

SOIL GAS RADON MAPPING OF MUZAFFARABAD CITY, PAKISTAN

by

**Aleem Dad Khan TAREEN¹, Muhammad RAFIQUE^{1*},
Kimberlee J. KEARFOTT², Muhammad BASHARAT³, and Bilal SHAFIQUE¹**

¹ Department of Physics, The University of Azad Jammu & Kashmir, Muzaffarabad, Azad Kashmir, Pakistan

² Department of Nuclear Engineering and Radiological Sciences, University of Michigan,
Ann Arbor, Mich., USA

³ Institute of Geology, The University of Azad Jammu & Kashmir, Muzaffarabad, Azad Kashmir, Pakistan

Scientific paper
DOI: 10.2298/NTRP1603291T

Soil-based radon investigations are of value in correlating radon production and its transportation into buildings through the processes of convection and diffusion. Such studies can help in identifying land areas that pose special concerns. We present preliminary results of soil radon gas measurements at 60 different locations in an attempt to map out the geohazard zone of the city of Muzaffarabad. The seismic geohazard microzonation for the area includes five microzones based on different hazard parameters: a very high hazard zone, a high hazard zone, a moderate hazard zone, a low hazard zone, and a safe zone. Measurements were taken with an active radon monitoring system at the depths of 30, 40, 50, and 60 cm below the ground surface. The results obtained were explained by the lithology of the area. Average soil radon gas concentrations were correlated with the depth from the ground surface and indoor radon values for the study area. No significant correlation was found between soil radon gas and meteorological parameters, however soil radon gas increases as the depth from the surface of the ground grows. The results showed a linear relation between soil radon concentrations with depth from ground surface ($R^2 = 0.9577$). The minimum soil radon concentration (68.5 Bq/m^3) was found at a depth of 30 cm in the very high hazard zone, the maximum value (53.300 Bq/m^3) at a depth of 60 cm in the seismically safe zone. Measured soil gas radon concentrations at depths of 30, 40, 50, and 60 cm were mapped for high, moderate, and low radon concentrations. Elevated soil radon gas concentrations were found in the safe zone, otherwise considered to be suitable for any type of construction.

Key words: radon, soil gas, geohazard zone, lithology, meteorological parameter

INTRODUCTION

Radon ^{222}Rn is a gaseous decay product of ^{226}Ra , basically originating from long-lived antecedent uranium (^{238}U) [1]. Uranium has a ubiquitous presence on Earth, its main source stemming from radium progeny in soil and rocks. The magnitude of radon emanation depends both upon the ^{226}Ra content and the mineral grain size. Mass diffusion (arising from concentration gradients between the point of birth of radon and the atmosphere) and advection (movement caused by air pressure differentials) are responsible for the transportation of radon in the environment [2]. Radon transport is, thus, controlled by geophysical and geochemical parameters, while exhalation is controlled by hydro-meteorological conditions [3, 4].

Measurements of radon gas in soil have many applications. Soil gas monitoring related to structural geology has been used for studying both fault activity and

seismic hazard [5, 6]. Another application involves the identification and mapping of active tectonic structures in faulted zones by measuring spatial patterns of radon soil gas [5, 7-10]. Radon anomalies in faulted areas have been reported by many researchers [11-15]. Through soil radon gas monitoring, an estimation of indoor radon concentrations within buildings can be made using already established correlations between soil and indoor radon concentrations [16].

In the current study, soil radon concentration maps were generated for the seismic geohazard zone of Muzaffarabad by means of a continuous active radon monitor [17]. A seismic geohazard microzonation along the Muzaffarabad Fault developed after the October 8, 2005 earthquake [18] was used. The reason for the geohazard microzonation was the appropriate relocation of the earthquake affected population and reconstruction of housing in Azad Kashmir [17, 18]. This study is a continuation of our previous studies, carried out with the aim of measuring radon concentra-

* Corresponding author; e-mail: rafique@gmail.com

tions [19-25] for the purpose of mapping the area for indoor and outdoor radon levels. We have also investigated the correlation between soil radon concentration with the depth from the ground surface and the lithology of the area.

DATA COLLECTION SITES

Soil radon gas measurements were carried out at 60 different sites within the geohazard zone of the city of Muzaffarabad, the capital of Azad Jammu and Kashmir. Open area measurements were taken in the vicinity of houses where the indoor radon levels were determined. The region was subdivided into five geohazard zones, namely: very high hazard, high hazard, moderate hazard, low hazard, and safe [17], by taking into consideration the geology, geomorphology, lithology, geohydrology, land usage and slope angles in the area, briefly discussed below.

Very high hazard zone

The zone consists of land forms with active mass movement and ground failure on susceptible steep slopes near the fault line. In this zone, construction is banned [17].

High hazard zone

This zone's landforms are primarily composed of sedimentary materials having moderate-to-high steepness. Mass wasting processes, such as landslides, gully, rill erosion and rock falls are common. Although the zone is not viable for settlement or construction purposes, on a limited scale, light structures can be constructed in it [17].

Moderate hazard zone

This zone incorporates landforms partially situated on sedimentary material and others partially positioned on fluvial deposits. It is impacted by active mass wasting processes at locations where the slopes have low-to-moderate steepness. The construction of houses is permitted within certain portions of the zone [17].

Low hazard zone

The landforms in the low hazard zone have low to moderately steep slopes and rest on materials that are loose and have a low shearing strength. As a consequence, the land itself is not suitable for construction. The zone is considered to be of low risk, as it is inadvisable to build any structures there [17].

Safe zone

This zone is of a generally stable nature, consisting predominantly of riverbed terraces made of well-cemented material suitable for any type of construction [17].

Measurements were taken with an active radon monitoring system, at the depths of 30, 40, 50, and 60 cm from ground level. In the selection of the site for the measurement of radon soil gas, it was planned that all main rock units (the Precambrian Hazara formation, Cambrian Muzaffarabad formation, Paleocene-Eocene sequence, Miocene Murree formation, Quaternary deposits) and soil types (colluvial and residual sediments) in the study area should be tested for soil radon gas. The study was carried out in the months of September and October.

GEOLOGY OF MUZAFFARABAD AND THE SURROUNDING AREA

Tectonically, the area is very complex because two major faults, the Muzaffarabad Fault and the Jhelum Fault, run through the area, intersecting northwest of the city of Muzaffarabad. Due to intensive tectonic activities, all rock units in the general area are highly sheared and fractured and the sedimentary and metamorphic rocks of Precambrian to Tertiary age exposed. The main rock units and soil types in the study area include the Precambrian Hazara formation, the Cambrian Muzaffarabad formation, the Paleocene-Eocene sequence (Hangu, Lochart, Patala, Margala, Chorgali, and Kuldana formations), the Miocene Murree formation, Quaternary deposits and unconsolidated deposits (colluvium and residual soil), as shown in fig. 1 [26].

The Precambrian Hazara formation is mainly comprised of slates, phyllite, shales, minor limestone and graphitic layers [27]. The slate and phyllite are green to dark green colored, while the limestone is dark grey to greyish. Geographically, the formation is well exposed on the Muzaffarabad-Grahibullah road along the right bank of the Jhelum river.

The Cambrian Muzaffarabad formation is located towards the north of the study area. It mainly consists of cherty and stromatolitic dolomites, cherty white and grey bands limestone and black shale [28]. The dolomites are grey to dark grey with sedimentary breccia and conglomerate layers on the top. The Muzaffarabad formation is highly fractured, jointed and crushed due to the Muzaffarabad fault.

The Hangu, Lochart, Patala, Margala, Chorgali and Kuldana formations are collectively mapped as a Paleocene-Eocene sequence and are exposed at Yadgar, Khilla, Maira Tanolia, Botha areas in Muzaffarabad. The Hangu formation is comprised of brecciated quartzite, bauxite, limonite, carbonaceous shale, sandstone, coal seams and conglomerates [29]. The Lochart formation consists of limestone and subordinate shale. At some places these limestone are

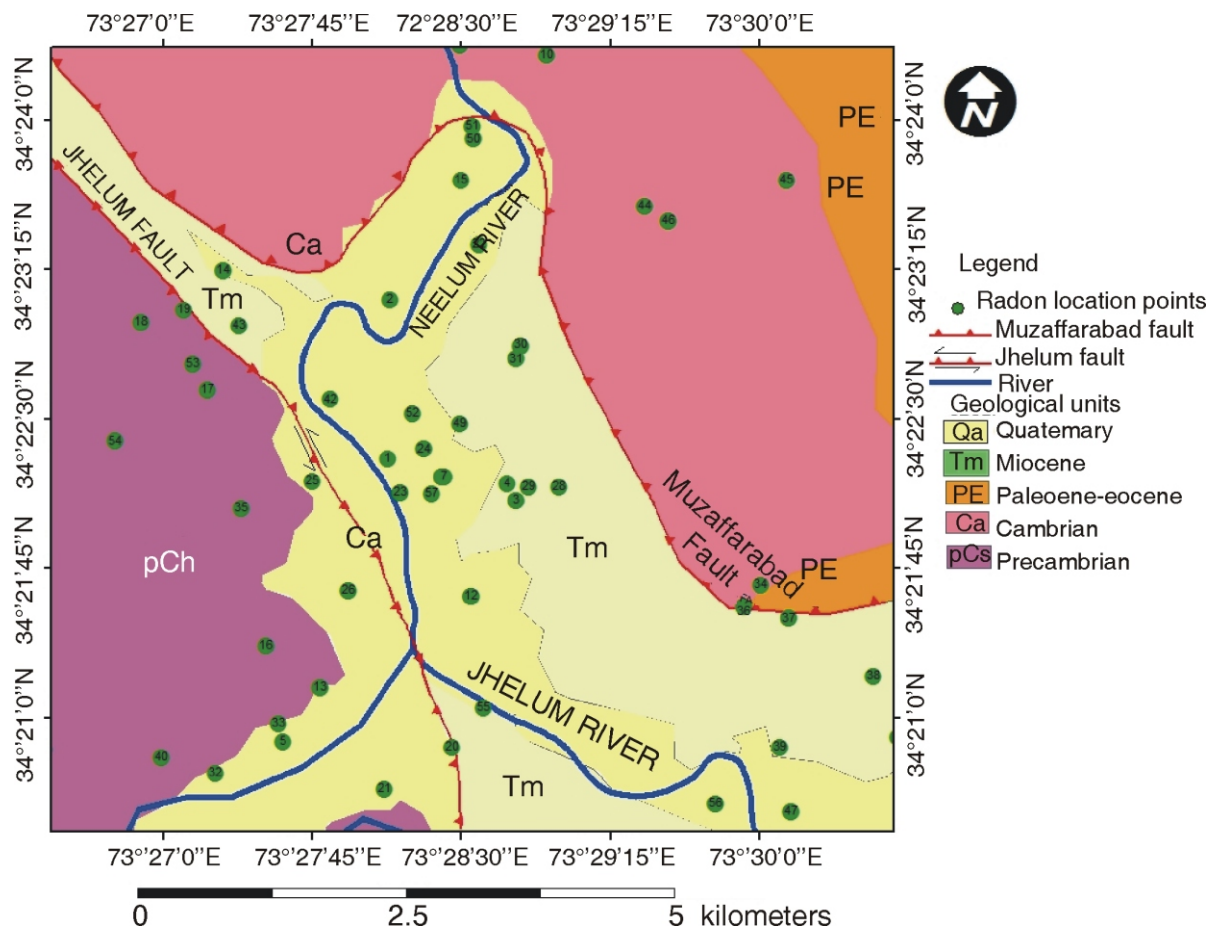


Figure 1. Geological map of Muzaffarabad city and surrounding area digitized after Hussain *et al.*, [26]

nodular. The Patala formation is composed of shale, clay stone, siltstone and sandy limestone [30]. The Margala Hill limestone consists of dark grey, fine-to-medium grained limestone with subordinate marl and shale. The Chorgali formation is made of shale, limestone and white to light grey dolomitic limestone [31]. The dolomitic limestone is white to light grey colored. The Kuldana formation consists of maroon to dark red clays and shale.

The Miocene Murree formation is located towards the southeast of Muzaffarabad. It is mainly composed of interbedded sandstone, siltstone, shale and clay stone [27]. The sandstone is grey to dark grey and reddish brown colored, whereas shales are reddish brown and fine to medium grained. The formation is well exposed in Muzaffarabad city and adjoining areas.

Quaternary sediments are composed of alluviums, colluviums, and terrace deposits. These deposits overlie a bed rock of a different age. The Quaternary deposits are present in Challah Bandi, Dhanni, Plate, Dharian, MairaTonalia, and Chatter areas in Muzaffarabad. The unconsolidated deposits that include debris material and residual soil are present in Makri, Shahwi, and upper Rinjata areas. The debris material is dominated by gravel, cobbles and boulders with smaller amounts of sand, silt and clay. Coarser material originates from the slope-forming process at the steep slopes. In contrast, the residual soil consists

of finer material derived from sediment such as sand and silt. It is difficult to distinguish between debris material and residual soil, hence, they are considered jointly, as an unconsolidated deposit.

INSTRUMENTATION

The multipurpose electronic radon detector with real-time monitoring and spectral analysis used in this study (RAD 7, Durrige Company, Inc., USA) [32] can be considered as a comprehensive system for radon-allowing measurements in air, soil and water. As for the detection systems used, three modes of soil gas measurement were used, namely: (1) the grab sampling mode, (2) continuous monitoring using standard protocols, and (3) the thoron mode. Figure 2 shows RAD7 with the soil probe connected through the desiccant to absorb the moisture. For setting the grab protocol before connecting the probe, RAD7 was purged with dry, fresh air for five minutes. Then the device was set at grab protocol and the measurement started. RAD7 pump was allowed to run for five minutes upon which the device waited additional five minutes and counted four readings, each spanning five-minute intervals. After completing a half-hour period, RAD 7 printed out a summary with the average radon concentration in soil gas from four data-set points

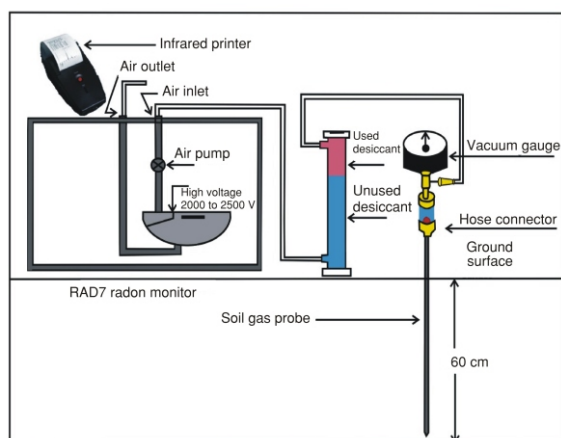


Figure 2. RAD7 schematic set-up of radon soil gas measurements (source: RAD7 manual)

spanning five-minute cycle measurements. The method is very practical because it uses the least amount of soil gas and gives quick (half hour) readings. The accuracy is typically better than 10 % and depends on the radon concentration. Sixty measurements of soil radon concentrations were taken at the depths of 30, 40, 50, and 60 cm from the surface of the ground. A single hole at successive depths of 30, 40, 50, and 60 cm was bored to get single-site measurements.

RESULTS AND DISCUSSION

The results for each of the geohazard zones, including 24 measurements in the safe zone, 6 measurements in low hazard zone, 11 measurements in medium hazard zone, 4 measurements in high hazard zone, and 15 measurements in very high hazard zones, are presented here.

Safe zone

At a depth of 30 cm in the safe geohazard zone, the minimum and maximum soil radon gas concentrations were found to be $730 \pm 160 \text{ Bq/m}^3$ and $37300 \pm 1200 \text{ Bq/m}^3$, respectively. The mean radon concentration at 30 cm was $8800 \pm 560 \text{ Bq/m}^3$. At a depth of 40 cm, soil radon gas concentrations were not significantly different from the ore shallow level, varying from $850 \pm 170 \text{ Bq/m}^3$ to $38100 \pm 1200 \text{ Bq/m}^3$, with a mean radon concentration of $11000 \pm 550 \text{ Bq/m}^3$.

At a depth of 50 cm, minimum and maximum soil radon gas was found to be $1090 \pm 190 \text{ Bq/m}^3$ and $44000 \pm 1300 \text{ Bq/m}^3$, respectively. The mean radon concentration at 50 cm was $13762 \pm 651 \text{ Bq/m}^3$. At 60 cm, radon gas concentration varied from $1120 \pm 200 \text{ Bq/m}^3$ to $53300 \pm 1400 \text{ Bq/m}^3$. The mean radon concentration at the depth of 60 cm was $16736 \pm 704 \text{ Bq/m}^3$.

Low hazard zone

Six measurements were taken in the low hazard zone. At the depth of 30 cm, minimum and maximum soil

radon gas was $1220 \pm 210 \text{ Bq/m}^3$ and $7030 \pm 500 \text{ Bq/m}^3$, respectively. The mean radon concentration at 30 cm was $3830 \pm 420 \text{ Bq/m}^3$. At 40 cm, minimum and maximum soil radon gas was $2010 \pm 260 \text{ Bq/m}^3$ and $7850 \pm 520 \text{ Bq/m}^3$, respectively. The mean radon concentration at the depth of 40 cm was $3855 \pm 353 \text{ Bq/m}^3$.

At 50 cm, minimum and maximum soil radon gas was $1870 \pm 250 \text{ Bq/m}^3$ and $6120 \pm 460 \text{ Bq/m}^3$, respectively. The mean radon concentration at 50 cm was $3655 \pm 345 \text{ Bq/m}^3$. At 60 cm, minimum and maximum soil radon gas was $2030 \pm 260 \text{ Bq/m}^3$ and $15100 \pm 700 \text{ Bq/m}^3$, respectively. The mean radon concentration at the depth of 60 cm was $8104 \pm 498 \text{ Bq/m}^3$.

Medium hazard zone

Eleven measurements were taken in the medium hazard zone. At a depth of 30 cm, radon gas varied from $529 \pm 130 \text{ Bq/m}^3$ to $7900 \pm 520 \text{ Bq/m}^3$. The mean radon concentration at the depth of 30 cm was $3858 \pm 338 \text{ Bq/m}^3$. At 40 cm, minimum and maximum soil radon gas was $975 \pm 180 \text{ Bq/m}^3$ and $21100 \pm 900 \text{ Bq/m}^3$, respectively. The mean radon concentration at 40 cm was $5590 \pm 406 \text{ Bq/m}^3$.

At a depth of 50 cm, minimum and maximum soil radon gas was $260 \pm 90 \text{ Bq/m}^3$ and $18200 \pm 800 \text{ Bq/m}^3$, respectively. The mean radon concentration at 50 cm was $5044 \pm 379 \text{ Bq/m}^3$. At 60 cm, minimum and maximum soil radon gas was 2130 ± 270 and $24500 \pm 900 \text{ Bq/m}^3$, respectively. The mean radon concentration at 60 cm was $8543 \pm 509 \text{ Bq/m}^3$.

High hazard zone

Four measurements were taken in the high hazard zone. At a depth of 30 cm, minimum and maximum soil radon gas was $2630 \pm 300 \text{ Bq/m}^3$ and $11800 \pm 600 \text{ Bq/m}^3$, respectively. The mean radon concentration at 30 cm was $8097 \pm 497 \text{ Bq/m}^3$. At 40 cm, minimum and maximum soil radon gas was $10700 \pm 600 \text{ Bq/m}^3$ and $13900 \pm 700 \text{ Bq/m}^3$, respectively. The mean radon concentration at the depth of 40 cm was $12333 \pm 667 \text{ Bq/m}^3$.

At 50 cm, minimum and maximum soil radon gas was $10800 \pm 600 \text{ Bq/m}^3$ and $15900 \pm 700 \text{ Bq/m}^3$, respectively. The mean radon concentration at 50 cm was $13133 \pm 667 \text{ Bq/m}^3$. At 60 cm, minimum and maximum soil radon gas was 11800 ± 600 and $17700 \pm 800 \text{ Bq/m}^3$, respectively. The mean radon concentration at 60 cm was $15033 \pm 700 \text{ Bq/m}^3$.

Very high zone

Fifteen measurements were taken in the very high zone. At a depth of 30 cm, soil radon gas varied from $68.5 \pm 47 \text{ Bq/m}^3$ to $40000 \pm 1200 \text{ Bq/m}^3$, respectively. The mean radon concentration at 30 cm was $7514 \pm 434 \text{ Bq/m}^3$. At 40 cm, minimum and maximum soil ra-

don gas was $77 \pm 54 \text{ Bq/m}^3$ and $27100 \pm 1000 \text{ Bq/m}^3$, respectively. The mean radon concentration at 40 cm was $7114 \pm 456 \text{ Bq/m}^3$.

At a depth of 50 cm, minimum and maximum soil radon gas was $1470 \pm 220 \text{ Bq/m}^3$ and $53300 \pm 1400 \text{ Bq/m}^3$, respectively. The mean radon concentration at 50 cm was $12445 \pm 617 \text{ Bq/m}^3$. At 60 cm, minimum and maximum soil radon gas was $197 \pm 80 \text{ Bq/m}^3$ and $46400 \pm 1300 \text{ Bq/m}^3$, respectively. The mean radon concentration at 60 cm was $12020 \pm 575 \text{ Bq/m}^3$.

Average soil radon concentrations at different depths are plotted for different zones in fig. 3. In the safe zone, an increase in depth is accompanied by a rise in soil radon concentration. The same trend may be noted for other hazard zones with a slight exception of the very high hazard zone. In the safe zone, maximum average soil radon concentration (16736 Bq/m^3) was found at the depth of 60 cm. The radon map for the geohazard zones of Muzaffarabad is shown in fig. 4.

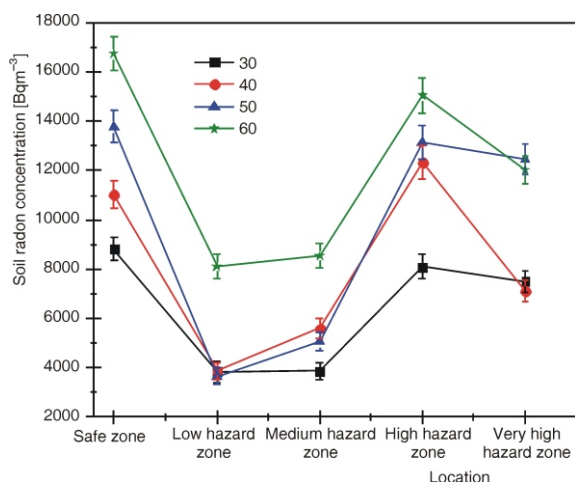


Figure 3. Average soil radon concentrations at different depths for different geohazard zones

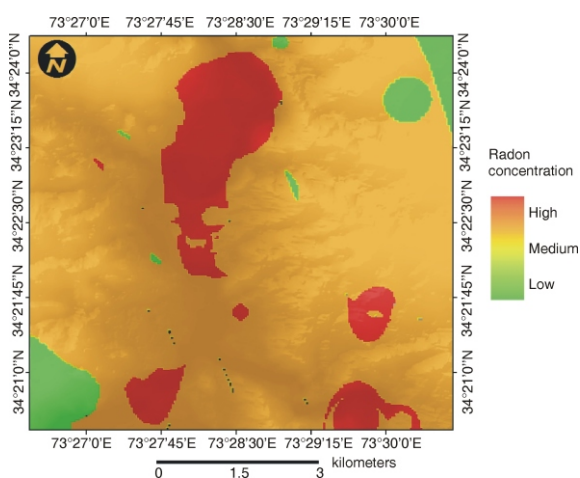


Figure 4. Soil radon gas map for geohazard zone of Muzaffarabad

DISCUSSION

Figures 3 and 5 show that, in the safe zone, the concentrations of soil and indoor radon gas within closed environments are higher than in other hazard zones. The safe zone is exposed by Hazara, Murree formation and Quaternary sediments. The Precambrian Hazara formation is mainly comprised of slates, phyllite, shales, minor limestone and graphitic layers and Quaternary sediments of alluviums, colluviums and terrace deposits. In this zone, the maximum concentration of 53.3 kBq/m^3 was found at the depth of 60 cm. The alluvium consists of silt, clay, sand and gravel. Despite the fact that bedrock geology has a major influence on radon distribution, soil characteristics are also important in determining radon production and its mobility. The principal contributing factors are the content of radium and uranium in the soil, as well as their distribution, porosity and permeability to gas movement and moisture contents. Average values of uranium and thorium concentration in sedimentary rocks (sandstones and shale other than black are reported to be 3.7 ppm and 12 ppm, respectively) [33]. On the other hand, the average value of uranium concentration in Earth's crust is reported to be 2.8 ppm. The most common sources of uranium and radium are heavy minerals and iron-oxide coatings on rock and soil grains and organic material in soils and sediments. Less common are phosphate and carbonate complexes and uranium minerals [34-36]. These lithological units may potentially be the cause of soil radon concentrations.

The results of linear regression analysis between average soil radon concentrations with the depth below the ground surface gives a slope of 223.34, with a coefficient of determination (R^2) equal to 0.9577, demonstrating a strong correlation of soil radon concentration with soil depth (see fig. 6). Expressed mathematically, the result is:

$$Rn_{\text{soil}} = 223.34 D_{\text{soil}} + 280.7 \quad (1)$$

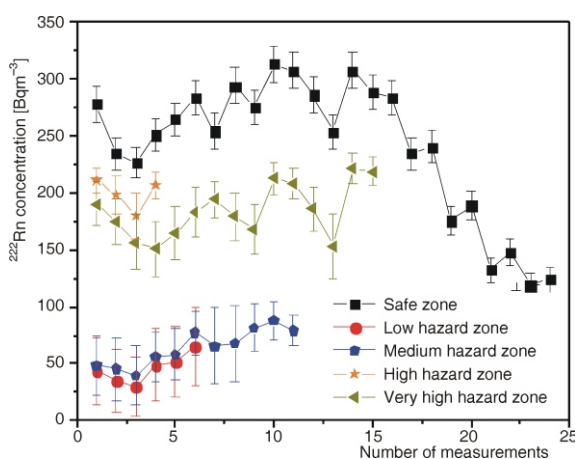


Figure 5. Indoor radon concentrations at 60 locations of different hazard zones

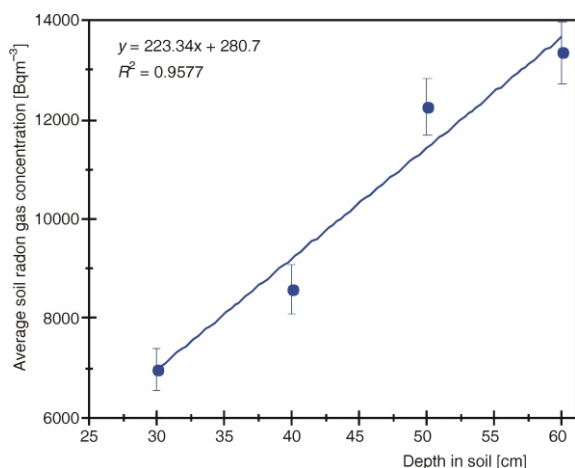


Figure 6. Linear correlation between soil radon concentration and depth inside ground

where, Rn_{soil} , represents radon in soil and D_{soil} shows the depth within soil.

Pearson's coefficient, used as a measure of correlation between meteorological variables and soil radon gas, was found to be 0.001 for temperature and -0.099 for relative humidity. The magnitudes of Pearson's coefficients imply that the average radon concentration is not correlated with the average air temperature or the average relative humidity. Similarly, a p -value of 0.984 was obtained for the average air temperature and that of 0.130 for the average relative humidity. These values are greater than 0.05, showing that there is no statistically significant correlation between radon and the two metrological parameters, *i.e.* average air temperature and average relative humidity, as can be seen in fig. 7(a, b).

The findings of our study are in agreement with studies carried out by Lindmark and Kovach [37, 38]. Both suggest that temperature has little or no effect on radon soil gas content.

In order to investigate the relation between soil radon concentrations with indoor radon values, measurements were made within the indoor environment of the study area in the same period in which soil radon gas measurements were being carried out. Indoor measurements were taken only at locations near the measurement sites of soil radon concentrations. In each house RAD7 was installed for a period of two consecutive day measurements. Data was collected for each of the 30 minute intervals. The ninety six values of indoor radon concentrations were averaged for a single representative value of two days. RAD7 installation rooms were rendered airtight in accordance with the US Environmental Protection Agency (USEPA 2014) radon measurement protocols [39].

Figure 8 shows the variation of indoor radon concentrations with respect to soil radon gas at a depth of 30 cm from ground level. It can be seen that indoor radon concentration increases with the increase in soil radon concentrations. Maximum and minimum indoor radon concentration, 240 and 46 Bq/m³, were found in the vi-

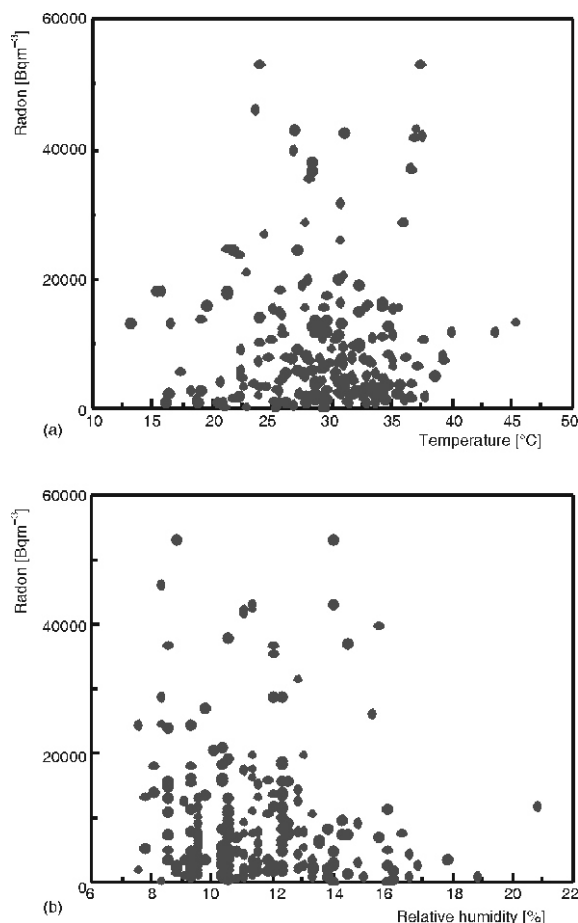


Figure 7. Relation between radon, temperature (a), and relative humidity (b) for all sites

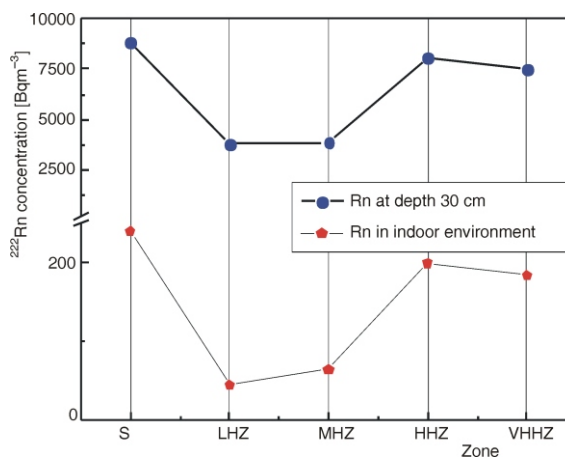


Figure 8. Relation between soil radon concentration with indoor radon concentration in safe zone (SZ), low hazard zone (LHZ), medium hazard zone (MHZ), high hazard zone (HHZ), and very high hazard zone (VHHZ)

cinity of the area with a soil radon concentration of 8084 and 3830 Bq/m³ at a depth of 30 cm in the safe and low hazard zones, respectively. This is a clear indication that an increase of indoor radon concentration is caused by the increase in soil radon concentration. In other words, in the area where soil ²²²Rn concentration was high, the atmospheric indoor radon concentration was

also high, as may be seen in figs. 5 and 8. This confirms the fact that radon from the soil beneath a home is typically the most significant source of contamination.

CONCLUSIONS

In the current study we have mapped the geohazard zone of Muzaffarabad city for soil radon levels. A positive correlation of soil radon gas with the lithology of the area and depth was found. With increasing depth, soil radon gas concentrations increased remarkably. No significant correlation was found between soil radon concentrations and meteorological parameters, however, a moderate correlation was found between soil radon concentration and indoor radon levels. As compared to other zones, small values of soil radon concentrations were found in the low hazard zone, whilst the safe zone carries the highest values of soil radon concentrations. Since the safe zone is suitable for any type of construction but has an elevated soil radon concentration, we recommend specialized housing designs with an adequate ventilation of rooms, radon resistant flooring, built with low radon contributing materials.

ACKNOWLEDGEMENT

The authors would like to thank the tenants and anonymous reviewers for their co-operation and valuable comments that helped us improve the quality of the manuscript.

AUTHORS' CONTRIBUTIONS

The manuscript was written and reviewed by M. Rafique and K. J. Kearfott. The geological segment of the manuscript, along with the mapping of the area for soil radon gas, was carried out by M. Basharat. Experimental data was provided by A. D. K. Tareen and B. Shafique. Figures were prepared by M. Rafique and K. J. Kearfott has carried out the proofreading of the manuscript. All co-authors were involved in analyzing the results and the critical discussion on the manuscript.

REFERENCES

- [1] Durrani, S. A., Ilic, R., *Radon Measurements by Etched Track Detectors*. World Scientific Publishing Co. Pte. Ltd., Singapore, 1997
- [2] ***, Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effect of Atomic Radiation Annex A., United Nations, New York, 1988
- [3] Etiope, G., Martinelli, G., Migration of Carrier and Trace Gases in the Geosphere: An Overview, *Phys. Earth Planet. In.*, 129 (2002), 3-4, pp. 185-204
- [4] Vaupotic, J., *et al.*, Radon Concentration in Soil Gas and Radon Exhalation Rate at the Ravne Fault in NW Slovenia, *Nat. Hazards Earth Syst. Sci.*, 10 (2010), 4, pp. 895-899
- [5] Ciotoli, G., *et al.*, Soil Gas Survey for Tracing Seismogenic Faults: A Case Study in the Fucino Basin, central Italy, *J. Geophys.*, 103 (1998), B10, pp. 23781-23794
- [6] Ciotoli, G., *et al.*, Geostatistical Analysis of Soil Gas Data in a High Seismic intermontane Basin: Fucino Plain, Central Italy, *J. Geophys. Res.*, 112 (2007), B5, p. 5407
- [7] Crenshaw, W. B., *et al.*, Fault Location by Radon and Mercury Detection at an Active Volcano in Nicaragua, *Nature*, 300 (1982), 5890, pp. 345-346
- [8] Papastefanou, C., Radon Measurements Along Active Faults in the Langadas Basin, Northern Greece, *Nat. Hazards Earth Syst. Sci.*, 1 (2001), pp. 159-164
- [9] Baubron, J. C., *et al.*, Soil-Gas Profile as a Tool to Characterize Active Tectonic Areas: the Jault Pass Example (Pyrenees, France), *Earth and Planetary Science Letters*, 196 (2002), 1-2, pp. 69-81
- [10] Burton, M., *et al.*, High Spatial Resolution Radon Measurements Reveal Hidden Active Faults on Mt. Etna, *Geophysical Research Letters*, 31 (2004), 7, L07618
- [11] Salazar, S., *et al.*, Radiological geohazard Survey in the South East of Manizales City (Colombia), *Proceedings, ICGG7*, 2003, pp. 3-5
- [12] King, C. Y., *et al.*, Spatial Radon Anomalies on Active Faults in California, *Applied Geochemistry*, 11 (1996), 4, pp. 497-510
- [13] Etiope, G., Lombardi, S., Evidence for Radon Transport by Carrier Gas through Faulted Clays in Italy, *Journal of Radioanalytical and Nuclear Chemistry*, 193 (1995), 2, pp. 291-300
- [14] Das, N. K., *et al.*, Continuous Monitoring of ^{222}Rn and its Progeny at a Remote Station for Seismic Hazard Surveillance, *Radiat. Meas.*, 41 (2006), 5, pp. 634-637
- [15] Humanante, B. F., *et al.*, Radon Signals Related to Seismic Activity in Ecuador, 1987, *Pure Appl. Geophys.*, 132 (1990), 3, pp. 505-520
- [16] Iskandar, D., *et al.*, The Transport Mechanisms of ^{222}Rn in Soil at Tateishi as an Anomaly Spot in Japan, *Applied Radiation and Isotopes*, 63 (2005), 3, pp. 401-408
- [17] ***, Seismic Hazard Microzonation Map of Muzaffarabad City, National Engineering Services Pakistan, 2006
- [18] Baig, M. S., *et al.*, Active Tectonics, October 8, 2005, Earthquake Deformation, Active Uplift, Scarp Morphology and Seismic Geohazards Microzonation, Hazara-Kashmir Syntaxis, Northwest Himalayas, Pakistan, *Journal of Himalayan Earth Sciences*, 43 (2010), pp. 17-21
- [19] Rafique, M., *et al.*, Radiation Doses Due to Indoor Radon Exposure, before and after 2005-Earthquake in the Dwellings of Muzaffarabad and Jhelum Valley, Azad Kashmir, Pakistan, *Indoor Built Environ.*, 20 (2011), 2, pp. 259-264
- [20] Rafique, M., *et al.*, Assessment of Lung Cancer Risk Due to Indoor Radon Exposure in Inhabitants of the State of Azad Kashmir; Pakistan, *Iran J. Radiat Res.*, 10 (2012), 1, pp. 19-29
- [21] Rafique, M., *et al.*, The Influence of Geology on Indoor Radon Concentrations in Neelum Valley Azad Kashmir, Pakistan, *Indoor Built Environ.*, 21 (2012), 5, pp. 718-726
- [22] Shafique, B., *et al.*, Monitoring of $^{222}\text{Rn}/^{220}\text{Rn}$ Concentrations at the Work Places of Muzaffarabad, Azad Kashmir, *Int. J. Phys. Sci.*, 7 (2012), 41, pp. 5577-5584

- [23] Rafique, M., et al., Measurement and Comparison of Indoor Radon Levels in New and Old Buildings in the City of Muzaffarabad (Azad Kashmir), Pakistan: a Pilot Study, *Radioisotopes*, 58 (2009), 11, pp. 749-760
- [24] Shafique, B., et al., Time Series Analysis and Risk Assessment of Domestic Radon: Data Collected in Dwellings Along Fault Line, *Indoor Built Environ*, 25 (2016), 2, pp. 397-406
- [25] Rafique, M., Ambient Indoor/Outdoor Gamma Radiation Dose Rates in the City and at High Altitudes of Muzaffarabad (Azad Kashmir), *Environ Earth Sci.*, 70 (2013), 4, pp. 1783-1790
- [26] Hussain, A., et al., Geological Maps of the Garhi Habibullah and Nauseri Area, District Muzaffarabad, A.J.K: Geol. Surv. Pakistan, *Preliminary Map Series*, 6, 2004, 14, Sheet No. 43 F/7, 11, 1:50,000
- [27] Calkins, J. A., et al., Geology of the Southern Himalaya in Hazara, Pakistan, and Adjacent Areas, *U. S. Geol. Surv. Prof. Paper*, 716-C, 1975, p. 29
- [28] Baig, M. S., Snee, L. W., The Evidence for Cambro-Ordovician Orogeny in Northwest Himalayas Pakistan, *Geol. Soci. Am. Abstr. Program*, 27 (1995), p. 305
- [29] Ashraf, M., et al., Petrology and Geochemistry of the Panjalvolcanics in Poonch, Muzaffarabad and Kaghan Valley, Unpublished Report, Pakistan Science Foundation, Islamabad, 19894
- [30] Munir, M. H., Baig, M. S., Paleogene Biostratigraphy of Tattapani, Kotli Azad Kashmir, Northwest Sub-Himalayas, Pakistan: *Jour. Him. Earth Sci.*, 39 (2006), pp. 39-48
- [31] Munir, H. M., et al., Upper Cretaceous of Hazara and Paleogene Biostratigraphy of Azad Kashmir, North-West Himalayas, Pakistan, *Geol. Bull. of Punjab Univ.*, 40 (2006), 41, pp. 69-87
- [32] ***, RAD 7 User Manual (Available at <http://www.durridge.com>), Assessed 27 March, 2016
- [33] ***, Exposure of the Population of the United States and Canada from Natural Background Radiation, National Council on Radiation Protection and Measurements, NCRP 94, Bethesda, Md., USA, 1987
- [34] Nash, J. T., et al., Geology and Concepts of Genesis of Important Types of Uranium Deposits, *Economic Geology*, 75th Anniversary Volume, 1981, pp. 63-116
- [35] DeVoto, R. H., Uranium Exploration, Uranium Geochemistry, Mineralogy, Geology, Exploration and Resources (Eds. B. Devivo, F. Ippolito, G. Capaldi, P. R. Simpson), The Institution of Mining and Metallurgy, London, 1984, pp. 101-108
- [36] Nagda, N. L., *Radon Prevalence Measurements, Health Risks and Control.*, ASTM Manual Series: MNL 15 ASTM Publication Code Number (PCN) 28-015094-17. 1994, ISBN 0-8031-2057-5
- [37] Lindmark, A., Rosen, B., Radon in Soil Gas-Exhalation Tests and in situ Measurements, *The Science of the Total Environment*, 45 (1985), pp. 397-404
- [38] Kovach, E. M., Meteorological Influences Upon the Radon Content of Soil Gas, *Transactions, American Geophysical Union*, 26 (1945), 2, pp. 241-248
- [39] ***, US EPA, United States Environmental Protection Agency. Radiation and health, http://www.epa.gov/rpdweb00/understand/health_effects.html (accessed June 12, 2016)

Received on April 5, 2016

Accepted on July 27, 2016

Алим Дад Кан ТАРИН, Мухамад РАФИК, Кимберли Ј. КЕРФОТ,
Мухамад БАШАРАТ, Билал ШАФИК

МАПИРАЊЕ РАДОНА У ЗЕМЉИШТУ ГРАДА МУЗАФАРАБАДА У ПАКИСТАНУ

Истраживања радона у земљишту значајна су због корелације производње радона и његовог транспорта у зграде процесима конвекције и дифузије. Оваква испитивања могу помоћи у идентификовању подручја на која треба обратити посебну пажњу. Овде су приказани прелиминарни резултати мерења гаса радона у земљишту на 60 различитих локација, у циљу прављења мапе геохазардних зона града Музафарабада. Сеизмичко геохазардно микрозонирање области подразумева пет микрозона заснованих на различитим хазардним параметрима: веома високу хазардну зону, високу хазардну зону, умерену хазардну зону, ниску хазардну зону и безбедну зону. Мерења су обављена системом за активни мониторинг радона на дубинама од 30, 40, 50 и 60 cm испод површине земље. Добијени резултати објашњени су литолошким особинама земљишта. Средње вредности концентрације радона у земљишту корелисане су са дужином у земљишту и вредностима концентрација радона у затвореном простору у испитиваном подручју. Нема значајне корелације између концентрације радона у земљишту и метеоролошких параметара, међутим концентрација гаса радона у земљишту расте са порастом дубине у земљишту ($R^2 = 0.9577$). Минимална концентрација радона (68.5 Bq/m^3) пронађена је на дубини од 30 cm у веома високо хазардној зони, а максимална концентрација радона (53300 Bq/m^3) уочена је на дубини од 60 cm у сеизмички безбедној зони. Измерене концентрације радона у земљишту на дубинама од 30, 40, 50, и 60 cm мапиране су за високе, средње и ниске концентрације радона. Повишене концентрације радона пронађене су у безбедној зони иначе погодној за било коју врсту изградње.

Кључне речи: радон, гас у земљишту, гео хазардна зона, литологија, метеоролошки параметар