- Maximum concentrations of radon are confined to the areas of ancient tectonic uplifts.

INTEGRATION OF THE OBTAINED RESULTS INTO THE EIRM

As mentioned at the beginning, the obtained results have been integrated into the EIRM using the data processing required to obtain homogeneous data-sets for all involved countries[1]. These standard procedures were decided during the 8th International Workshop on the Geological Aspects of Radon Risk Mapping in 2006.

Basically, the measured area is split into 10 km × 10 km grid cells and filled with the mean annual indoor radon concentration in ground-floor rooms of dwellings, as defined by the JRC[7–9]. Since the measurement period in Azerbaijan was shorter, modeling and seasonal corrections due to a standard estimate, developed by the Swiss Federal Office of Public Health were applied, adding 12% of the measured mean value during the summer period and subtracting 12% during the winter period.

In Figure 7, the results of this elaboration, representing the number of measurements per 10 km × 10 km cell, are shown. Figure 8 shows the arithmetic mean (AM) of the indoor radon concentration, calculated for the same cells.

The recent EIRM (from November 2015) for 30 European countries is shown in Figure 9. Figure 10 expresses the AM applied again over the 10 km × 10 km cells for all involved countries[10].

All the data processing for the EIRM was performed by the JRC.

CONCLUSIONS

(1) The study showed that the average indoor radon concentrations in Azerbaijan are low due to the absence of thermally insulated edifices and tight building construction methods. Most of the houses contain just one single heated room, windows are generally leaky and there is direct contact between soil air and indoor air. Especially in rural areas, the inhabited space has a wooden floor that is situated above a crawl space, making the habitation highly permeable to radon.

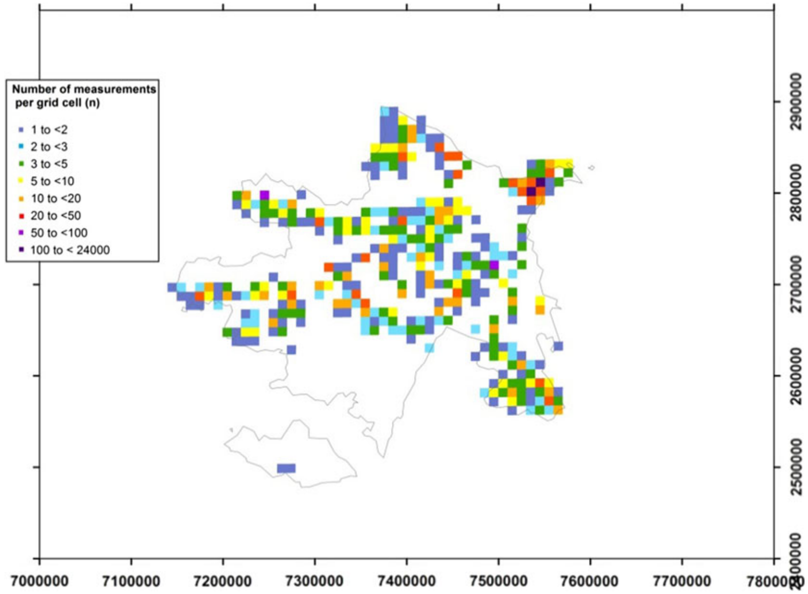

Figure 7. Number of measurements per 10 km × 10 km cell of long-term radon concentration in ground-floor rooms in Azerbaijan. Source: European Commission, JRC, Institute for Transuranium Elements (ITU), REM project.

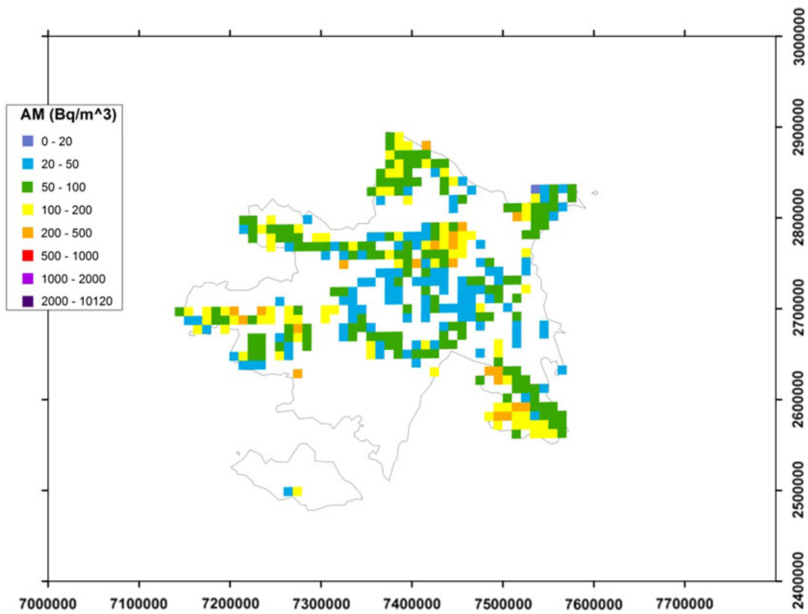

Figure 8. AM over 10 km × 10 km cells of long-term radon concentration in ground-floor rooms in Azerbaijan. (The cell mean is neither an estimate of the population exposure, nor of the risk.) Source: European Commission, JRC, ITU, REM project.

(2) Despite this fact, in some buildings the concentration results were very high. Given the movement toward improving construction to produce more energy-saving buildings, the radon concentrations may increase substantially.

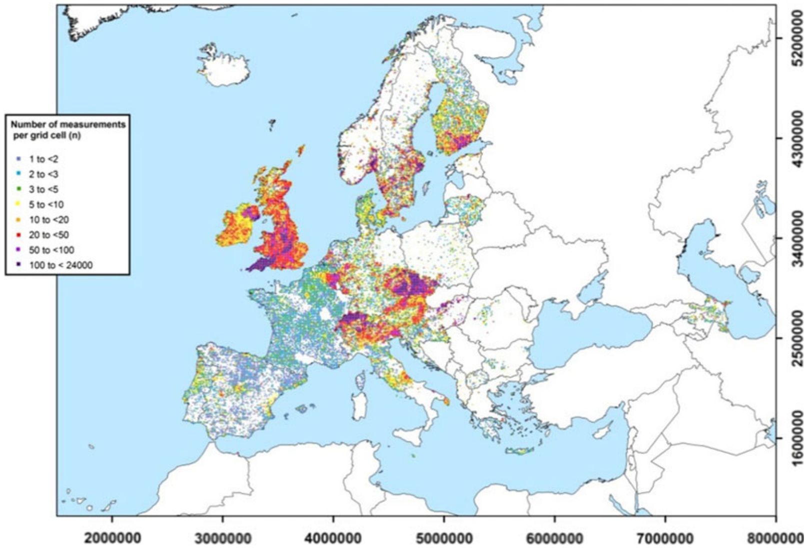

Figure 9. Number of measurements per 10 km × 10 km cell of long-term radon concentration in ground-floor rooms of 30 European countries. Latest update, November 2015. Source: European Commission, JRC, ITU, REM project.

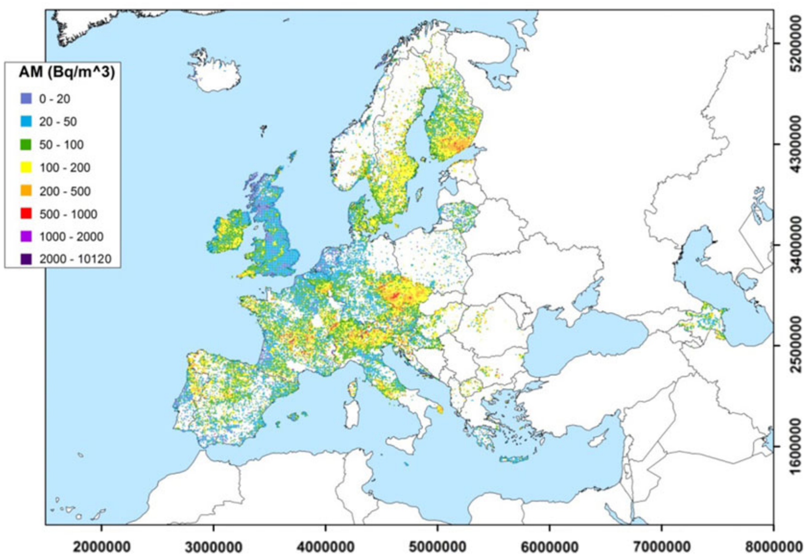

Figure 10. AMs over 10 km × 10 km cells of long-term radon concentration in ground-floor rooms of 30 European countries. Latest update, November 2015. (The cell mean is neither an estimate of the population exposure, nor of the risk.) Source: European Commission, JRC, ITU, REM project.

(3) These conclusions are preliminary. The analysis of identified radon concentrations in Azerbaijan continues and includes the following objectives:
- Analysis of the relation between the level of lung cancer among the population and the distribution of radon (jointly with regional organizations of the Ministry of Public Health of Azerbaijan).
- Development and implementation of activities to reduce the level of radon in living spaces.

(4) The obtained indoor radon map has been integrated into the EIRM by the JRC, following the standard procedures established for that map.

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