The Role of Geology Formation and Anthropogenic Activities in Radionuclide Distribution in Selected Regions in Ghana

Doctoral (PhD) thesis

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Veszprem, 2025

Introduction

Investigations of natural and artificial radionuclides distribution in the environment are of interest to the public, governments, and international organizations due to the associated health risks. This is because radiations from natural radionuclides U-238/ Ra-226, Th-232, and K-40 make significant contributions to the dose induced in humans, and thus evaluating the radiation levels of natural radionuclides is an important part of radiation monitoring. Human activities including mining concentrate natural and artificial radionuclides in the environment. Hence, determining radioactivity levels and their distribution pattern in a geological area is significant for radiological impact assessment and future monitoring activities.

Radionuclides provide significant information regarding the exposure to ionizing radiation levels in anthropogenic and naturally occurring radioactive materials (NORM) samples. The research investigated the natural and artificial radioactivity levels of environmental media that act as sources of ionizing radiation to the human body and organs. The radiological risks associated with the concentrations were estimated and reported, and finally, recommendations were made.

Aim

The aim of the dissertation is to investigate the radioactivity concentration of natural and artificial radionuclides in soil, sediment, water, indoor air, and consumed products such as cigarettes in selected regions of Ghana and to evaluate the consequential radiological effects associated with the radioactivity concentrations in the environmental samples.

Materials and methods

The radioactive materials studied in this research include soil, sediment, tobacco leaves in cigarettes, indoor air, surface water, and groundwater samples. Sediment and soil samples were collected from coastal and mining areas in Ghana. Indoor radon measurements were conducted in the Greater Accra Region and tobacco leaves in cigarettes were also sampled from the same region. Radioisotopic measurement techniques were employed to measure the radioactivity levels of radionuclides in the investigated materials. Soil, sediment, and water samples were measured by gamma ray spectrometry to determine Ra-226, Ra-228, Th-232, K-40 and Cs-137 while indoor Rn-222 and Po-210 in cigarettes were measured by alpha spectrometry. After the measurements, the generated spectra were analyzed and the activity concentrations and radiological hazards were determined.

Results

Different radionuclide distribution patterns and activity concentrations of Ra-226, Th-232, and K-40 were observed in coastal and inland soils and sediment. This can be attributed to the various geological formations and characteristics in these parts of the country. Ra-226 concentrations measured in sediment samples along the coastal areas were higher than all the concentrations of Th-232 and in some cases above the world average value of 35 Bq/kg. Th-232 and Ra-228 activity concentrations in soils, sediment, and water studied in mining areas were generally observed to be higher than Ra-226 concentrations in those samples. Indoor radon levels measured in the Greater Accra region were less than 100 Bq/m^3. This could be due to soil composition, the geology of the area, building materials used in construction, and the lifestyle of residents. Poor ventilation contributed to relatively high indoor radon concentrations, especially in densely populated areas. The induced mean annual effective dose due to Po-210 in cigarettes was estimated to be 0.067 mSv/y for an adult Ghanaian smoker.

Though the low radiological values were estimated for soil and sediment, signifying that they could be used as building materials, the relatively high AGDE values recorded at some locations suggest that such soil and sediment may be used cautiously due to the radiation risk they pose to human health. The mean Ra-226 and Ra-228 activity concentrations in surface water and groundwater samples were above world reference values of 1.0 Bq/L and 0.1 Bq/L, respectively. Consequently, the committed effective doses were observed to be above 0.3 mSv/y. This indicates that the population is vulnerable to radiological risks associated with the consumption of such water resources, especially infants and children. Lung cancer risks associated with indoor radon and Po-210 concentrations were estimated to contribute approximately 5% to the overall lung cancer cases recorded in Ghana.

Thesis Points

I. Thesis

I investigated the use of natural materials as building materials as a means of exposure to ionizing radiation. I measured natural and artificial gamma emitting isotopes in soils and sediment in coastline and mining areas. Radioactivity concentrations measured in beach sediment along the entire coastline of Ghana were between 14 ± 4 and 134 ± 7 Bq/kg for Ra-226, 8 ± 1 and 77 ± 1 Bq/kg for Th-232, 207 ± 75 and 1273 ± 69 Bq/kg for K-40 and 1.1 ± 0.6 and 111.4 ± 0.3 Bq/kg for Cs-137. The average concentrations were 43 ± 6 Bq/kg, 22 ± 1 Bq/kg, 393 ± 74 Bq/kg, and 8.4 ± 0.5 Bq/kg for Ra-226, Th-232, K-40, and Cs-137, respectively.

Radioactivity measurements determined in soils and sediment from Atiwa West district (mining area) ranged from 12.9 ± 1.4- 29.1 ± 1.8 Bq/kg (mean: 22.1 ± 2.1 Bq/kg) for Ra-226, 10.8 ± 1.2- 44.0 ± 1.8 Bq/kg (mean: 27.5 ± 2.3 Bq/kg) for Th-232 and 40.0 ± 10- 429 ± 36 Bq/kg (mean: 198 ± 22 Bq/kg) for K-40. Although the low radiological values were estimated for studied materials, signifying that they could be used as building materials, the relatively high AGDE values recorded at some locations suggest that such sediment may be used cautiously due to the radiation risk they pose to human health.

II. Thesis

I investigated the lung cancer risk associated with indoor radon and Po-210 in cigarettes. The indoor radon measurements in the study area ranged between 36.1 ± 2.7 and 92.0 ± 5.2 Bq/m^3, with an estimated annual mean of 50.8 ± 3.4 Bq/m^3. All the measured dwellings recorded radon levels below the WHO reference level of 100 Bq/m^3. The annual effective doses were between 0.9 and 2.3 mSv/y, with a mean of 1.3 mSv/y. The average LCC evaluated for the region was 23.1 people per million population.

Po-210 activity concentrations measured in cigarettes ranged from 16.4 ± 2.5- 32.3 ± 5.2 mBq/cig (mean: 26.5 ± 4.2 mBq/cig). The committed annual effective doses due to inhalation of Po-210 in cigarette smoke were between 0.041 mSv/y and 0.082 mSv/y (mean:

0.067 mSv/y) which is below the reference values set by ICRP (0.1 mSv/y) and UNSCEAR (0.3 mSv/y). The average ELCR was estimated as 0.234×10^{-3}, below the world average of 1.16×10^{-3} for internal radiation exposure. This study is considered a preliminary investigation of the effect of internal radiation exposure of natural radionuclides such as Rn-222 levels in family houses and Po-210 in cigarette products consumed in Ghana.

III. Thesis

I studied the influence of mining activities on activity concentrations of radionuclides in water resources. The recorded activity concentrations of Ra-226 (0.52- 1.31 Bq/L; mean: 1.02 Bq/L) and Ra-228 (3.92- 5.12 Bq/L; mean: 4.53 Bq/L) in surface water samples were above world reference values of 1.0 Bq/L and 0.1 Bq/L, respectively. The resultant annual committed effective dose (2.25-2.88 mSv/y; mean: 2.55 mSv/y) and lifetime cancer risks (7.88×10^{-3}- 10.09×10^{-3}; mean: 8.94×10^{-3}) determined for the water samples were above the recommended levels of 0.3 mSv/y and 0.29×10^{-3}, respectively. This means that the population is susceptible to radiological dangers due to miners washing gold ores directly in water bodies and sometimes direct the liquid wastes into the water bodies of the study area.

In the case of groundwater resources activity concentrations of Ra-226 (0.05- 0.13 Bq/L; mean: 0.10 Bq/L) was below the reference level as compared to Ra-228 (0.29- 0.41 Bq/L; mean: 0.36 Bq/L). The estimated mean effective doses for infants (0.55 mSv/y) and children (0.52 mSv/y) were above reference levels. Similarly, the ELCR factors were above 0.29×10^{-3}. The results showed that mining activities enhanced radionuclide concentrations in underground water.

List of Publications

Publications that pose the base of the dissertation

Publications international journals

1. **Akuo-ko, E.O**., Shahrokhi, A., Adelikhah, M., Amponsem, E., Samolej, K., Csordás, A., Kovács, T. (2025). Horizontal distribution of natural radionuclides and Cs-137 in sediment along Dixcove beach. Journal of Marine Science and Engineering, 13, 452. https://doi.org/10.3390/jmse13030452
2. **Akuo-ko, E.O.**, Otoo, F., Glover, E.T., Amponsem, E., Tettey-Larbi, L., Csordás, A., Kovács, T., Shahrokhi, A. (2024). A comprehensive radiological survey of groundwater resources in artisanal mining communities in the Eastern region of Ghana: water quality vs. mining activities. Water, 16, 62, 1-14. 10.3390/w16010062
3. **Akuo-ko, E.O.**, Otoo, F., Glover, E.T., Amponsem, E., Shahrokhi, A., Csordás, A., Kovács, T. (2024). Statistical assessment of natural radioactivity, radon activity, and associated radiological exposure due to artisanal mining in Atiwa West district of the Eastern region, Ghana. Heliyon, 10, e34705, 1-14. 10.1016/j.heliyon.2020.e34705
4. **Akuo-ko, E.O.**, Adelikhah, M., Amponsem, E., Csordas, A. and Kovacs, T. (2023). Radiological assessment in beach sediment of coastline, Ghana. Heliyon 9, 2023, 16690, 1-14. 10.1016/j.heliyon.2023.e16690
5. **Akuo-ko, E.O.**, Adelikhah, M., Amponsem, E., Csordás, A., Kovács, T. (2023). Investigations of indoor radon levels and its mapping in Greater Accra region, Ghana. Journal of Radioanalytical and Nuclear Chemistry, 333, 2975-2986. 10.1007/s10967-023-09165-z

Conference Presentations

1. **Esther Osei Akuo-ko**, Mohammemad Adelikhah, Serwaa Adjei-Kyereme, Lordford Tettey-Larbi, Thomas Onumah, Anita Csordás and Tibor Kovács. Investigations of Indoor Radon Levels in Dwellings and Its Associated Health Risks. 6th International World Health Congress 2024. ISBN/ISSN: 978-625-8254-61-7
2. **Esther Osei Akuo-ko**, Serwaa Adjei-Kyereme, Lordford Tettey-Larbi, Thomas Onumah, Anita Csordás, Tibor Kovács. Investigations of Radioactivity Levels in Soils from Various Gold Mining Communities in Eastern Region, Ghana. 6th International Anatolian Scientific Research Congress 2024. ISBN/ISSN: 978-625-367-952-1
3. **Esther Osei Akuo-ko**, Serwaa Adjei-Kyereme, Lordford Tettey-Larbi, Tuvshinsaikhan Ganbaatar, Thomas Onumah, Anita Csordás and Tibor Kovács. Radiological Assessment of Surface Water Resources within Gold Mining Areas, Ghana. Materials Science Day XXIII of PhD Students 2024
4. **Esther Osei Akuo-ko**, Lordford Tettey-Larbi, Francis Otoo, Anita Csordás, Tibor Kovács. Analysis of radionuclides dissolved in water resources within gold mining areas, Ghana. 7th International Ankara multidisciplinary studies congress. 2024. ISBN/ISSN: 978-625-8254-40-2
5. **Esther Osei Akuo-ko**, Lordford Tettey-Larbi, Francis Otoo, Eric Tetteh Glover, Anita Csordás, Tibor Kovács. Evaluation of radioactivity concentrations in soils from gold mining areas in Eastern region, Ghana. 10th International New York conference on evolving trends in interdisciplinary research and practices. 2024 ISBN/ISSN: 978-625-367-739-8
6. **Esther Osei Akuo-ko**, Francis Otoo, Eric Tetteh Gover, Lordford Tettey-Larbi, Anita Csordás, Tibor Kovács, Amin Shahrokhi. Evaluation of activity concentration of ^{226}Ra, ^{232}Th, ^{40}K and ^{222}Rn in soils from some gold mining communities in Atiwa West, Ghana. IRPA 16 HPS 2024
7. **Esther Osei Akuo-ko**, Anita Csordás, Tibor Kovács. Investigations of the radiological safety of groundwater resources in mining areas in the Eastern region, Ghana. International Graduate-Student Seminar on Radiation Medicine and Protection 2023
8. **Esther Osei Akuo-ko**, Lordford Tettey-Larbi, Tuvshinsaikhan Ganbaatar, Gergely Tóth, Máté Novák, Amin Shahrokhi, Anita

Csordás, Tibor Kovács. Polonium-210 activity concentrations in different brands of cigarettes smoked in Ghana and evaluation of the induced radiation dose. 13th PhD Students' Material Science Day Conference 2023.

9. **Esther Osei Akuo-ko**, Lordford Tettey-Larbi, Tuvshinsaikhan Ganbaatar, Gergely Tóth, Máté Novák, Amin Shahrokhi, Anita Csordás, Tibor Kovács. ^{210}Po activity concentrations, annual effective dose and lung cancer risk assessment in cigarettes smoked in Ghana. 5th International Black Sea Modern Scientific Research Congress. ISBN: 978-1-9550 94-60-3
10. **Esther Osei Akuo-ko**, Lordford Tettey-Larbi, Francis Otoo, Aissa Benselhoub, Anita Csordás, Amin Shahrokhi, Tibor Kovács. Radiological safety of water resources within selected gold mining areas in the Eastern region of Ghana. 4th International Symposium on Mineral Industry and Environment. ISBN: 978-9969-9735-0-1
11. **Esther Osei Akuo-ko**, Lordford Tettey-Larbi, Francis Otoo, Anita Csordás, Tibor Kovács. Surveying the quality of groundwater resources in gold mining areas in eastern Region, Ghana. 4th International Meditarranean Scientific Research Congress. ISBN: 978-625-367-154-9
12. **Akuo-ko E. O.**, Otoo F., Adelikhah M., Amponsem E., Csordás A. and Kovács T. Indoor ^{222}Rn measurement in residential homes and its spatial distribution in Greater Accra, Ghana. ESRAH 2022 Conference
13. **Akuo-ko E. O**., Otoo F., Adelikhah M., Csordás A. and Kovács T. Evaluation of the suitability of beach sediments for use as building materials in Ghana. Material Science Day Conference for PhD students. 2022
14. **Akuo-ko E. O.**, Otoo F., Adelikhah M., Amponsem E., Csordás A. and Kovács T. Indoor ^{222}Rn measurement in residential homes and its spatial distribution in Greater Accra, Ghana. AFRIRPA 06 Conference 2022.
15. **E. O. Akuo-ko**, M. Adelikhah, E. Amponsem, T. Ganbaatar, A. Csordás, T. Kovács. Indoor radon measurements and its inhalation dose assessment in residences within Greater Accra, Ghana. TREICEP 2022. ISBN/ISSN: 978-615-81632-2-4
16. **E. O. Akuo-ko**, M. Adelikhah, E. Amponsem, T. Ganbaatar, A. Csordás, T. Kovács. Radiological assessment of natural and artificial radioactivity in sediments along the coastal area of Ghana.

TREICEP 2022. ISBN/ISSN: 978-615-81632-2-4
17. Gergely Tóth, **Esther Osei Akuo-ko**, Mohammademad Adelikhah, Eunice Amponsem, Tuvshinsaikhan Ganbaatar, Anita Csordás, Tibor Kovács. Indoor radon concentration measurements and the radiological risk assessment within Accra dwellings, Ghana. RAD 2022. https://doi.org/10.21175/rad.spr.abstr.book.2022.37.9
18. **Esther Osei Akuo-ko**, Mohammademad Adelikhah, Tuvshinsaikhan Ganbaatar, Eunice Amponsem, Anita Csordás, Gergely Tóth, Tibor Kovács. Measurement of natural and artificial radioactivity in sediment samples along the coastline of Ghana. RAD 2022. https://doi.org/10.21175/rad.spr.abstr.book.2022.34.7

Conference presentations not tightly connected to the dissertation

1. A. Shahrokhi, **E. Osei Akuo-ko**, L. Tettey.Larbi, T. Ganbaatar, S. Adjei-Kyereme, T. Onumah, E. Tóth-Bodrogi, T. Kovács. atmospheric radon: Reliability and its potential as an earthquake precursor. TREICEP 2024. ISBN/ISSN: 978-615-81632-3-1
2. Lordford Tettey-Larbi, **Esther Osei Akuo-ko**, Tuvshinsaikhan Ganbaatar, Gergely Tóth, Máté Novák, Serwaa Adjei-Kyereme, Thomas Onumah, Edit Tóth-Bodrogi, Tibor Kovács. Gross alpha and beta activity screening in water: A baseline study in the vicinity of a gold mine in Ghana. Materials Science Day XXIII of PhD Students 2024.
3. Serwaa Adjei-Kyereme, Lordford Tettey-Larbi, **Esther Osei Akuo-ko**, Tuvshinsaikhan Ganbaatar, Gergely Tóth, Máté Novák, Thomas Onumah, Edit Tóth-Bodrogi, Tibor Kovács. Potassium and essential mineral profiling in Lippia Multiflora and Bridelia Ferruginea: Implications for hypertension treatment. Materials Science Day XXIII of PhD Students 2024.
4. Thomas Onumah, Lordford Tettey -Larbi, **Esther Osei Akuo-ko**, Serwaa Adjei-Kyereme, David Kpeglo, Francis Otoo, Eva Tabuaa Gyamfi, Edit Tóth-Bodrogi, Tibor Kovács. Determination of bioaccessibility of radionuclides in herbal medicines for internal dose assessment. Materials Science Day XXIII of PhD Students 2024.
5. S. Adjei-Kyereme, L. Tettey.Larbi, T. Onumah, **E. Osei Akuo-ko,** E. Tóth-Bodrogi, T. Kovács, A.Shahrokhi. The migration simulation of natural radionuclides in groundwater of Ghana with help of Comsol Multiphysiscs modeling program: a case study of the Greater Accra Region. TREICEP 2024. ISBN/ISSN: 978-615-81632-3-1
6. A. Shahrokhi, L. Tettey-Larbi, S. Adjei-Kyereme, T. Onumah, **E. Osei Akuo-ko**, E. Tóth-Bodrogi, T. Kovács. Atmospheric remote sensing for environmental sustainability: How radiation sensing Can help achieve sustainability during extreme weather events. TREICEP 2024. ISBN/ISSN: 978-615-81632-3-1
7. L. Tettey.Larbi, T. Onumah, **E. Osei Akuo-ko**, S. Adjei-Kyereme, E. Tóth-Bodrogi, T. Kovács, A. Shahrokhi. An overview of industrial enhanced radionuclides dispersion over mining area in

Ghana. TREICEP 2024. ISBN/ISSN: 978-615-81632-3-1
8. A. Shahrokhi, T. Ganbaatar, S. Adjei-Kyereme, L. Tettey.Larbi, T. Onumah, **E. Osei Akuo-ko,** E. Tóth-Bodrogi, T. Kovács. How the biomonitoring indicators can be used as a management tool in contaminated sites: case study earthworms. TREICEP 2024. ISBN/ISSN: 978-615-81632-3-1
9. Miklós Hegedűs, **Esther Osei Akuo-ko**, Anita Csordás, Edit Tóth-Bodrogi, Tibor Kovács. Implications of the relative strictness of building material indices. RAD 2023 Conference. https://doi.org/10.21175/rad.abstr.book.2023.36
10. Lordford Tettey-Larbi, Amin Shahrokhi, **Esther Osei Akuo-ko**, Edit Tóth-Bodrogi, Tibor Kovács. Surveying the NORM contamination of soils, sediments and water due to mining activities from the Lower Basin of River Pra in the Central and Western Regions of Ghana. RAD 2023 Conference. https://doi.org/10.21175/rad.abstr.book.2023.39
11. A.V. Panitsky, Zh.A. Baigazinov, T.N. Bayserkenova, S.A. Baigazy, I.A. Alexandich, **E.O. Akuo-ko**, E. Toth-Bodrogi, T. Kovacs. Assessment of ^{137}Cs, ^{90}Sr, ^{241}Am, $^{239+240}$Pu, ^{3}H (HTO, OBT) concentrations in the fish from nuclearshell craters and rivers of Semipalatinsk test site. TREICEP 2022. ISBN/ISSN: 978-615-81632-2-4
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13. Lordford Tettey-Larbi, **Esther Osei Akuo-ko,** Gergely Toth, Augustine Faanu, Amin Shahrokhi, Edit Toth-Bodrogi, Tibor Kovács. Assessment of naturally occurring radionuclides in soils and water in some mining communities in Ghana. IRPA 16 HPS 2024
14. Lordford Tettey-Larbi, **Esther Osei Akuo-ko,** Amin Shahrokhi, Anita Csordás, Tibor Kovács. The conception of radiological sustainability possibilities by reutilization of norm residues in building materials. 10th New York Conference. ISBN/ISSN: 978-625-367-739-8
15. Lordford Tettey-Larbi, **Esther Osei Akuo-ko,** Edit Tóth-Bodrogi, Tibor Kovács. Natural occuring radionuclides contamination of River Pra due to illegal mining activities. 4SIMINE23. ISBN: 978-

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16. Lordford Tettey-Larbi, **Esther Osei Akuo-ko,** Tuvshinsaikhan Ganbaatar, Gergely Tóth, Máté Novák, Amin Shahrokhi, Edit Tóth-Bodrogi, Tibor Kovács. Investigating the naturally occuring radionuclide activity concentrations in Ghana's mining communities. 5th International Black Sea Modern Scientific Research Congress. ISBN: 978-1-9550 94-60-3
17. Lordford Tettey-Larbi, Esther Osei Akuo-ko, Tuvshinsaikhan Ganbaatar, Gergely Tóth, Máté Novák, Amin Shahrokhi, Edit Tóth-Bodrogi, Tibor Kovács. Environmental impact of naturally occuring radionuclides in Ghana's mining areas. 13th PhD Students' Material Science Day Conference 2023
18. Tuvshinsaikhan Ganbaatar, Amin Shahrokhi, Lordford Tettey-Larbi, **Esther Osei Akuo-ko**, Edit Tóth-Bodrogi, Tóth Gergely, Fehervari Máté, Tibor Kovács. The new conception of radiological sustainability possibilities by reutilization of residues products and building materials. 13th PhD Students' Material Science Day Conference 2023
19. Lordford Tettey-Larbi, **Esther Osei Akuo-ko**, Amin Shahrokhi, Anita Csordás, Tibor Kovács. Natural occurring radionuclides gross alpha and beta activity concentration and annual committed effective doses of some Ghanaian medicinal plants. 2nd International Congress on Natural and Medical Sciences. ISBN/ISSN: 978-625-367-146-4