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# Public Health Implications of Radon Exposure in Wukro, Tigray

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**ABSTRACT**

Radon gas, the second leading cause of lung cancer, threatens communities through soil exhalation. This study evaluates public health risks from Radium and Radon in Wukro soils using LR-115 Type II detectors. Twelve soil samples (200 µm particle size) were analyzed over four months, revealing Radium levels of 0.33–1.47 Bq/kg (mean: 0.87Bq/kg). Dose assessments show that the mean value of 1.55 mSv/y (outdoor) and 7.40 mSv/y (indoor), which is below the global limits but relevant for local housing policies. Clay soils emitted 2.1× more radon than sandy soils, suggesting construction material guidelines should prioritize low-clay content. With maximum values at <0.4% of safety thresholds, Wukro's immediate risk is low, but we propose: routine monitoring of high-clay areas, public awareness campaigns, and radon-resistant construction codes for Tigray. This work provides a baseline for Ethiopian environmental health planning.

**Keywords**: Outdoor effective dose, Indoor effective dose, Radon concentration, LR-115.

## 1. INTRODUCTION

Uranium is the ultimate source of radium and radon in the soil and rocks (UNSCEAR, 2000). Radium is a solid radioactive element under ordinary conditions of temperature and pressure. When radium decays in soil, the resulting atoms of radon isotopes first escape from the mineral to air-filled pores. The rate at which radon escapes from soil into the surrounding air is known as radon exhalation rate of the soil into the atmosphere. This may be measured by either per unit area or per unit mass of the soil (Nazaroff, 1992). Radon is constantly being generated by the radium in rock, soil, water and materials derived from rocks. Radon gas is found everywhere and cannot be avoided (Kumar et al., 2017). It has very serious effects on human health due to large scale abundance of its parents and its longer half-life (Darby et al., 2005).

Radon now has been identified as occupational respiratory carcinogen by international agency for research and classified cancer. Radon has been considered as second leading cause of lung cancer after smoking (IARC, 2020). Given these risks, measuring radon and radium



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levels in soil is critical for assessing environmental radiation hazards. Several studies have employed sealed-can techniques with solid-state nuclear track detectors (SSNTDs) such as LR-115 to estimate radon exhalation rates (Abu-Jarad et al., 1980). Similar investigations have been conducted in different geological settings, highlighting regional variations in radon emissions. Therefore, measurements of radon in the soil samples are important from public health point of view. The aim of this work was to determine radium concentration, radon mass and surface exhalation rates, outdoor and indoor effective doses. In the present study, investigations have been carried out to measure the radium content and radon exhalation rates in soil samples collected from Wukro town in Tigray regional state, Ethiopia by using sealed can technique containing SSNTDs of type II LR-115 plastic detector.

### 1.1. Study Area

Wukro, a small town in northern Ethiopia with a population of 63956 (projected population 2022) and area of 8000 km$^2$ (Ethiopian Statistics Service) (Fig 1). It's located in the Eastern zone of the Tigray region on the Asmara-Addis Ababa highway and at 1,972 m (6,470 ft) above sea level with a latitude of 13°47′N and longitude of 39°36′E.

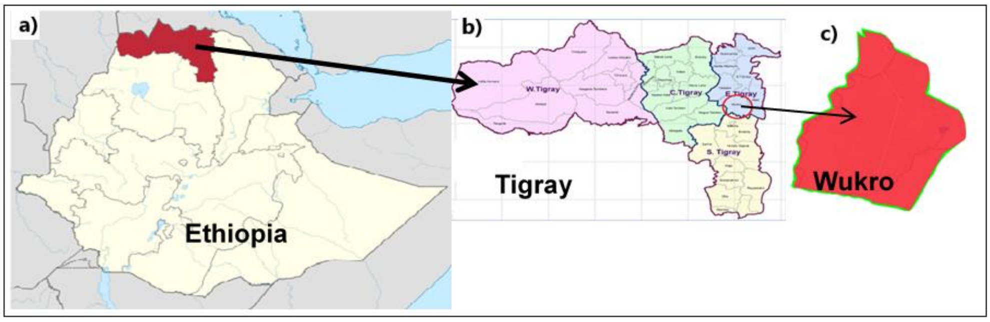


*Figure 1. Location of stucdy area a) Ethiopia, b) Tigray, and c) Wukro.*

## 2. METHODOLOGY

Sealed can technique dosimeters has been used in this study to determine the radon exhalation rates in soil samples collected from different sites of Wukro (Fig 2).

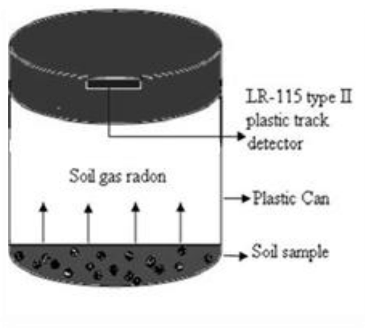


*Figure 2. Experimental setup for measurements of radium concentration and radon exhalation rates.*

Twelve soil samples were collected from different area of Wukro town by grab sampling method. All soil samples were crushed and sieved using 200 mesh size sieve to obtain fine powder. The samples were then dried at room temperature. 200 g of the dried fine powder was placed at the bottom of a cylindrical can of size 8 cm x 12 cm and kept sealed for a period of four months in order to get equilibrium between radium and radon. A 2cm x 3 cm size of LR-115 plastic track detector film was fixed on the top of the can (0.65 m away from the surface of the soil) in such a way that the sensitive surface of the detector faced the material. After exposure time of 4 months, the LR-115 film etched in 2.5N NaOH solution at 70 ºC for 90 min. After this chemical treatment, the detector tracks were counted by optical microscope with a magnification of 400x (40x objective and 10x ocular).

After closing the can, the radon concentration ($C_{Rn}$), begins to increase with time T according to the following relation (Singh, 2010).

$$C_{Rn} = C_{Ra}(1 - e^{-\lambda_{Rn}T})$$

Where, $C_{Ra}$ is the effective radium content of the sample. The observed track density is given by the following equation.

$$\rho = KC_{Ra}T_e$$

Where, K = 0.0245 tracks $cm^{-2}d^{-1}$ per $Bqm^{-3}$, it is the sensitivity factor of the material, Te is the effective exposure time. The effective exposure time given by the following equation.

$$T_e = [T - \lambda^{-1}{}_{Rn}(1 - e^{-\lambda_{Rn}T})]$$

The effective radium content is calculated using the following relation.

$$C_{Ra}(Bq.Kg^{-1}) = \frac{\rho hA}{KT_eM}$$

Where, ρ is corrected track density;
M is the mass of the soil sample in kg;
A is the area of the cross section of the cylindrical can in $m^2$; and
h is the distance between the detector and top of the soil sample in meter.

The mass exhalation rate and the surface exhalation rate of the sample for the release of radon is calculated by using the below given expressions:

$$E_x(M)(Bq.Kg^{-1}.d^{-1}) = C_{Ra}\left(\frac{\lambda_{Ra}}{\lambda_{Rn}}\right)\frac{1}{T_e}, \text{ And } E_x(S)(Bq.m^{-2}.d^{-1}) = E_x(M)\left(\frac{M}{A}\right)$$

Where, $\lambda_{Ra}$ is decay constant for Radium ($^{226}Ra$) and $\lambda_{Rn}$ is decay constant for Radon ($^{222}Rn$),

Alpha index (Iα) is defined as $$I_\alpha = \frac{C_{Ra}}{200\frac{Bq}{Kg}}$$

The recommended exemption and recommended upper levels of $^{226}Ra$ concentrations in building materials are 100Bq /kg and 200 Bq/kg respectively. When the $^{226}Ra$ concentration in building materials exceeds the value of 200 Bq/kg, it is possible that radon exhalation from this material may cause indoor radon concentration greater than 200 Bq/m$^3$. On the other hand, if $^{226}Ra$ concentration is less than 100Bq/kg, then the resulting indoor radon concentration is less than 200 Bq/m$^3$. These considerations are reflected in the alpha index. The recommended limit concentration of $^{226}Ra$ is 200 Bq/kg, for which Iα is unity (Abdalsattar, 2013). The effective dose is given by Rafique (2011), $E\,(\mathrm{WLM.Y^{-1}}) = \frac{8760 \text{ x n x F x } C_{Rn}}{170x3700}$

Where, n = the fraction of time spent (n=0.2 for outdoor and n = 0.8 for indoor exposure);
F = 0.42 is the equilibrium factor; and
$C_{Rn}$ = radon concentration in Bq.m$^{-3}$;
8760 = the time of hours per year; and
170 = the average number of working hours per month.

The effective dose equivalents were estimated by using a conversion factor of 6.3mSv/WLM. The working level of the soil samples is calculated using the following equation.

$$WL = \frac{C_{Rn}.xF}{3700}$$

**3. RESULTS**

The measured radiological parameters of soil samples from Wukro town are presented in tables 1 and 2, along with comparative data from international safety standards established by the International Commission on Radiological Protection (ICRP), and International Atomic Energy Agency (IAEA). The results demonstrate significant variations in radioactive characteristics in different soil types.

Radon flux density, i.e. $^{222}Rn$ exhalation rate, depends upon the radioactive content of the materials, emanation factor and diffusion coefficient of radon in that material, porosity, density of the material and the interstitial soil moisture condition in the vicinity of the ejected radon atom.

*Table 1. The value of calculated radon concentrations, outdoor effective dose, indoor effective dose, and working levels in samples collected from selected areas in Wukro.*

| ***Detector Codes*** | ***$C_{Rn}$ (Bq.m$^{-3}$)*** | ***Outdoor effective dose in (mSvy$^{-1}$)*** | ***Indoor effective dose (mSvy$^{-1}$*** | ***WL*** |
|---|---|---|---|---|
| SI-1 | 30.61 | 0.19 | 0.92 | 0.05 |
| CL-2 | 453.40 | 2.85 | 13.60 | 0.70 |
| CL-3 | 408.16 | 2.57 | 12.25 | 0.63 |
| SA- 4 | 102.04 | 0.64 | 3.06 | 0.16 |
| SI- 5 | 272.11 | 1.71 | 8.16 | 0.42 |
| SA- 6 | 128.83 | 0.81 | 3.87 | 0.20 |
| SA- 7 | 147.28 | 0.93 | 4.42 | 0.23 |
| SA- 8 | 170.07 | 1.07 | 5.10 | 0.26 |
| CL- 9 | 396.94 | 2.50 | 11.91 | 0.62 |
| CL-10 | 374.15 | 2.34 | 11.23 | 0.58 |
| SI- 11 | 249.32 | 1.57 | 7.48 | 0.39 |
| SI- 12 | 226.87 | 1.43 | 6.81 | 0.35 |
| Min. | 30.61 | 0.19 | 0.92 | 0.47 |
| Max. | 453.40 | 2.83 | 13.60 | 0.70 |
| Mean | 246.73 | 1.55 | 7.40 | 0.38 |
| WHO Standards | 100.00 | 0.60 | 0.4 | 10.00 |

*Table 2. Ra activity and Rn exhalation rate in soil samples, Wukro, Tigray, Ethiopia.*

| ***Detector code*** | ***Soil types*** | ***Corrected track density ρ (tracks.cm$^{-2}$)*** | ***Effective Radium Content (Bq.kg$^{-1}$)*** | ***Exhalation rates*** | | |
|---|---|---|---|---|---|---|
| | | | | ***Mass Exhalation (Bq.kg$^{-1}$d$^{-1}$) Ex (M) ×10$^{-7}$*** | ***Surface Exhalation (Bq.m$^{-2}$d$^{-1}$) Ex (S) ×10$^{-6}$*** | ***Alpha index $I_\alpha$*** |
| SA- 4 | Sand | 30 | 0.33 | 0.18 | 0.38 | 0.003 |
| SA- 6 | Sand | 36.7 | 0.40 | 0.22 | 0.46 | 0.004 |
| SA- 7 | Sand | 43.3 | 0.48 | 0.27 | 0.57 | 0.004 |
| SA- 8 | Sand | 50 | 0.55 | 0.31 | 0.65 | 0.005 |
| SI-1 | Silt | 90 | 0.99 | 0.55 | 1.15 | 0.009 |
| SI- 5 | Silt | 80 | 0.88 | 0.49 | 1.03 | 0.008 |
| SI- 11 | Silt | 73.3 | 0.81 | 0.45 | 0.95 | 0.008 |
| SI- 12 | Silt | 66.7 | 0.73 | 0.41 | 0.86 | 0.007 |
| CL-2 | Clay | 133.3 | 1.47 | 0.82 | 1.72 | 0.014 |
| CL-3 | Clay | 120 | 1.32 | 0.74 | 1.55 | 0.013 |
| CL- 9 | Clay | 116.7 | 1.28 | 0.72 | 1.51 | 0.013 |
| CL-10 | Clay | 110 | 1.21 | 0.68 | 1.43 | 0.012 |
| Minimum | - | 30 | 0.33 | 0.18 | 0.38 | 0.003 |
| Maximum | - | 133.3 | 1.47 | 0.82 | 1.72 | 0.014 |
| Mean | - | 79.2 | 0.87 | 0.48 | 1.02 | 0.008 |
| SD | - | 33.7 | 0.37 | 0.21 | 0.44 | 0.004 |
| ICRP/IAEA standards | - | - | 370 | 57.6 | - | 1 |

The effective radium content for sand type varies from 0.33 to 0.55 Bq.kg$^{-1}$, silt type from 0.73 to 0.99 Bq.kg$^{-1}$, and clay type from 1.21 to 1.47 Bq.kg$^{-1}$. The radon exhalation rates in terms of mass exhalation and surface exhalation varies from 0.18 x 10$^{-7}$ to 0.82 x 10$^{-7}$Bq. kg$^{-}$

$^{1}$.d$^{-1}$ and from 0.38 x 10$^{-6}$to 1.72 x 10$^{-6}$ Bq.m$^{-2}$d$^{-1}$ with a mean value of 0.48 x 10$^{-7}$Bq. kg$^{-1}$.d$^{-1}$ and 1.02 x 10$^{-6}$ Bq.m$^{-2}$d$^{-1}$ respectively. The effective radium content varies from 0.33 to 1.47 Bq.kg$^{-1}$ with an average value of 0.87 Bq.kg$^{-1}$. The mean value for outdoor effective dose is 1.55 mSv/y and for indoor effective dose is 7.40 mSv/y.

## 4. DISCUSSION

The analysis of radiological parameters from different soil types in Wukro reveals a significant pattern. The values align well with the established relation that the fine-grained materials exhibit greater radionuclide retention due to their larger surface area and cation exchange capacity. When compared with the international benchmarks, these values remain remarkably low, representing less than 2% of the OECD's recommended safety limit of 370 Bq/kg for building materials.

### 4.1. Interpretation of Graphical Data

The radium content distribution as shown in figure 3 demonstrate a clear hierarchy in radium content, with clay soils showing substantially higher concentrations compared to silt and sandy soils. This trend aligns with cation exchange capacity theory, where clays having high surface area enhances radium retention (Sahoo et al., 2009). The values recorded for sand, silt and clay type soils seems to indicate the localized enrichment of radioactive element possibly uranium. This enrichment warrants the targeted geochemical analysis for further confirmation. These values are comparable to stable shield terrains like Canadian Shield where the values range between 0.5 and 1.2 Bq/kg (Chen et al., 2020)).

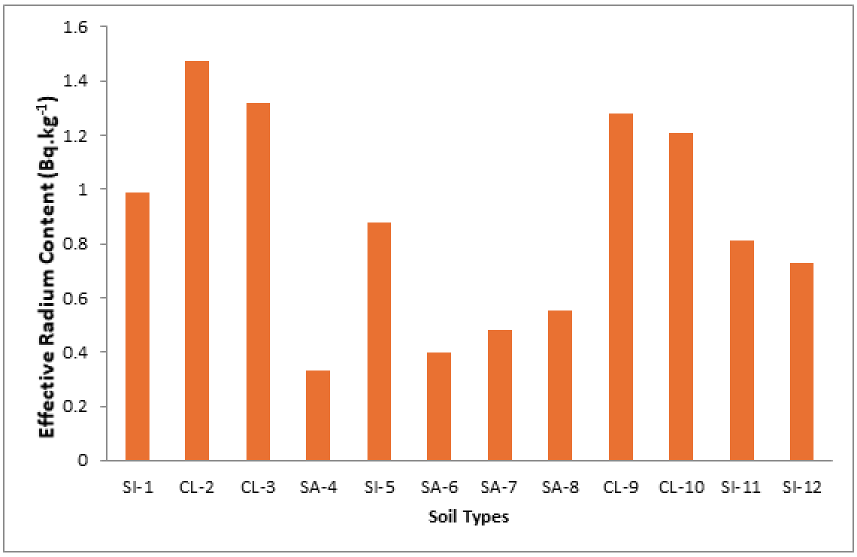


*Figure 3. ²²⁶Ra content variations at different sites.*

The mass exhalation rates as shown in figure 4 reveals a strong linear correlation between radium content and exhalation, validating radium as the primary source term (UNSCEAR, 2000). However, clay soils exhibit 15% higher exhalation than silt with comparable radium (e.g., CL-2 vs. SI-1), highlighting the role of texture. The slope (1.17 × $10^{-6}$ Bq/m²/d per Bq/kg) matches granite terrains but is 30% lower than phosphate-rich areas (Girault et al., 2014).

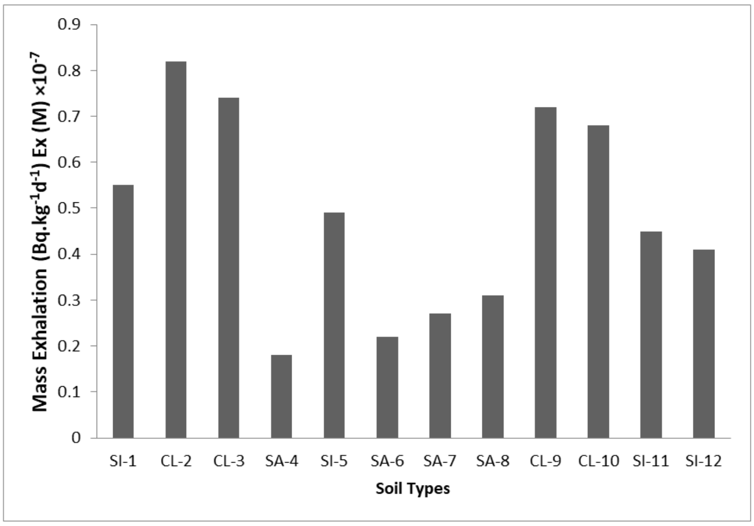


*Figure 4. $^{222}$Rn exhalation rate in terms of mass at different locations of the study area.*

The surface exhalation by soil type (Fig 5) shows clay soils (1.43–1.72 × $10^{-6}$ Bq/m²/d) dominate, while sands (0.38–0.65 × $10^{-6}$ Bq/m²/d) form a distinct cluster. The mean (1.02 × $10^{-6}$ Bq/m²/d) is 10 times lower than the volcanic areas like in Italy where the values are recorded as 10–15 × $10^{-6}$ Bq/m²/d (Bossew et al., 2017).

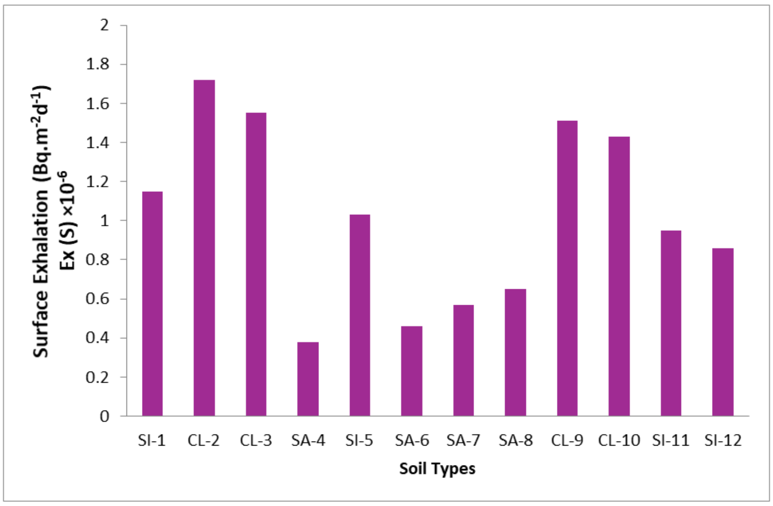


*Figure 5. $^{222}$Rn variation in terms of surface exhalation rates.*

## 5. CONCLUSION AND RECOMMENDATIONS

### 5.1. Conclusion

This investigation of radium content and radon exhalation characteristics in Wukro's soils has yielded several important findings. The measured radiological parameters are significantly lower than global averages and established safety limits, indicating minimal health risks associated with natural radiation exposure in the study area. The observed variations between soil types, particularly the enhanced exhalation in clay-rich soils, provide valuable insights into radon transport mechanisms in different geological media. The strong correlation between radium content and exhalation rates validates the experimental methodology while reinforcing fundamental principles of radon generation and release in natural environments.

### 5.2. Recommendations

Based on these findings, several recommendations emerge for future research and public health practice. First, extended monitoring across different seasons would help characterize temporal variations in exhalation rates related to changing moisture and temperature conditions. Second, complementary indoor radon measurements in residential buildings would provide empirical validation of the soil-based risk assessments. Third, while radiological risks appear low, basic public awareness initiatives regarding radon and its health effects would be prudent. Finally, additional investigations should examine radon concentrations in local groundwater supplies and commonly used building materials to develop a comprehensive understanding of radiation exposure pathways in the region.

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## 7. CONFLICT OF INTEREST

There is no conflict of interests.

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