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К РЕШЕНИЮ СОВРЕМЕННЫХ ПРОБЛЕМ:
КОМПЛЕКСНЫЙ АНАЛИЗ
И ПРАКТИЧЕСКАЯ РЕАЛИЗАЦИЯ**

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STUDY ON THE TRANSFER FACTORS (TF) FROM SOIL TO PLANT IN MUONG HUM AREA, LAO CAI PROVINCE

Abstract

In this study, the authors conducted research on the process of radioisotope transport from soil to plants (water spinach) after a growing period of 4 to 6 weeks in the Muong Hum area, Lao Cai Province. Measurements were performed using a gamma spectrum analysis system with a high purity germanium detector HPGe. The results showed that after a period of planting, beta radiation activity decreased 1.68 times. While the natural radioactivity of ^{238}U and ^{232}Th gradually increases with the growth and development of the plant, the activity of ^{40}K decreases with the time of planting. The results of the soil to plant transfer factors (TF) for ^{238}U , ^{232}Th and ^{40}K are respectively: $\text{TF}(^{238}\text{U}) = 1.37 - 2.18$; $\text{TF}(^{232}\text{Th}) = 0.53 - 1.47$; $\text{TF}(^{40}\text{K}) = 1.14 - 1.69$.

Keyword

Transfer factors (TF), radioactivity, crops, rare earth, vegetables, Lao Cai

1. Introduction

Along with global economic development, the issues of air, soil, and water pollution have increasingly become urgent concerns for countries around the world. Environmental

pollution has caused negative impacts on human health and ecosystems, increasing the economic burden on nations due to the costs of mitigating consequences. Among these, soil pollution is receiving particular attention, as soil serves as a medium through which pollutants are transferred into plants and water sources—ultimately affecting human health via the food supply.

Currently, the use of bioindicators for monitoring, evaluating, and remediating environmental conditions has been extensively studied and applied worldwide. Bioindicators are closely related to the state of the living environment. Plants, for instance, cannot distinguish between isotopes of elements. Radioisotopes are widely used as tracers in plant physiology and animal biochemistry studies. Generally, plants respond to radioactive isotopes similarly to how they respond to chemically and physically analogous stable isotopes. Moreover, plants play a key role in transporting radioactive nuclei from pollution sources to humans and can serve as indicators for monitoring environmental radioactive contamination through biological markers [1–3].

In Vietnam, research on the transport of radioactive isotopes from soil to plants is an area of growing interest. In recent years, several Vietnamese scientists such as the research groups of Nguyen Hao Quang and Dang Duc Nhan [10] have studied the transfer factor (TF) of radioactive isotopes ^{134}Cs and ^{84}Sr from soil to rice and cabbage as part of a collaborative research program with the International Atomic Energy Agency (IAEA) [2]. Investigations have been carried out to determine the residual levels of ^{90}Sr , ^{137}Cs and $^{239+240}\text{Pu}$ in cultivated and uncultivated soils in Vietnam, as well as radioactivity levels in soil and plants [4, 10, 11].

Over recent decades, the study of radioactivity and heavy metals in plants has attracted considerable attention from scientists worldwide. These studies aim to: (i) assess the levels of radioactivity and heavy metals in crops to evaluate their potential health impacts on humans, and (ii) determine the transfer factors of radionuclides and metals from soil to plants to support phytoremediation efforts in contaminated areas. Pew Basu et al. (2018) evaluated the internal radiation dose of ^{40}K in food consumed by residents near the Kalpakkam nuclear power plant. Yadav et al. [16] measured the activity of natural radioactive isotopes ^{40}K , ^{226}Ra and ^{232}Th in wheat over two years using gamma spectrometry. Tetey - Larbi et al. [17] assessed the activity and annual effective dose of natural radionuclides ^{238}U , ^{232}Th and ^{40}K in herbs. Al - Hamarneh [12] measured the radioactivity of natural isotopes ^{226}Ra , ^{228}Ra , ^{40}K , and ^{210}Pb , as well as artificial isotope ^{137}Cs , in soil and various parts of rice plants in the area surrounding the Kaiga nuclear power station. Luu Viet Hung [14] studied the accumulation of radioactive isotopes from soil into plants, such as sweet leaf, tea, and corn grown in Ferralic Acrisol soil with rare earth and radioactive mineral deposits, showing relatively low levels of accumulation in edible parts. Vandenhove et al. [13] investigated the TF of U, Th, Ra, Pb, and Po in over 700 plant samples categorized into nine major groups: cereals, leafy vegetables, non - leafy vegetables, root crops, tubers, fruits, herbs, pastures / grasses, and fodder. The highest TF values were found in the groups of fodder, pastures / grasses, and leafy vegetables, while lower values were observed in legumes and cereals. Asaduzzaman Kh.

et al. [18] studied the ^{226}Ra , ^{232}Th , ^{40}K and ^{88}Y from soil to vegetable roots in several regions of Malaysia, with artificial radionuclide ^{88}Y detected in cassava samples from the Puchong area.

Evaluating the transport of radionuclides from soil to plants is crucial in modeling the impact of radiation on human health. However, the absorption of radionuclides through plant roots is difficult to quantify due to the complex nature of soil systems. Therefore, the transfer factor (TF) is commonly used to assess this process. TF is defined as the ratio of the concentration of a radionuclide (in dry mass) in the plant to that in the corresponding dry soil sample from the same location [5–7].

This study investigates the activity levels of natural radionuclides (U, Th, K) in *Ipomoea aquatica* (water spinach) after a cultivation period in Muong Hum, Lao Cai Province.

2. Subjects and Research Methods

2.1. Study Site

The vegetables were cultivated in the Muong Hum area, Lao Cai Province. This region contains numerous mineral deposits with high concentrations of radionuclides and heavy metals, and is currently undergoing exploration and resource evaluation activities. Examples include rare earth elements in Muong Hum, as well as lead - zinc and iron ores. These activities pose a potential environmental risk due to the release and dispersion of radioactive and metallic elements into the soil and water environment [4]. Therefore, it is necessary to assess the quality of fresh vegetables grown in this area by evaluating the concentration of radionuclides and heavy metals in harvested crops.

During their growth and development, plants absorb and accumulate certain amounts of natural radionuclides and metals. However, the nutritional requirements of plants vary depending on their growth stage. When humans consume leafy vegetables, they may inadvertently ingest radionuclides and metals through food, leading to internal radiation exposure. Thus, assessing the absorption and accumulation of such substances in vegetables during different stages of plant development is essential.

In this study, we investigated and monitored the variation in radionuclide accumulation in *Ipomoea aquatica* (water spinach) over a cultivation period of 4 to 6 weeks. Water spinach was chosen as the subject of study because it is one of the most common vegetables in Vietnam. It is easy to grow, suitable for various soil types, and can be cultivated year - round. Its short growth cycle, typically from 4 to 6 weeks, makes it a practical crop for observation and assessment.

At the study site, five soil samples and five water spinach samples were collected to determine the activity concentrations of radionuclides in both soil and plant before and after the cultivation period.

Table 1. Sampling time points for water spinach

No	Sample code (water spinach)	Cultivation duration (Days)
1	RM.01	24
2	RM.02	28

No	Sample code (water spinach)	Cultivation duration (Days)
3	RM.03	32
4	RM.04	36
5	RM.05	40



Figure 1. Study location

2.2. Research Methods

2.2.1. Determination of Transfer Factor (TF)

The transfer of radioactive isotopes from soil to plants is one of the pathways through which radionuclides can enter the human body. The Transfer Factor (TF) is the simplest parameter used to quantify and predict radioactive contamination in crops originating from the soil environment. TF is determined using the following formula [11], [20]:

$$TF = \frac{C_{thv}}{C_d} \quad (1)$$

Where:

C_{thv} : Radioactivity concentration in the plant (Bq / kg dry weight);

C_d : Radioactivity concentration in the soil (Bq / kg dry weight).

To calculate the transfer factor, strict procedures must be followed when collecting soil and plant samples [20]. The radioactivity in soil is always measured on a dry weight basis, typically at depths of 20 or 50 cm depending on the root systems of different crops, except for grasses which are sampled at a depth of 10 cm. When determining radioactivity in plants, the edible parts (such as grains, tubers, fruits, edible leaves, etc.) are commonly studied, and their activity is also expressed on a dry weight basis.

2.2.2. Analytical Methods

a. Gamma Spectrometry using HPGe Detector

The collected soil samples are first air - dried under sunlight. Then, they are oven - dried at 110°C until the weight change is less than 1 %. The dried soil samples are sieved using a mesh with holes of 1–2 mm diameter to remove any remaining stones, and then ground to achieve a particle size of 0.5 mm.

The entire sample of water spinach (*Ipomoea aquatica*) is carefully washed with clean water to remove soil and dust, then dried at 110°C and ground to obtain particles sized

1–2 mm. All processed samples are homogenized to ensure uniformity and packed into cylindrical containers with a diameter of 74 mm and a height of 30 mm. The mass of each soil sample is 180 g, while each water spinach sample weighs 100 g. All samples are sealed and stored for about 4 weeks to allow radioactive equilibrium to be established before measurement [19].

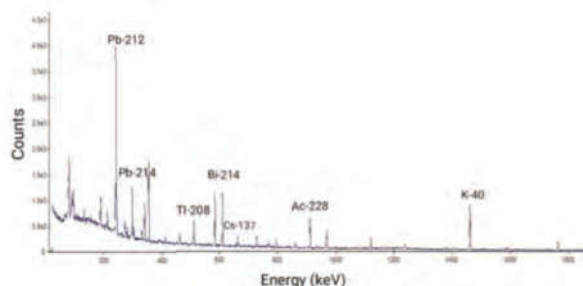


Figure 2. Gamma spectrum of the soil sample at the study area

The samples were measured using a low - background gamma spectrometry system shielded with lead (CANBERRA), equipped with a high - purity germanium (HPGe) detector with a resolution of 1.86 keV at the 1,332.49 keV photopeak of Co - 60 and a relative efficiency of 15 %. To collect sufficient statistical data and reduce statistical errors, the counting time was set to 100,000 seconds for soil samples and 150,000 seconds for plant samples. Additionally, background measurements were performed for 100,000 seconds. The Genie 2000 software was used for data acquisition and spectral analysis. The activity concentrations of ^{238}U and ^{232}Th ... in the samples were inferred using a method developed by our team, which averages based on a single absolute efficiency value at 1,460.82 keV (the characteristic gamma energy of ^{40}K and the relative efficiency curve [18]. For each sample, a relative efficiency curve $F(E)$ was constructed based on the gamma peaks at 295.57 keV and 351.9 keV of ^{214}Pb , and 609.31 keV, 1,120 keV, and 1,764.49 keV of ^{214}Bi . The activity of ^{232}Th was determined from the 911.1 keV gamma line of ^{228}Ac and the 583.19 keV gamma line of ^{208}Tl .

b. Gross Alpha–Beta Counting System

The LB4200 counting system was used to measure the total alpha and beta radioactivity in the vegetable samples. The system is equipped with a lead - shielded chamber to reduce environmental background and an anti - coincidence system to suppress cosmic background radiation. The background count rate was reduced to below 0.1 counts per minute (cpm) for alpha and below 0.75 cpm for beta. The gross alpha detection efficiency was greater than 38 % using a ^{210}Po standard source, and the gross beta detection efficiency was greater than 45 % using a $^{90}\text{Sr} / ^{90}\text{Y}$ standard source. The sample tray had a diameter of 4.5 cm. After collection, the vegetable samples were fully ashed. The ash was evenly spread on the tray and measured for a duration of 86,400 seconds.

3. Results and Discussion

3.1. Total Radioactivity in the Analyzed Samples

The results of alpha and beta activity concentrations in soil and vegetable samples are presented in **Table 2**. From Table 2, it can be observed that the alpha and beta activities in vegetable samples vary according to the plant's growth period. The beta activity in the vegetables gradually decreases over the cultivation period, reaching its highest value in sample **RM.01** at **712.87 Bq / kg**, and the lowest value in sample **RM.05** at **423.89 Bq / kg**. Over a 16 - day period, from sample RM.01 to RM.05, the beta activity decreased by a factor of **1.68**. This decrease is mainly due to the reduction of potassium content in the vegetable samples over time. Potassium is a major contributor to the total beta activity (with a correlation coefficient between ^{40}K activity and total beta of $R^2 = 0.8097$), and its concentration decreases as the plant grows and develops. The alpha activity reached a maximum of **13.31 Bq / kg** in sample **RM.04** after **36 days** of cultivation and a minimum of **7.93 Bq / kg** in sample **RM.02** after **28 days**.

Table 2. Total Alpha and Beta activity in soil and vegetable samples

No	Sample ID	Total Activity (Bq / kg)			
		Soil		Vegetable	
		Alpha	Beta	Alpha	Beta
1	RM.01	132.13±12.43	325.76±21.43	11.22±2.23	712.87±43.42
2	RM.02	143.25±14.22	287.54±18.21	7.93±1.23	576.75±38.64
3	RM.03	165.42±16.45	407.45±25.32	8.32±1.76	469.30±36.32
4	RM.04	167.32±17.67	427.43±27.42	13.31±3.65	451.17±35.78
5	RM.05	157.38±15.54	303.54±22.12	12.42±2.43	423.89±33.34

3.2. Transfer Factors of ^{238}U , ^{232}Th and ^{40}K from Soil to Water Spinach

The data of radioactive isotope activity analysis in water spinach and in soil are given in Table 3. From Table 3, it can be seen that the natural radioactivity in soil of ^{238}U has values from (80.71÷124.93)Bq / kg dry; ^{232}Th has values from (74.61÷143.12) Bq / kg dry; and ^{40}K has values from (242.73÷386.67)Bq / kg dry. The natural radioactivity in vegetables after the planting period of ^{238}U has values from (65.78÷98.29)Bq / kg dry; ^{232}Th has values from (33.84÷76.53)Bq / kg dry; and ^{40}K has values from (397.53÷447.27)Bq / kg dry.

Table 3. Activity concentrations of ^{238}U , ^{232}Th and ^{40}K in soil and water spinach samples

Sample type	Sample	U - 238 (Bq / kg dry)	Th - 232(Bq / kg dry)	K - 40(Bq / kg dry)
Soil	Đ.01	124.93±1.02	143.12±1.13	386.67±24.12
	Đ.02	100.49±1.11	119.74±0.46	338.69±26.55
	Đ.03	80.71±0.98	74.61±0.88	242.73±24.13
	Đ.04	95.78±0.76	88.58±0.97	273.77±25.41

	Đ.05	112.09±1.13	123.18±0.98	324.58±20.14
Vegetable	MR.01	83.63±1.26	64.25±0.97	435.36±14.25
	MR.02	98.59±1.42	76.53±0.84	447.27±18.74
	MR.03	76.49±1.33	33.84±1.26	401.84±22.41
	MR.04	98.29±1.01	43.87±0.92	397.53±26.98
	MR.05	65.78±0.98	35.97±1.12	428.92±25.41

From Table 3, it can be seen that ^{238}U is more readily absorbed by the plant than ^{232}Th . This observation is consistent with the findings of Mortvedt, who demonstrated that plants absorb more uranium than thorium [20].

Based on the measured activity concentrations of natural radionuclides ^{238}U , ^{232}Th , and ^{40}K in both the soil and the water spinach, the calculated transfer factor (TF) values from soil to plant are presented in Table 4.

Table 4. Transfer Factor (TF) Values from soil to water spinach after cultivation period

No	Sample ID	TF - ^{238}U	TF - ^{232}Th	TF - ^{40}K
1	MR.01	1.78	0.53	1.14
2	MR.02	1.98	0.99	1.37
3	MR.03	2.03	1.04	1.69
4	MR.04	2.18	1.47	1.48
5	MR.05	1.37	0.89	1.35

From Table 4, it can be seen that the transfer factor (TF) values for ^{238}U in water spinach range from 1.37 to 2.18; for ^{232}Th , from 0.53 to 1.47; and for ^{40}K , from 1.14 to 1.69. Table 4 also shows that the uptake capacity of natural radionuclide ^{238}U by water spinach is approximately 1.4 times higher than that of ^{232}Th . Based on the analysis results, correlations between the radionuclide activity in soil and the TF values in water spinach were established. These results are presented in Figures 2, 3, and 4.

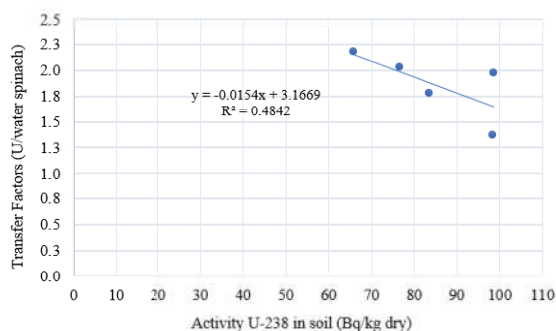


Figure 2. Correlation between ^{238}U activity in soil and TF(U / water spinach)

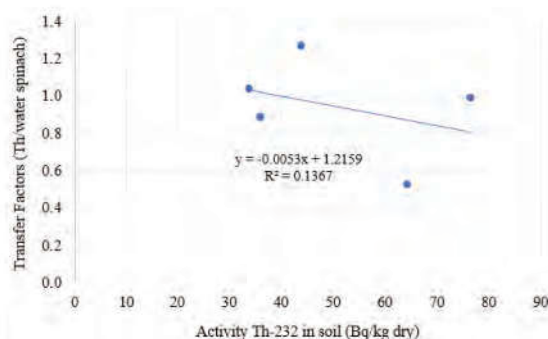


Figure 3. Correlation between ^{232}Th activity in soil and TF(Th / water spinach)

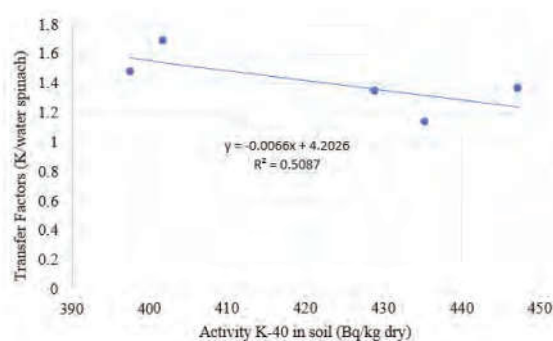


Figure 4. Correlation between ^{40}K activity in soil and TF(K / water spinach)

From **Figures 2, 3, and 4**, it can be observed that there is an **inverse correlation** between the activity concentration of radioactive isotopes in the soil and their respective **transfer factors (TF)**. This indicates that as the concentration of radionuclides in the soil increases, the plant's ability to absorb them decreases. The degree of TF reduction depends on both the **plant species** and the **type of radionuclide**.

4. Conclusion

The research results determined the activity concentrations of natural radionuclides ^{238}U , ^{232}Th and ^{40}K in water spinach throughout its growth and development stages. As the cultivation time increased, the activity levels of ^{238}U and ^{232}Th in the plant also increased. The **total alpha activity** in the samples showed **little variation**, while the **total beta activity decreased by a factor of 1.68** over the plant's growth period. The findings also revealed that **water spinach absorbs ^{238}U more efficiently than ^{232}Th** .

Furthermore, the results established a **positive correlation** between the activity concentration of a given radionuclide in the soil and in the plant. However, the **transfer factor (TF)** shows a **negative correlation** with soil activity. In other words, as the

radionuclide activity in the soil increases, the plant tends to reduce its uptake, maintaining only an optimal amount necessary for its growth.

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**APPLICATION OF CLOUD COMPUTING TECHNOLOGY IN THE ASSESSMENT
AND MANAGEMENT OF WATER QUALITY IN THE BA CHE RIVER,
BA CHE DISTRICT, QUANG NINH PROVINCE**

Annotation

In the context of rapid urbanization and industrialization occurring in Ba Che District, the water quality of the Ba Che River has been increasingly affected by wastewater from