International Journal of Environmental Science and Technology (2023) 20:5937–5944
https://doi.org/10.1007/s13762-022-04398-z

ORIGINAL PAPER

Health risks in association with indoor radon exposure in Northeastern Romania

C. Cojocaru[1] · P. Cojocaru[2] · R. M. Barbu[3] · F. Pinzariu[4] · E. Cojocaru[3]

Received: 31 October 2021 / Revised: 22 April 2022 / Accepted: 11 July 2022 / Published online: 30 July 2022

Abstract
The radon level was assessed in houses from two rural areas localized in Northeastern Romania. Long-term measurements were performed for a period of four months using a digital radon detector, model *Corentium Home, AirThings 222*. In addition, for every environment included in the study, investigations concerning the building materials, the floor type, the building year and the heating system were made. Accordingly, Spearman's correlation coefficients of the study variables were calculated. The World Health Organization recommends an upper threshold of 100 Bq/m^3 as a national reference level. For both studied areas, we calculated a mean indoor radon level of more than 100 Bq/m^3, but in the Tomesti-Osoi area were recorded values of over 100, respectively 300 Bq/m^3 in significantly more households. Indoor exposure to radon of people in the investigated houses was found in 75 and 35.3% of the cases, respectively, above the level accepted by international recommendations, with a moderate correlation between mean radon levels and the features of the residential buildings.

Keywords Health risk · Indoor radon · Home assessment · Radon measurements · Romania

Introduction

Radon is a gas situated in the 18th group, that of rare gases, in the periodic table of elements. It forms as a product of uranium decay, being one of the most important sources of radiation in the Earth's crust. Ernest Rutherford and Robert B. Owens (Thornton and Burdette 2013) discovered it in 1899; in normal conditions of temperature and pressure, it forms a monatomic gas with a density of 9.73 kg/m^3, approximately 8 times higher than that of Earth's atmosphere. Thus, radon is a heavyweight among natural gases, which explains its tendency to accumulate not only in mines, but also in the basements of houses or even bedrooms, if there is no basement.

From a physics viewpoint, this noble gas is colorless, tasteless and odorless at standard pressure and temperature, being freed from Earth's crust through surface cracks. Rapid increases in radon concentration in Earth's crust are correlated with telluric movements, and are likely indicators of an imminent surface earthquake (Kim et al. 2018). Following radon decay, radioactive alpha particles are released, consisting of two protons and two neutrons. It has been observed that radon accumulations appear in insufficiently ventilated areas.

As a consequence of radioactive decay, radon emits 5.49 MeV alpha particles. When radon's decay products, ^{218}Pb and ^{214}Pb, are inhaled, these settle on the bronchial wall, leading to a persistent irradiation of cellular structures in that area. Exposure to alpha particles may cause damage to the helicoidal structure of the Deoxyribonucleic Acid (DNA) and to abnormal proliferation of the damaged cells, which can result in bronchopulmonary tumors. Due to variations in the morphology of the bronchial tract and to aerodynamics, gas distribution and density are inhomogeneous (Farkas et al. 2011). In addition, radon settling is

Editorial responsibility: Hari Pant.

✉ P. Cojocaru
paula.cojocaru@academic.tuiasi.ro

1 Medical III Department, Faculty of Medicine, "Grigore T. Popa" University of Medicine and Pharmacy, Iasi, Romania

2 Department of Land Improvement and Environmental Protection, Faculty of Hydrotechnics, Geodesy and Environmental Engineering, "Gheorghe Asachi" Technical University of Iasi, 700050 Iasi, Romania

3 Morpho-Functional Sciences II Department, Faculty of Medicine, "Grigore T. Popa" University of Medicine and Pharmacy, Iasi, Romania

4 Faculty of Visual Arts and Design, "George Enescu" National University of the Arts, Iasi, Romania

significantly modified by the mucociliary clearance (Farkas and Szőke 2013). As described by a Stochastic Lung Model, particles can deposit and enter into the mucus layer during inhalation and exhalation, preponderantly in airway generations higher than the fifth (Farkas 2020).

Even during Greek and Roman times, there were concerns linked to therapy with radioactive radon gas, using thermal springs, considered sacred for their curative properties. Despite their controversial usage, these therapies would be applied to treat various ailments, from rheumatoid arthritis (Verhagen et al. 2015) to psoriasis (Evstigneeva et al. 2018). Nowadays, radon therapy is accepted and covered by Health Insurance in Austria and Germany, the Bad Gastein caves in the Austrian Alps being rich in radon. Romania also possesses some medical establishments that use it. At the Herculane resort, because of its direct contact with the air, radon concentration is greatly diminished (Cosma et al. 1996). In the Covasna mofettes, carbon dioxide emanations entrain a small quantity of natural radon (Cucoş Dinu et al. 2014). In balneology, only radon isotope 222 (^{222}Rn) is acknowledged to have positive effects. Even though such areas rich in radon have gained fame over time, more recent observations of a high incidence of lung cancer among miners exposed to radon gas and its decay products have raised suspicion about its harmful effects (Zdrojewicz and Belowska-Bień 2004).

According to a WHO-Europe report (WHO-Europe 2009), the relationship between radon and lung cancer risk is revealed by the arithmetic mean of radon levels found in dwellings, and is the most relevant indicator for assessing its impact on public health. The wide variations in national radon reference levels also leads to very different health impacts in different countries. The overall risk of lung cancer is estimated to increase by 16% for each 100 Bq/m^3 increase in radon concentration (WHO-Europe 2009). Based on the methodology used in the European pooled study, attributable risk estimates range from about 3% of lung cancer deaths in the Netherlands or the United Kingdom, to 21% in the Czech Republic. Besides, taking into account the EU common action level of 200 Bq/m^3, there is a significant difference between the minimum (20 Bq/m^3), found in Netherlands and the United Kingdom, and the maximum (120–140 Bq/m^3) reported for the Czech Republic and Finland. In addition, in Europe, there are countries with insufficient or unreliable data. According to a study, the geometric mean (GM) and the geometric standard deviation (GSD) for residential radon were of 84 (respectively 2.5) Bq/m^3, one of the highest levels in the world, next to Mexico, Finland, Poland, the Czech Republic and Armenia (Gaskin et al. 2018). The WHO recommends an upper threshold of 100 Bq/m^3 as a national reference level (WHO 2021).

Indoor radon is considered a menace, according to criteria defined by the United Nations Office for Disaster Risk Reduction (UNDRR 2020): (1) It has the potential to impact the community (elevating the risk of lung cancer), (2) Proactive and reactive measures are available (e.g., specific building codes, radon mitigation), and (3) It has a measurable spatial and temporal component (depending on geogenic factors and seasonal variations).

Air and surface water pollution, in addition to indoor radon exposure, could be aggravating factors. When solid fuels are used for domestic heating or food preparation, CO, CO_2, volatile organic compounds, particulate matter, aerosol, biological pollutants, and other pollutants are released into the atmosphere (Kumar and Imam 2013). The effects on neurocognitive performance have been well studied, and it has been shown that in poorly ventilated rooms, CO_2 threshold values are quickly exceeded. (Cetin 2017) (Çetin et al. 2017). In the case of surface water pollution, exposure to heavy metals was correlated with hypertension, abdominal pain, renal dysfunction, fatigue, sleeplessness, and arthritis. As a result, it is necessary to keep a monitor on pollution levels and only use low-pollution water in homes and farms. (Ozel et al. 2019).

The aim of our research was the investigation of the level of indoor radon and its connection with the specificities of the population, buildings and geological structures, in two Northern-Eastern areas in Romania. To our knowledge, it is the first study on radon exposure in the region studied, the methodology is reproducible, and can serve as a good reference point for larger studies in this region. We consider the two studied areas as representative for the region of the Moldavian Plateau that, in turn, forms a large part of Romania. We designed preventive and corrective measures that would assist in minimizing the effects of radon exposure on humans, particularly in settings where people reside for prolonged periods, such as homes. We can raise awareness of the dangers of radon gas exposure in interior areas and encourage people to take action to prevent it, in two areas where this has never been done before.

Materials and methods

Characterizing the research area

In the researched regions, no previous systematic investigation has ever been carried out to measure indoor radon levels. The regions are defined by the administrative territorial units of the Deleni area, Vaslui County and the Tomesti-Osoi area, Iasi County, respectively. In choosing the two areas, different features of the soil morphology were taken into account, as well as their geographical specificity: the sediment cover of loessic clays, generally waterproof, but pierced by cracks that allow gas permeation.

The Deleni region (found at coordinates [N46°32′34″, E27°44′46″]) (Fig. 1) is situated in the Central Moldavian

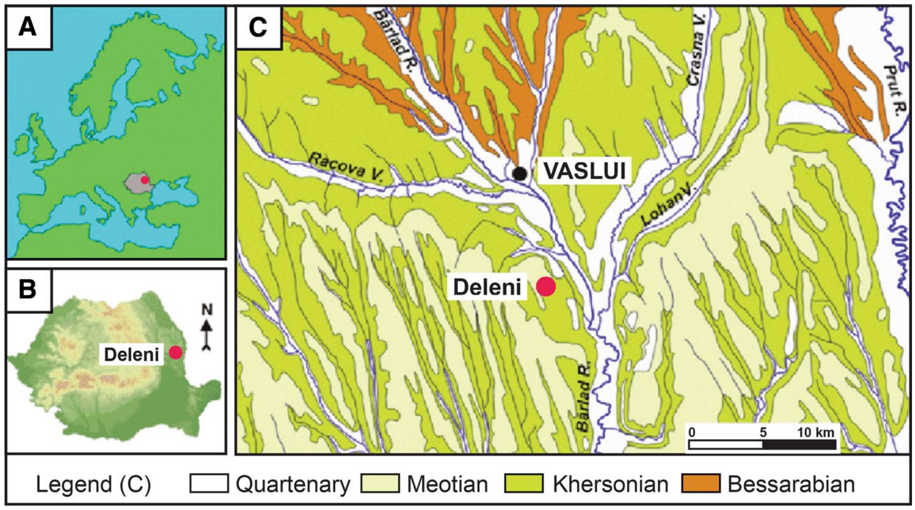

Fig. 1 The geological map of the studied Deleni area (adapted from Jeanrenand 1961)

Plateau, with a hilly landscape and structural platforms separated by deep valleys, characterized by middle and late Miocene (Sarmatian and Meotian) clayey-sandy layers (Ionita et al. 2014).

The Tomesti-Osoi region (found at coordinates [N47°7′51″, E27°41′53″]) (Fig. 2) geologically consists of a platform with a landscape carved in Sarmatian formations. This consists of various deposits, mostly loams, siltstones, marls and sands, but also limestones and sandy limestones, among which oolitic limestones represent a frequent and peculiar element (Ionesi et al. 2005).

Experimental procedure

Based on free written consent, the persons that took part in this study allowed the placement, inside their homes, of a radon concentration measurement device for 48–72 h. The measurements took place in the main room, approximately 30 cm away from the wall and 0.7 m above the floor.

Measurements were taken using a digital Radon detector, *Corentium Home, AirThings 222,* short-term and respectively long-term type. While analyzing data, only the long-term results were used. The number of radioactive decays per time unit represents radioactive activity, and the unit of measurement in the international system (SI) is 1 Bq (Becquerel). A specific activity is that of a radiation unit relative to a mass, volume or surface, and the result is expressed in Bq/kg, Bq/m^3 or Bq/m^2. For the measurements in this study, the unit of measurement was Bq/m^3.

The study encompassed 29 homes, measurements being taken during January–April 2021. Written consent of the house owners was obtained regarding the measurements, the

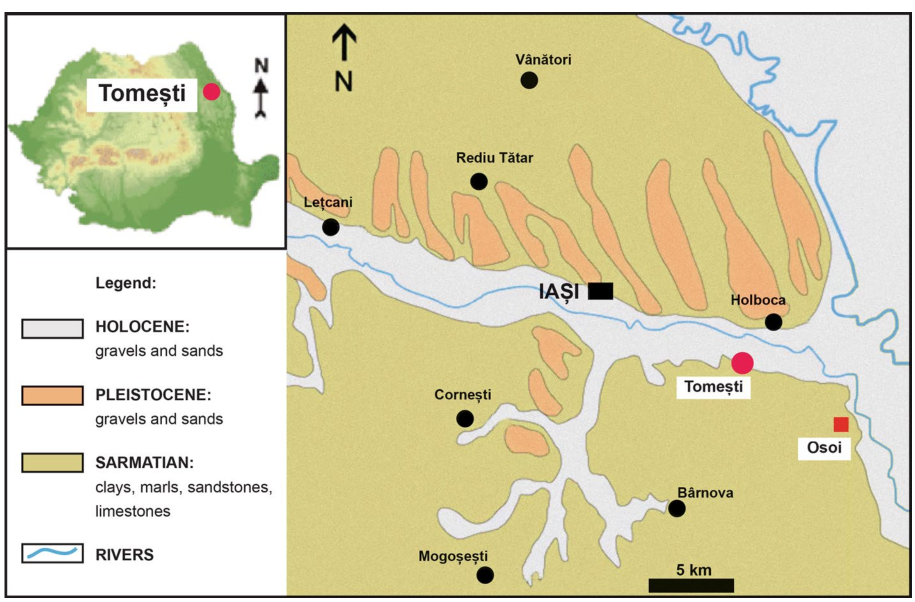

Fig. 2 The geological map of the studied Tomesti-Osoi (adapted from Saulea 1966)

technical features of the buildings, together with a clinical data anamnesis.

In order to establish the impact of local conditions on the indoor radon level, information regarding the building materials, the floor materials, the building year and the heating system were collected.

For standardization, information was structured as follows:

- Building year: 0–20 years old, 21–40 years old, over 40 year old buildings;
- Building materials: brick, clay/ clay-based material;
- Floor material: concrete, wood;
- Radon level: 1–20 Bq/m^3, 21–50 Bq/m^3, 51–100 Bq/m^3, 101–200 Bq/m^3, 201–500 Bq/m^3, 501–1000 Bq/m^3, 1001–2000 Bq/m^3, 2001–10,120 Bq/m^3.

Data were also collected regarding the age, smoker/non-smoker status and chronic diseases of each assayed building's owner. As data concerning chronic diseases were scarce or poorly documented, they were not included in the analysis. All houses were single-story (ground floor) and without a basement.

Table 1 The main characteristics of the study groups; data are given as mean ± SD or counts

Data groups	Osoi area	Deleni area	*P*
Houses (no.)	12	17	–
Age of the owner, years	55.9 ± 14.3	66.3 ± 13.5	0.813
Smoker	1 (8.3%)	2 (11.8%)	0.7534
Building year (median)	1998	1963	–
0–20	3 (25%)	2 (11.8%)	0.667
21–40	5 (41.7%)	1 (5.9%)	0.0602
> 40	4 (33.3%)	14 (82.4%)	0.0217*
Floor			
Concrete	7 (58.3%)	10 (58.8%)	0.722
Wood	5 (42.7%)	7 (41.2%)	0.763
Building materials Brick	7 (58.3%)	4 (23.5%)	0.13
Clay	5 (41.7%)	13 (76.5%)	0.13
Heating system			
Wood stove	5 (41.7%)	16 (94.1%)	0.0072*
Gas boiler	5 (41.7%)	1 (5.9%)	
Radon level (Bq/m^3)	480.7	125.8	< 0.001*

*$P < 0.05$

Results and discussion

Results

Main features of the two areas

Twenty-nine valid records of radon level in the study environments were taken into account. A comparative analysis of the main features in the two areas (Table 1) shows an older population in the Deleni area, though the difference is not significant. Population age is concordant with the age of the buildings. Thus, for the Deleni area, we notice a higher proportion of buildings older than 40 years. Ancient houses in Deleni were mainly built with clay-based materials (76.5%), compared to only 41.7% in the Tomesti-Osoi area. A main promoter of indoor radon release risk is formed by cracks in Earth's crust. Thus, it is estimated that the lack of compact concrete structures allows an indoor release of radon. In the study group, we noticed a slight preponderance in the use of concrete for floors, in both geographical areas. Considering that the study is focused on areas with a temperate-continental climate characterized by long periods of cold temperatures, when people spend most of the time indoors and homes need to be heated, we identified the house heating system as an extra risk factor. As such, we observed that most of the houses in Deleni use wood stoves for heating (94.1%) compared to only 41.7% in the Tomesti-Osoi area.

The above data show that the two areas have specificities concerning both the building type and the geological features.

Radon level results

Various maps have been plotted that illustrate levels of radon emission around the world (Mccoll et al. 2015). Radon emission data in Romania are few and usually refer to the North-West (Cosma et al. 2013). A study observing indoor ^{222}Rn levels in 72 countries reported a medium value for Romania (arithmetic mean) of 25.0 Bq/m^3 with a maximum value of 564 Bq/m^3 (Chambers and Zielinski 2011). Another review of national surveys carried out by the European Commission Joint Research Centre (JRC) showed that the estimated arithmetic mean concentration of indoor radon in Romania was of 45 Bq/m^3 (European Commission 2005). However, considering that radon emission depends on soil and subsoil features, there may be large variations between different areas. On the other hand, there are important differences in the methods of construction and materials used inside buildings.

Radon levels in the studied houses is detailed in Table 2. We can see that, though there are significant differences between the mean values calculated for the Tomesti-Osoi area compared to the Deleni area, in both geographical areas we recorded high exposures to radon (over 100 Bq/m^3). Nevertheless, exposure is far greater in Tomesti-Osoi, both from the point of view of the mean level and the number of houses

Table 2 Radon level correlated per groups and exposure level

Data groups	Osoi area (12)	Deleni area (17)	*P*
Radon level(Bq/m^3)	480.7	125.8	< 0.001*
1–20	1 (8.3%)	3 (17.6%)	
21–50	1(8.3%)	2 (11.8%)	
51–100	1 (8.3%)	6 (35.3%)	
101–200	2 (16.7%)	3 (17.6%)	
201–500	3 (25%)	2 (11.8%)	
501–1000	2 (16.7%)	1 (5.9%)	
1001–2000	2 (16.7%)	0	
> 100	9 (75%)	6 (35.3%)	0.0836
> 300	7 (58.3%)	1 (5.9%)	0.0072*

*$P < 0.05$

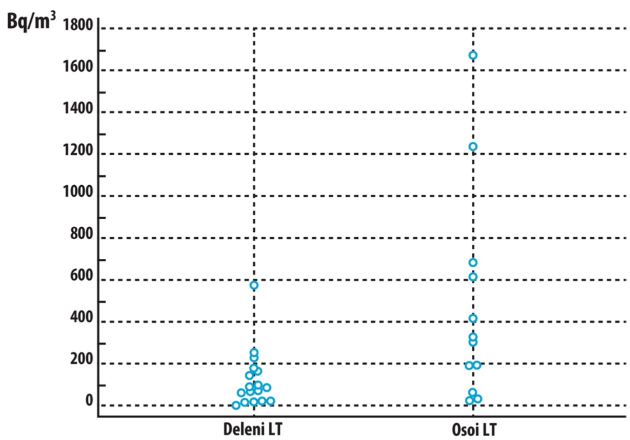

Fig. 3 Long term radon level in Deleni versus Osoi area

where values of over 100 and 300 Bq/m^3 were registered, respectively.

The distribution of radon levels measured in the two areas is shown in Fig. 3. As can be seen, this distribution is more heterogeneous and also shows a few extremely high levels for some environments in the Tomesti-Osoi area.

Based on the differences observed between the two areas, we wished to examine whether there is any correlation between indoor radon levels and the houses' features. In this respect, we calculated Spearman's correlation coefficients among study variables. Results are shown in Table 3.

There are moderate correlations between radon levels and the age of houses among the above groups, building materials, including the floor and the heating system. In these conditions, we conclude that the main cause for high radon levels is the geological structure of the soil and the physical features of the two regions.

During the studied period (January-April 2021), the average daily values for O3, CO, NO, NO2, and SO2 at Vaslui-1 station (10 km from Deleni) and Iași-5 in Tomești area did not exceed the maximum limits allowed. In the case of heavy metals, only data from Vaslui-1 station was available, with no daily average value exceedances (RNMCA 2021).

Discussion

Romania is the European Union's sixth most populous country and one of the countries with the highest seismic potential (earthquakes of intermediate or subcrustal depth, occurring in outbreaks at depths between 60 and 220 km in the Vrancea area) (INFP 2021). Over 150,000 km^2 of soil experiences a maximum estimated acceleration of over 0.2 g. There also exist over 30 solid radioactive mining waste deposits as a result of uranium mining that took place between 1962 and 2004. (Pavel 2017) (Petrescu et al. 2010).

The two areas belong to the Moldavian Plateau, the soil structure of which is based on a foundation of Precambrian crystal rocks overlapping Ordovician-Silurien formations. Alternative consolidated rocks like gritstones, limestones and less-common micro-conglomerates, with unconsolidated rocks, like clays, silts and sands form this area's lithology (Mărgărint and Niculiță 2017). These rocks allowed the formation of deep soils with low skeleton contents, mainly Luvisols intermixed with Cambisols, Phaeozems and Chernozems. Hills and plateaus are part of this landscape morphology, which is largely wavy (91%), with altitudes ranging between 100 and 500 m (Bireescu et al. 2018).

The area is also one of the regions in Romania that are highly susceptible to slumps. Croplands, human settlements and infrastructure are especially affected by these (Grozavu et al. 2012).

Table 3 Spearman rank correlation coefficient

	LT total	Building year	Building material	Floor	Heating
LT total		− 0.014	0.047	0.435*	0.115
Building year	− 0.014*		0.447*	0.406*	− 0.475*
Building material	0.047	0.447*		0.512*	− 0.445*
Floor	0.435*	0.406*	0.512*		− 0.182
Heating	0.115	− 0.475*	− 0.445*	− 0.182	

*$P < 0.05$

All these pedogenetic factors as well as the natural phenomena that take place at soil level could be causes for the presence of radon.

Most of the ancient houses lacked a foundation, the floor consisting of compacted soil covered with a floorboard. Gas exhaled from the ground can easily penetrate the structure and accumulate indoors. The structure of the walls, made of local materials, does not afford an efficient protection against radioactive gas.

Impact of radon exposure on human health

The respiratory tract seems to be the main entryway into the body, via aerosols dispersed in the air. Approximately an hour after inhalation, 90% of the inhaled radon is expelled, and is completely eliminated after 4–5 h. It seems that most of the harm is caused by the formation of free radicals. Cell deterioration takes place under the action of the free radicals and oxidants, along with mutations at the DNA structure level and chromosomal aberrations. Greater harm is incurred by young cells, which have a higher multiplication rate.

According to the linear no-threshold model, it is assumed that any ionizing radiation dose is noxious, which doesn't require establishing a minimum level of radiation. Extrapolations performed in various regions (Vukotic et al. 2019) made possible to estimate the allowed dose for ionizing radiations.

Considering data concerning both beneficial and harmful effects on the, the theory based on the Arndt-Schultz rule–stating the effect is dependent on the dose–is admitted to be correct. The theory stipulates that low radiation doses stimulate the mechanisms of cellular protection while high doses exceed cell protection capacity and lead to neoplastic cell proliferation. Moreover, smoking associated with radon exposure doubles cancer risk (Lubin et al. 1997). In our study, the low rate of smokers reduces the risk for inhabitants of the analyzed houses.

The mean radon level registered in our study suggests that this geographical area is one with moderate exposure risk, modulated by the geological features of each of the study areas. Nevertheless, the higher levels found in certain homes can be a cause of neoplastic pathology in these spots, suggesting that certain measures should be taken, like preventive medical investigation of the inhabitants, better isolation of the floors, proper airing of the rooms, geological analysis prior to house building.

In the European Union and all around the world, creating maps to indicate areas with high potential for radon exposure is necessary (JRC Publications Repository—The European Radon Mapping Project 2022). The release of radon from the earth's crust is important both in terms of the impact on human health due to its accumulation in houses and in terms of the impact on agricultural activities. (Swistock et al. 1993). As is being shown, there are few studies measuring radon levels in this part of Europe, especially in Moldova's plateau. The study was conducted in a mainly agricultural area, and much of the grown produce is used in European Union countries (Andrei et al. 2020). Given the current state, the current study might form a pilot study that identifies the main realities of the population's living conditions in this part of Europe. Future studies should include other harmful factors such as indoor and outdoor pollution, as well as surface and deep-water pollution.

The study limitations consist in insufficient evaluation of the known pathology for inhabitants in the investigated areas. The relatively low number of study homes, partially due to people's discomfort with placing the measurement device inside their homes can also be a limitative factor. Therefore, larger studies should include one component of public authority to increase the degree of trust of the study's population. The goal of this study was not to evaluate the impact of air and water pollution on population health in association with radon exposure. We consider there are no significant concerns, based on the zonal data provided by the competent authorities, in the rural areas where the study was conducted, which were free of significant sources of outdoor pollution. Aggressive urban modeling interventions that could imbalance the interaction between humans and the environment were not used in the studied areas. (Çetin and Sevik 2016).

Romanian authorities should monitor and map indoor radon, imposing detailed recommendations for preventing and mitigating indoor radon exposure. The aim is to reduce health risks from radon exposure by performing reliable radon level measurements, by controlling measures for indoor radon reduction and assessing their costs and benefits.

Conclusion

Exposure to radon radiation increases the risk of lung cancer and other significant diseases. High levels of radon may be recorded indoor, depending on the building structure (raw materials) and the soil geology. The WHO has launched a global radon project to raise awareness, collect data, and encourage countries to take action to reduce radon risks. So far, in Romania, there has been a shortage of studies in the field, and no consistent data this part of the European Region. Due to the particularity of the buildings in the area (intensive usage of natural resources in house construction) and to a high risk of lung cancer, we proposed a systematic measurement of the ionized radiation, inside a national survey. It is necessary to evaluate if there is a significant indoor exposure to radon radiation and to design risk maps useful in the improvement of early detection of this severe disease.

Implementation of some education strategies in schools about radon exposure must be a priority for the competent authorities in order to implement measures such as an efficient home ventilation, basic radon membranes, under floor ventilation.

Acknowledgements We would like to thank all the participants from the two study areas.

Author contributions The research presented in this manuscript is original, and has not been previously published elsewhere. Mr. C.C. coordinated the team and managed the obtained data during the research in order to obtain the best results of the study. He also coordinated the interpretation of the data taken over by the members of the research team. Mrs. C.P. did research on the building materials, the floor type, the building year and the heating system of the houses in 14 of the 29 studied locations. She also helped to interpret the taken data. Mrs. R.M.B. contributed by collecting the data obtained with the help of the digital Radon detector type *Corentium Home, AirThings 222* located in the two studied areas. She also helped to interpret the taken data. Mr. F.P. contributed to the graphical representation of the obtained data and the processing of the maps within the article. Mrs. C.E. did research on the building materials, the floor type, the building year and the heating system of the houses in 15 of the 29 studied locations. She also helped to interpret the taken data. All authors read and approved the final manuscript. They also agree that the manuscript should be submitted to the International Journal of Environmental Science and Technology.

Funding No funding was received for this study.

Availability of data and materials The dates on which the paper was based are stored on the server of the Medical III Department, Faculty of Medicine, "Grigore T. Popa" University of Medicine and Pharmacy, Iasi, Romania.

Declarations

Conflict of interest The authors declared that they have no conflict of interest.

Consent for publication The manuscript does not contain any individual person's data in any form (including any individual details, images or videos).

"Not applicable" in this section.

Ethics approval and consent to participate Based on free written consent, the persons that took part in this study have allowed the radon measurement device to be placed inside their homes, for 48–72 h.

The study comprised 29 homes, measurements being taken during January–April 2021. Written consent of the house owners was obtained regarding the measurements, the technical features of the buildings and the clinical data anamnesis.

References

Andrei JV, Popescu GH, Nica E, Chivu L (2020) The impact of agricultural performance on foreign trade concentration and competitiveness: empirical evidence from Romanian agriculture. J Bus Econ Manag 21(2):317–343. https://doi.org/10.3846/JBEM.2020.11988

Bireescu G, Dazzi C, Papa GL (2018) Features of selected benchmark soils along an elevational transect of the Northeastern part of the Moldavian Plateau (Romania). Int Soil Water Conserv Res 6:325–330

Çetin M (2017) A change in the amount of CO2 at the center of the examination halls: case study of Turkey. Kamla Raj Enterp 10(2):146–155. https://doi.org/10.1080/09735070.2016.11905483

Çetin M, Sevik H (2016) Change of air quality in kastamonu city in terms of particulate matter and CO2 amount. Oxid Commun 39(4):3394–3401

Çetin M, Sevik H, Saat A (2017) Indoor air quality: the samples of safranbolu bulak mencilis cave. Fresenius Environ Bull 26(10):5965–5970

Chambers DB, Zielinski JM (2011) Residential radon levels around the world. Encycl Environ Health 5(2):508–519

Cosma C, Ristoiu D, Poffijn A, Meesen G (1996) Radon in various environmental samples in the Herculane Spa, Cerna Valley, Romania. Environ Int 22(1):383–388

Cosma C, Cucoş Dinu A, Dicu T (2013) Preliminary results regarding the first map of residential radon in some regions in Romania. Radiat Prot Dosim 155(3):343–350. https://doi.org/10.1093/rpd/nct015

Cucoş Dinu A, Vasilniuc S, Timar-Gabor A, Manea P, Cosma C (2014) Contribution of radon dose to the patient exposure in themofette of Covasna sanatorium Romania. Carpath J Earth Environ Sci 9(3):69–74

World Health Organization-Europe (2009) ENHIS- European environment and health information system, radon levels in dwellings factsheet 4.6 z December 2009 z Code: RPG4_Rad_Ex1. https://www.euro.who.int/__data/assets/pdf_file/0006/97053/4.6_-RPG4_Rad_Ex1-ed2010_editedViv_layouted.pdf.

Evstigneeva S, Kulikov AG, Yarustovskaya OV, Shakhova AS, Lutoshkina MG (2018) Physical therapy of psoriasis. The modern methodological approaches. Vopr Kurortol Fizioter Lech Fiz Kult 95(1):53–58. https://doi.org/10.17116/kurort201895153-58

Farkas Á (2020) Simulation of the effect of mucociliary clearance on the bronchial distribution of inhaled radon progenies and related cellular damage using a new deposition and clearance model for the lung. Radiat Environ Biophys 59:651–661. https://doi.org/10.1007/s00411-020-00868-5

Farkas Á, Szőke I (2013) Simulation of bronchial mucociliary clearance of insoluble particles by computational fluid and particle dynamics methods. Inhal Toxic 25:593–605

Farkas Á, Hofmann W, Balásházy I, Szőke I, Madas BG, Moustafa M (2011) Effect of site-specific bronchial radon progeny deposition on the spatial and temporal distributions of cellular responses. Radiat Environ Biophys 50:281–297

Gaskin J, Coyle D, Whyte J, Krewksi D (2018) Global estimate of lung cancer mortality attributable to residential radon. Environ Health Perspect 126(5):057009. https://doi.org/10.1289/EHP2503

Grozavu A, Margarint MC, Patriche CV (2012) Landslide susceptibility assessment in the Brăieşti-Sineşti sector of Iaşi Cuesta. Carpath J of Earth Environ Sci 7(1):39–46

INFP-National Institute for Earth Physics (2021) http://www.infp.ro/index.php?i=dct

Ionesi L, Ionesi B, Lungu A, Roșca V, Ionesi V (2005) Sarmațianul mediu și superior de pe Platforma Moldovenească. Ed. Academiei Române, pp 593. https://www.researchgate.net/publication/273000483_Sarmatianul_mediu_si_superior_de_pe_Platforma_Moldoveneasca#fullTextFileContent.

Ioniță I, Chelaru P, Niacșu L, Butelcă D, Andrei A (2014) Land slide distribution and their recent development within the Central Moldavian Plateau of Romania. Carpath J Earth Environ Sci 9(3):241–252

Jeanrenand P (1961) Contributions to geology of the Central Moldavian Plateau. Scientific Transactions of the "Al. I. Cuza" University, Iaşi, s. II, t VII, f.2., pp 417–432 (In Romanian).

JRC Publications Repository–The european radon mapping project (2022). https://publications.jrc.ec.europa.eu/repository/handle/JRC84757. Accessed 17 Apr 2022

Kim JW, Joo HY, Kim R, Moon JH (2018) Investigation of the relationship between arthquake sand indoor radon concentrations at a building in Gyeongju, Korea. Nucl Eng Technol 5:512–518. https://doi.org/10.1016/j.net.2017.12.010

Kumar P, Imam B (2013) Footprints of air pollution and changing environment on the sustainability of built infrastructure. Sci Total Environ 444:85–101. https://doi.org/10.1016/J.SCITOTENV.2012.11.056

Lubin JH, Tomásek L, Edling C (1997) Estimating lung cancer mortality from residential radon using data for low exposures of miners. Radiat Res 147(2):126–134

Mărgărint and Niculiță (2017) Landslide type and pattern in MOLDAVIAN Plateau, NE Romania. In: LANDER - Landform dynamics and evolution in Romania, pp 271–304. https://doi.org/10.1007/978-3-319-32589-7_12

McColl N, Auvinen A, Kesminiene A (2015) European code against cancer 4th edition: ionising and non-ionising radiation and cancer. Cancer Epidemiol. 39 (1): 93–100. https://reader.elsevier.com/reader/sd/pii/S1877782115000983?token=5A179804799250760C6B81E489D5B5D077B6620C0B5F2F56193D979645F84E8F899E0DDC5C03A7CE5736CC1B6836D53A&originRegion=eu-west-1&originCreation=20220421130708.

Ozel HU, Ozel HB, Cetin M, Sevik H, Gemici BT, Varol T (2019) Base alteration of some heavy metal concentrations on local and seasonal in Bartin River. Environ Monit Assess 191(9):594. https://doi.org/10.1007/S10661-019-7753-0

Pavel F (2017) Next future large earthquake in Romania: a disaster waiting to happen? Seismol Res Lett 88(1):1–3. https://doi.org/10.1785/0220160140

Petrescu L, Bilal E, Iatan L (2010) The impact of a uranium mining site on the stream sediments (Crucea Mine, Romania). Sci Ann Sch Geol 100:121–126

RNMCA (Rețeaua Națională de Monitorizare a Calității Aerului). (2021) Calitate aer. https://www.calitateaer.ro/public/home-page/?__locale=ro.

Saulea E, Bratu E, Sandulescu J (1966) The geological background of the Tomesti-Osoi study area. In: The geological map of Romania-Sheet L-35-XI, Institutul Geologic.

Swistock BR, Sharpe WE, Robillard PD (1993) A survey of lead, nitrate and radon contamination of private individual water systems in Pennsylvania on JSTOR. J Environ Health 5:6–12

Thornton BF, Burdette SC (2013) Recalling radon's recognition. Nat Chem 5(9):804

UNDRR (2020) Hazard definition and classification review. United Nations office for disaster risk reduction, Geneva. https://www.undrr.org/publication/hazard-definition-and-classification-review.

Verhagen AP, Bierma-Zeinstra SMA, Boers M, Cardoso JR, Lambeck J, de Bie R, de Vet HCW (2015) Balneotherapy (or spatherapy) for rheumatoid arthritis. Cochrane Database Syst Rev. https://doi.org/10.1002/14651858.CD000518.pub2/full

Vukotic P, Antovic N, Djurovic A (2019) Radon survey in Montenegro: a base to set national radon reference and "urgent action" level. J Environ Radioact 196:232–239. https://doi.org/10.1016/j.jenvrad.2018.02.009

World Health Organisation (2021) Radon and health.https://www.who.int/news-room/fact-sheets/detail/radon-and-health. Accessed 17 Apr 2022

Zdrojewicz Z, Belowska-Bień K (2004) Radon and ionizing radiation in the human body. Postepy Hig Med Dosw 58:150–157