STUDY ON THE TRANSFER OF NATURAL RADIOACTIVES FROM SOIL TO WATER SPINACH IN HANOI AND ITS IMPACT ON PEOPLE

Thi-Thuy-Linh Ha[1], Thi-Hong Bui[1], Van-Loat Bui[1], Duc-Thang Duong[2], Ngoc-Thiem Le[2], Van-Khanh Tran[1], Viet-Hoang Tran[1,3], Hoai-Nam Tran[3] ,Van-Hao Duong[4,*], Dinh-Khoa Tran[5], Giang T.T. Phan[6,7]

[1] *Faculty of Physics, VNU University of Science, 334 Nguyen Trai, Hanoi, 100000, Viet Nam*

[2] *Institute for Nuclear Science and Technology, Vietnam Atomic Energy Institute, 179 Hoang Quoc Viet, Hanoi, Viet Nam*

[3] *Phenikaa Institute for Advanced Study, Phenikaa University, Hanoi 12116, Viet Nam*

[4] *VNU School of Interdisciplinary Sciences and Arts, 144 Xuan Thuy, Cau Giay, Hanoi, 100000, Viet Nam*

[5] *Dalat Nuclear Research Institute, Vietnam Atomic Energy Institute (VINATOM), 1 Nguyen Tu Luc, Dalat, Lamdong, Viet Nam*

[6] *Faculty of Fundamental and Applied Sciences, Duy Tan University, Da Nang 550000, Viet Nam*

[7] *Phenikaa Institute for Advanced Study, Phenikaa University, Hanoi 12116, Viet Nam*

1. Introduction

Plants play a crucial role in human nutrition, serving as a primary source of essential nutrients, including vitamins, proteins, carbohydrates, minerals, and dietary fiber. Although the natural radionuclide transfer pathway from soil to plants and subsequently to humans is relatively minor and indirect, the accumulation of these radioactive isotopes in human organs can result in significantly high internal radiation doses [2]. Water spinach, *Ipomoea aquatica Forssk*, is the most common vegetable for human consumption and livestock's food, widely grown in tropical countries such as Vietnam, China, India and other Southeast Asian countries [6]. Water spinach is highly nutritious vegetable containing various vitamins of A, B1, B2, B12, C, E and K [3]. Moreover, it is a semi-aquatic tropical plant (can be easily cultivated in various flooded or unflooded environmental conditions) and can be harvested multiple times within a short period. The accumulation of natural and artificial radionuclides such as ^{228}Th, ^{226}Th, and ^{40}K in plants can occur through root uptake from soil. For humans, in addition to external radiation exposure from environmental sources, internal exposure from ingested food and organ irradiation must also be considered [7]. The radionuclides appearing in water could also be transferred to vegetables. Thus, in the preset work, the transfer characteristics of natural radionuclides, i.e., ^{232}Th, ^{226}Ra and ^{40}K from soil to water spinach in Hanoi, Vietnam were investigated. Further investigation of the activity concentrations of natural radionuclides, radiological hazard indices and their uptake from soil to plant, particularly to water spinach is necessary.

2. Material and methods

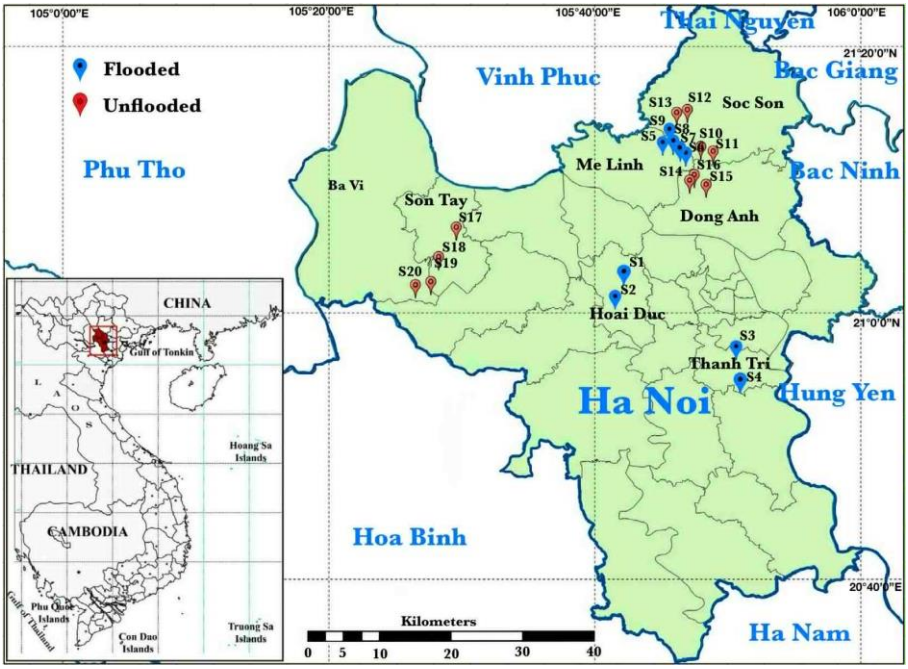

FIGURE 1. SITE MAP AND THE SAMPLING LOCATIONS OF THE SOIL AND WATER SPINACH IN HANOI, VIETNAM

The soil and plant samples were collected at twenty typical farms for water spinach planting in Hanoi. Hanoi, the capital and second-most populous city in the north of Vietnam, features a distinct four-season monsoon subtropical climate. Fig.1 displays the site map, the detailed locations and the environmental conditions of the sampling sites. The environmental conditions were classified into two categorizes: flooded soil (flooded) and normal soil (unflooded). At each sampling site, the stems and leaves of water spinach amounting to 5 kg was collected. The water spinach was washed to eliminate the surface contamination. At the laboratory, the water spinach were dried in an oven at the temperature of 90°C to achieve a constant weight, and then ground into powder. The powdered water spinach samples were homogenized, with 300 g aliquot preserved in 780 cm³ Marinelli beakers. Corresponding to the water spinach samples, twenty soil samples at the depth of 0-10 cm were also collected at the same sites.

The gamma spectra of the water spinach and soil samples were measured using a low-background gamma spectrometer with GC5019 detector at Institute of Nuclear Science and technology (Hanoi). The measurement protocols and determination of radioactive activity concentrations in the study samples were performed in strict accordance with the methodology outlined in Reference [3]. In addition to the transfer factor (TF), in order to assess the radiological hazards associated with natural occurring radioactivity materials, radium equivalent activity (Ra_{eq}), absorbed gamma dose rate (D), annual effective dose equivalent (AEDE) have been evaluated from the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K [2].

3. Results and discussion

TABLE I. Statistic parameters of the soil-to-Water spinach TFs of ^{228}Ra, ^{226}Ra and ^{40}K

Condition	Parameter	Transfer factor (TF)		
		^{228}Ra (^{232}Th)	^{226}Ra	^{40}K
Flooded	Min	0.01	0.02	0.34
	Max	0.17	0.13	2.49
	Mean	0.07	0.05	1.38
	GM	0.05	0.04	1.17
	GSD	2.41	1.88	1.89
	Skewness	0.96	1.75	0.32
	Kurtosis	-0.44	3.15	-1.34
Unflooded	Min	0.01	0.01	0.32
	Max	0.06	0.04	1.61
	Mean	0.03	0.03	1.00
	GM	0.03	0.03	0.89
	GSD	2.12	1.82	1.73
	Skewness	-0.09	-0.65	-0.23
	Kurtosis	-1.87	-0.89	-1.20

Table I summarizes the soil-to-water spinach transfer factors (TFs) of natural radionuclides obtained from water spinach samples in flooded and unflooded areas. For flooded areas, the TFs of ^{228}Ra ranged from 0.01 to 0.17, with the GM(GSD) of 0.05(2.41). In contrast, for unflooded areas, the TFs fell within 0.01–0.06, with a GM(GSD) of 0.03(2.12). This demonstrates that the ^{228}Ra TFs were significantly higher in flooded samples. The TFs of ^{226}Ra are within the ranges of 0.02–0.13 and 0.01–0.04 for flooded and unflooded sites, respectively. The GM(GSD) values are 0.04(1.88) and 0.03(1.82), respectively. The TFs of ^{226}Ra in the flooded sites are greater than that in the unflooded sites. For ^{40}K, the TFs ranged from 0.34–2.49 (flooded) and 0.32–1.61 (unflooded), with corresponding GM(GSD) values of 1.17(1.89) and 0.89(1.73). These values were substantially higher than those of ^{228}Ra and ^{226}Ra, exceeding 1.0 at half of the sampling sites. The consistent results indicate that flooded conditions significantly enhance the transfer of radionuclides.

TABLE II. Comparison of the soil-to-Water spinach TFs of the natural radionuclides among worldwide regions.

Country	^{228}Ra (^{232}Th)	^{226}Ra	^{40}K
Hanoi, Vietnam	0.05	0.04	1.19
Ho Chi Minh, Vietnam [4]	0.12	0.08	69.1
Bangka Belitung, Indonesia [5]	0.05	0.02	28.6
World average [1]	0.05	0.04	1.4

Table II presents the soil-to-plant transfer factors (TFs) of natural radionuclides in comparison with other regions. The TFs for Ra in Hanoi (0.05 and 0.04, respectively) align closely with the world averages (0.05 and 0.04). However, the TF for ^{40}K (1.19) is notably lower than that reported in Ho Chi Minh (69.1) and Indonesia (28.6), suggesting regional variations in

soil-plant uptake mechanisms. The TFs of the radionuclides are greater in the flooded sites. Statistical analysis suggests that the TFs are significantly different between the flooded and unflooded conditions.

TABLE III. Radiological hazard indices in the study samples

Paramater	Ra_{eq}(Bq/kg)	D (nGy/h)	AEDE (mSv/y)
Min	137.9±3.95	64.9±2.35	0.079±0.002
Max	399.5±7.81	188.1±4.97	0.23±0.006
Average	225.9±4.45	108.2±3.06	0.13±0.004
World average [1]	370	59	0.07

In Table III, The measured values of Ra_{eq} ranged from 137.9 (S2) Bq/kg to 399.5 (S12) Bq/kg, with an average of 225.9 Bq/kg, which is below the world average limit of 370 Bq/kg. The absorbed dose rate (D) varied between 64.9(S2) to 88.1 (S12) nGy/h, averaging 108.2 nGy/h, significantly higher than the global average of 59 nGy/h. The annual effective dose equivalent (AEDE) ranged from 0.079 (S2) to 0.23 (S12) mSv/y, with an average of 0.13 mSv/y, still well below the safety limit of 1 mSv/y. These results indicate that while some localized areas exhibit elevated radiation levels, the overall radiological risk remains within acceptable thresholds.

4. Conclusions

This study provides a comprehensive assessment of radiological hazards and soil-to-plant transfer factors (TFs) of natural radionuclides in the investigated region. The results indicate that while the average radium equivalent activity (D) and annual effective dose equivalent (AEDE) were above internationally established thresholds, excluding Ra_{eq}, localized areas exhibit elevated radiation levels, warranting further monitoring. The comparison of TFs with other regions reveals significant variability, particularly for ^{40}K emphasizing the influence of local environmental and geochemical conditions on radionuclide uptake.

ACKNOWLEDGMENTS

This work was funded by Vietnam National Foundation for Science and Technology Development (NAFOSTED).

REFERENCES

[1] IAEA, 1994. Handbook of Parameter Values for the Prediction of Radionuclide Transfer. To Wildlife. Technical Report, Technical Reports Series No. 364. Vienna.
[2] B. V. LOAT, et al. Natural radioactivity and radiological hazards in soil samples in Savannakhet province, Laos. Journal of Radioanalytical and Nuclear Chemistry (2019).
[3] B. V. LOAT, et al. Transfer of natural radionuclides from soil to water spinach (Ipomoea aquatica Forssk) under flooded and unflooded conditions in Hanoi, Vietnam. Journal of Environmental Radioactivity 277 (2024).
[4] B. N. THIEN, et al. Estimation of the soil to plant transfer factor and annual effective dose due to ingestion of food crops in Ho Chi Minh city, Vietnam. Chemosphere 259, (2020).
[5] E. NURTJAHYA, et al. Study of soil-to-plant transfer factors (TFs) of 226Ra, 232Th, and 40K on plants cultivated on ex-tin mining land in Bangka Belitung, Indonesia. Journal of Environmental Radioactivity 261 (2023).
[6] Daniel F.Austin, et al. Water Spinach (Ipomoea aquatica, Convolvulaceae) A food gone wild, U.S.A. Ethnobotany Research & Applications 5:123-146 (2007).
[7] UNSCEAR, 2000. Sources of ionizing radiation. Volume I: Sources.