ORIGINAL ARTICLE

Comparison of the Radioactivity Level of Bird's Eye Chillies in Chemical and Natural Fertilizers

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Keywords:
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ABSTRACT

Background: Concerns regarding naturally occurring radionuclides in agricultural inputs have increased due to their potential transfer into food crops. This study evaluates the activity concentrations of K-40, Th-232, and Ra-226 in chemical and natural fertilizers and examines their subsequent uptake in bird's eye chillies to assess radiological safety. **Methods:** Twelve samples comprising chemical fertilizers, natural fertilizers and bird's eye chillies were collected and analyzed using a High Sensitivity Gamma Spectrometer GDM 10C equipped with WinDAS software. Activity concentrations of the selected radionuclides were quantified, and further assessments of radium equivalent activity (Ra_{eq}), absorbed dose rate, and annual effective dose were performed. Data processing and comparative analyses were conducted using Microsoft Excel. **Results:** All three radionuclides were detected in both fertilizer types. Activity concentrations in fertilizers ranged from 1.3329×10^{-5} to 6.3679×10^{-5} Bq/kg, while bird's eye chillies samples showed higher values ranging from 3.9453×10^{-5} to 9.7137×10^{-5} Bq/kg. Chemical fertilizers exhibited higher radioactivity indicators, with average Ra_{eq} (3.6147 Bq/kg), absorbed dose rate (1.6472 nGy/h), and annual effective dose (0.0202 mSv) compared to natural fertilizers (1.7146 Bq/kg, 0.7941 nGy/h, and 0.0097 mSv, respectively). Correspondingly, chillies grown with chemical fertilizers showed a higher annual ingestion dose of K-40, Th-232, and Ra-226. **Conclusion**: Although radioactivity levels were higher in samples influenced by chemical fertilizers compared to natural fertilizers, all measured doses remained well below the public exposure limit of 1 mSv/year. Therefore, the bird's eye chillies samples analyzed in this study are considered radiologically safe for human consumption.

INTRODUCTION

Radioactivity is a natural phenomenon caused by the spontaneous decay of unstable atomic nuclei, emitting various forms of radiation such as alpha, beta, and gamma rays. Radioactive elements are present in varying concentrations and can be found in natural and man-made substances. Among these substances are chemical and natural fertilizers, which play a crucial role in modern agriculture by providing essential nutrients for plants. However, concerns have arisen regarding the potential presence of radioactive elements in fertilizers and their influence on the activity concentration in plants.

According to Boukhenfouf & Boucenna (2011), soil nutrients are replaced by chemical fertilizers, primarily compounds marketed as NPKs (nitrogen (N), phosphorus (P), and potassium (K)), which provide the necessary elements to attain high agricultural output. Phosphorus is sourced from phosphate rocks, which contain elevated levels of naturally occurring Uranium-238, Thorium-232, and K-40 and their radioactive daughters. There is a significant risk towards the consumers, workers, members of the public, and the environment regarding the radiation hazards of fertilizer materials as it contains naturally occurring radioactive materials (Sarkar et al., 2024).

A previous study by Nguyen et al. (2020) examined the amount of radioactivity transferred from soil to plants. However, since the study focused on high-risk radiation areas, it did not account for radioactivity levels in fertilizers. In other study that measured the radioactivity level in fertilizer, it did not focus on the effect of the edible plants (Thabayneh & Hreaz, 2025). Therefore, this study is important because understanding radionuclide transfer and accumulation in crops is essential for food safety, environmental protection, and public health. Even when measured activity concentrations may fall below the safety threshold of 1 mSv/year, chronic low-level exposure from continuous dietary intake may still pose long-term health risks, especially in regions where chemical fertilizers are widely used.

This study aimed to provide an overview of the radioactivity levels of Ra-226, Th-232, and K-40 in chemical

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and natural fertilizers and to compare their influence on the radioactivity level in bird's eye chilies to ensure it is safe and harmless for consumers to ingest. Specifically, the study evaluated whether fertilizer type affects the radionuclide uptake in the edible portion of the plant and whether the resulting levels remain within radiological safety limits for consumers, while providing baseline data of the natural radioactivity level of bird's eye chilies to inform safer agricultural practices.

MATERIALS AND METHODS

Material and Equipment

Radionuclide activities in samples of chemical fertilizer, natural fertilizer and bird's eye chili were quantified using a High Sensitivity Gamma Spectrometer (Model GDM 10C) as in Figure 1 coupled with WinDAS software. The GDM 10C is a scintillation detector equipped with a 2x2 inch sodium iodide (NaI) crystal. The detector assembly, measuring 12 cm in diameter and 40 cm in height, is encased in 1-inch-thick cylindrical lead shielding to minimize background radiation.

Figure 1: High Sensitivity Gamma Spectrometer GDM 10C

The WinDAS software version 3.4.20 was used to measure and analyze gamma radiation from the radionuclide activity in the samples. The software is designed to automatically determine several radionuclides available in the data library such as Ra-226, Th-232, and K-40. The frequency diagram of the energy distribution of the detected gamma quanta was demonstrated in Figure 2.

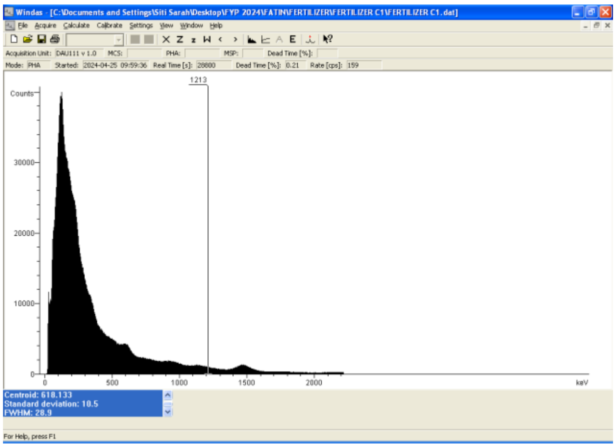

Figure 2: WinDAS Software

Methodology

Sample selection

Radionuclide activities in samples of chemical fertilizer, natural fertilizer, and bird's eye chili were quantified using a High Sensitivity Gamma Spectrometer (Model GDM 10C) coupled with WinDAS software. The GDM 10C is a scintillation detector equipped with a 2x2 inch sodium iodide (NaI) crystal. The detector assembly, measuring 12 cm in diameter and 40 cm in height, is encased in 1-inch thick cylindrical lead shielding to minimize background radiation.

The experimental framework involved the cultivation of ten (n=10) bird's eye chillies saplings to assess the transfer of radionuclides. The saplings were potted individually in a controlled domestic environment to simulate typical small-scale agricultural conditions. To evaluate the impact of different nutrient sources, the plants were segregated into two distinct experimental cohorts, consisting of five replicates each (n=5).

The first cohort was subjected to a regimen of commercial chemical fertilizer, while the second cohort was treated exclusively with natural organic fertilizer. All other environmental variables, including sunlight exposure and irrigation, were maintained consistently across both groups. Upon reaching maturity, representative samples were systematically collected for radiological analysis. The final sample inventory comprised four distinct matrices: (1) raw chemical fertilizer, (2) raw natural fertilizer, (3) chili harvested from the chemically treated saplings, and (4) chili harvested from the organically or naturally treated saplings. The visual for the sample selection is shown in Figure 3.

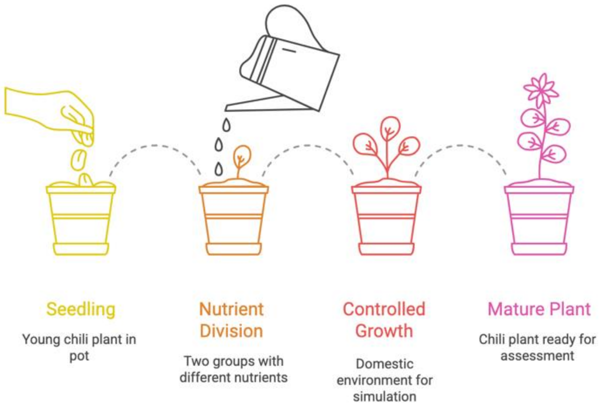

Figure 3: Visual for Chili Sapling

Sample preparation

A total of 12 samples were prepared, comprising three chemical fertilizer samples, three natural fertilizer samples, three bird's eye chillies samples cultivated with chemical fertilizer, and three bird's eye chillies samples cultivated with natural fertilizer. The fertilizer samples were dried in a dehydrator at 55°C for 8 h to remove moisture.

For the chilli samples, they were rinsed with tap water to remove adhering dirt then dried in a dehydrator at 55°C for 12 h to ensure moisture elimination. Longer time required to eliminate the moisture for chilli samples. Subsequently, all samples were ground to a fine powder using a mortar and pestle to achieve homogenization. Each powdered sample was weighed to 10 g on a digital balance, placed in labelled containers as listed in Table 1 and stored at room temperature for 28 days to allow radioactive equilibrium to be established between parent nuclides and their daughter products prior to gamma-ray spectrometric analysis (Kessaratikoon et al., 2021).

Table 1: Samples and its coded label

Type of sample	Coded label
Natural fertilizer	NF1
*NF = natural fertilizer	NF2
	NF3
Chemical fertilizer	CF1
*CF = chemical fertilizer	CF2
	CF3
Bird's eye chillies fertilized by natural fertilizer	NC1
*NC = natural chilli	NC2
	NC3
Bird's eye chillies fertilized by chemical fertilizer	CC1
*CC = chemical chilli	CC2
	CC3

Sample reading

The radionuclide activities were determined using the GDM 10C gamma spectrometer equipped with a sodium iodide (NaI) detector. The system was calibrated with a Co-60 source to quantify activity levels and to convert channel numbers on the x-axis to corresponding energies expressed in keV. Sample measurements for chemical and natural fertilizers were conducted for 28,800 seconds (8 hours), while bird's eye chillies samples were measured for 18,000 seconds (5hours) to minimise statistical uncertainty. Background radiation was recorded by operating the detector without any sample. Net counts for each sample were obtained by subtracting the background spectrum from the respective sample spectra. Each sample was measured in triplicate to derive mean activity values. The flow of the sample selection and sample preparation were shown in Figure 4. The counts corresponding to the characteristic energy peaks of each radionuclide are presented in Table 2.

Table 2: Source, energy, and emission probability of the radionuclides

Source	Daughter Nuclide	Energy (keV)	Emission Probability (%)
K-40	-	1460.8	10.7
Th-232	Ac-228	911.1	29.0
	Tl-208	583.1	86.0
Ra-226	Pb-214	352.0	37.1
	Bi-214	609.3	46.1

Sample analysis

All data were analyzed using Microsoft Excel. The specific activity concentration, A (Bq/kg) of each radionuclide in fertilizers and bird's eye chillies samples were calculated using Equation 1 as stated in a study conducted by Salih et al. (2019) :

$$A, (Bq.kg^{-1}) = ((Net\ count))/(\varepsilon \times I\gamma \times t \times m) \quad (1)$$

where, $I\gamma$ = emission probability per decay of the specific peak
ε = absolute gamma peak efficiency for the detector at a particular photopeak
t = is the counting time in seconds
m = mass of the sample in kilogram.

To assess the real activity level of K-40, Th-232, and Ra-226 in fertilizers, a common radiological index has been defined in terms of radium equivalent activity (Ra_{eq}) in Bq/kg can be used, providing a very useful guideline in regulating the safety standards in radiation protection for a human population. The index was calculated through the following formula by Alharbi (2013) :

$$Ra_{eq}\text{ (Bq/kg)} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (2)$$

where, C_{Ra} = specific activities (Bq/kg) of Ra-226
C_{Th} = specific activities (Bq/kg) of Th-232
C_K = specific activities (Bq/kg) of K- 40

The measured activity of K-40, Th-232, and Ra-226 were converted into doses by applying the factors 0.0417, 0.604, and 0.462 respectively (UNSCEAR, 2000). These factors were used to calculate the total absorbed gamma dose rate in air at 1 m above the ground level using the following equation by Alharbi (2013):

$$D\ (nGy/h) = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K \quad (3)$$

where, C_{Ra} = specific activities (Bq/kg) of Ra-226
C_{Th} = specific activities (Bq/kg) of Th-232
C_K = specific activities (Bq/kg) of K- 40

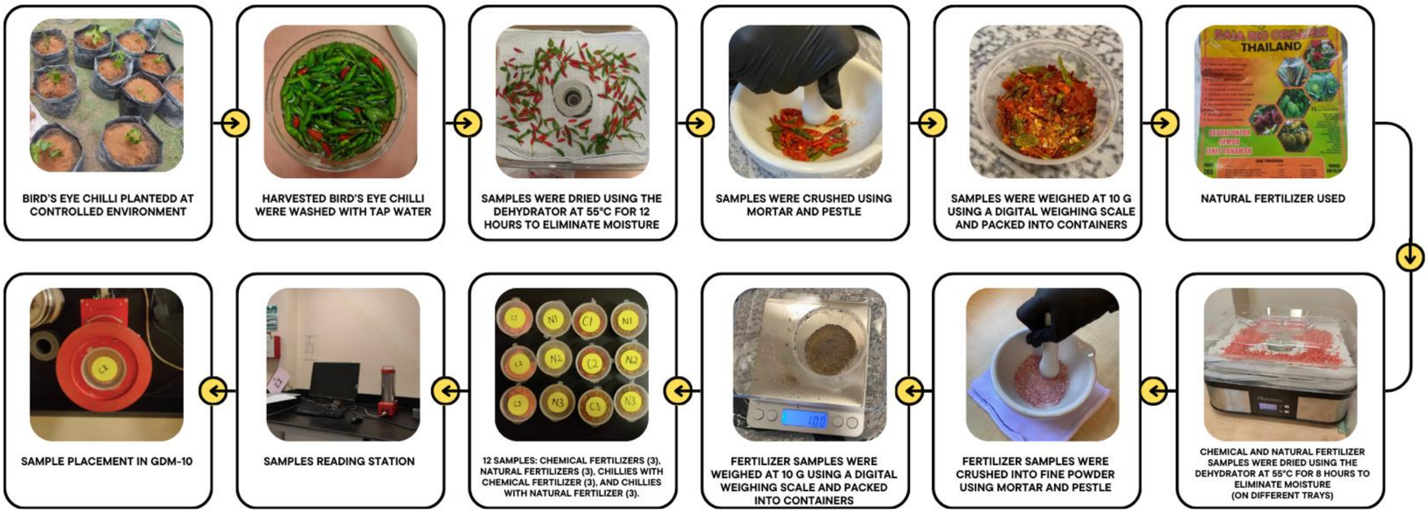

Figure 4: Flow of sample selection and sample preparation

To estimate annual effective doses, must be considered of the conversion coefficient from absorbed dose in air to effective dose. The annual effective doses are determined as follows:

$$AED\ (mSv) = D \text{ x } 8760 \text{ h x } 0.2 \text{ x } 0.7\frac{Sv}{Gy}\ x\ 10^{-6} \quad (4)$$

where, D = absorbed dose
8760 = number of hours in a year
0.2 = outdoor occupancy factor

Annual estimated average effective dose equivalent received by a member is calculated using a conversion factor of 0.7 Sv/Gy.

RESULTS

Radioactivity Level in Fertilizers

The measured activity concentration of K-40, Th-232, and Ra-226 in chemical and natural fertilizers is presented in Table 3. Each sample of both chemical and natural fertilizers have different activity concentrations of K-40, Th-232, and Ra-226. However, there are also the studied radionuclides not detected in several samples.

Table 3: Activity concentration in chemical fertilizer and natural fertilizer

Sample	Activity concentration ($\times 10^{-5}$ Bq/kg)		
	K-40	Th-232	Ra-226
NF1	1.3773	0.0459	ND
NF2	ND	ND	4.9720
NF3	ND	ND	ND
Average	0.4591	0.0153	1.6573
CF1	1.5994	0.3088	ND
CF2	1.3329	1.1738	2.0739
CF3	ND	0.0394	6.3679
Average	0.9774	0.5073	2.8139
Minimum	1.3329	0.0394	2.0739
Maximum	1.5994	1.1738	6.3679
Mean	0.7182	0.2613	2.2356

The activity concentration in all fertilizer samples is in the range of 1.3329×10^{-5} Bq/kg to 1.5994×10^{-5} Bq/kg for K-40, 0.0394×10^{-5} Bq/kg to 1.1738×10^{-5} Bq/kg for Th-232, and 2.0739×10^{-5} Bq/kg to 6.3679×10^{-5} Bq/kg for Ra-226. The highest and lowest activity of K-40, Th-232, and Ra-226 was found in chemical fertilizer samples.

Radioactivity Level in Bird's Eye Chili

The measured activity concentration of K-40, Th-232, and Ra-226 in bird's eyes chillies fertilized by chemical and natural fertilizers is presented in Table 4. All samples of bird's eye chillies have different activity concentrations of K-40, Th-232, and Ra-226. The activity concentration in all bird's eye chilli samples is in the range of 3.9453×10^{-5} Bq/kg to 6.3622×10-$^{-5}$ Bq/kg for K-40, 1.3382×10^{-5} Bq/kg to 3.0362×10^{-5} Bq/kg for Th-232, and 1.7504×10^{-5} Bq/kg to 9.7137×10-$^{-5}$ Bq/kg for Ra-226.

Table 4: Activity concentration in bird's eye chillies fertilized with chemical and natural fertilizer

Sample	Activity concentration (×10^{-5} Bq/kg)		
	K-40	Th-232	Ra-226
CC1	6.3622	3.0362	2.3943
CC2	5.8646	2.9241	9.0190
CC3	4.7983	1.8308	9.7137
Average	5.6750	2.5970	7.0423
NC1	3.9453	2.5180	6.0198
NC2	4.1230	1.3382	2.4519
NC3	5.5092	2.7858	1.7504
Average	4.5258	2.2140	3.4073
Minimum	3.9453	1.3382	1.7504
Maximum	6.3622	3.0362	9.7137
Mean	5.1004	2.4055	5.2249

The highest activity concentration of K-40, Th-232, and Ra-226 was found in bird's eye chillies fertilized with chemical fertilizer samples. The lowest activity concentration of K-40, Th-232, and Ra-226 was found in bird's eye chillies fertilized with natural fertilizer samples. Figure 5 compares the annual ingestion doses of K-40, Th-232, and Ra-226 across all samples. Overall, the comparison indicates that chemical fertilizer is associated with higher radionuclide ingestion doses, particularly for Ra-226.

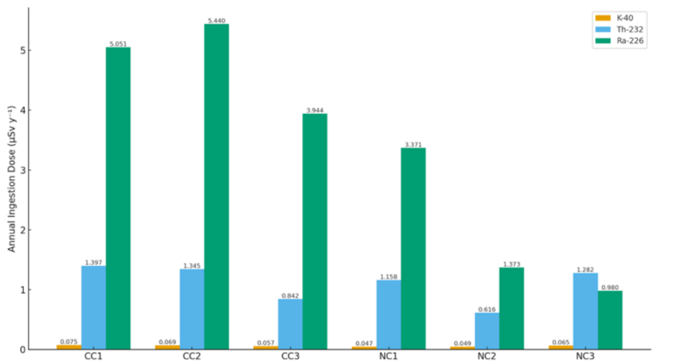

Figure 5: Comparison of the annual ingestion doses of K-40, Th-232, and Ra-226 across all samples

Radiological Health Hazard

The Radium equivalent activity, absorbed dose, and annual effective dose were calculated using the specific activity concentration of the radionuclides in each fertilizer sample as shown in Table 5. Radium equivalent is used to assess the potential health risks associated with natural gamma emitters present in NORM, as it allows to unify the radiation exposure effect caused by different isotopes. Chemical fertilizer has higher Radium equivalent activity with the average of 3.6147 Bq/kg compared to natural fertilizer which only gives the average reading of 1.7146 Bq/kg.

Table 5: Radium equivalent activity, absorbed dose, and annual effective dose of K-40, Th-232, and Ra-226 for chemical and natural fertilizers

Sample	Ra_{eq} (Bq/kg)	Absorbed dose (nGy/h)	Annual effective dose (mSv)
NF1	0.1717	0.0852	0.0010
NF2	4.9720	2.2971	0.0282
NF3	-	-	-
Average	1.7146	0.7941	0.0097
CF1	0.5647	0.2532	0.0031
CF2	3.8551	1.7227	0.0211
CF3	6.4242	2.9658	0.0364
Average	3.6147	1.6472	0.0202

Absorbed dose is a vital factor in radiation protection as it allows estimating the potential negative effect of radiation from soil on human. Chemical fertilizer has higher absorbed dose with the average of 1.6472 nGy/h compared to natural fertilizer which only gives the average reading of 0.7941 nGy/h. Annual effective dose can be obtained by using the absorbed dose. Chemical fertilizer shows a higher value of annual effective dose compared to natural fertilizer with the average of 0.0202 mSv and 0.0097 mSv respectively.

The annual ingestion dose of K-40, Th-232, and Ra-226 for bird's eye chillies fertilized with chemical and natural fertilizers are presented in Table 6. The dose due to ingestion of Ra-226 has a maximum value of 5.0506 µSv y^{-1} in the bird's eye chillies fertilized with chemical fertilizer. The minimum dose was detected in the Bird's Eye chilli fertilized with natural fertilizer of 0.9802 µSv y^{-1} for Ra-226.

Table 6: Annual ingestion dose of K-40, Th-232, and Ra-226 for Bird's Eye chilli fertilized with chemical and natural fertilizers

Sample	Annual Ingestion Dose (µSv y^{-1})		
	K-40	Th-232	Ra-226
CC1	0.0751	1.3967	5.0506
CC2	0.0692	1.3451	5.4397
CC3	0.0566	0.8422	3.9437
Average	0.0670	1.1946	4.8113
NC1	0.0466	1.1583	3.3711
NC2	0.0487	0.6156	1.3731
NC3	0.0650	1.2815	0.9802
Average	0.0534	1.0184	1.9081
Minimum	0.0466	0.6156	0.9802
Maximum	0.0751	1.3967	5.0506
Range	0.0466 – 0.0751	0.6156 – 1.3967	0.9802 – 5.0506

The dose due to Th-232 has a range between 0.6156 µSv y^{-1} for bird's eye chillies fertilized with natural fertilizer and 1.3967 µSv y^{-1} for bird's eye chillies fertilized with chemical fertilizer. Bird's eye chillies fertilized with chemical fertilizer recorded the maximum K-40 dose of about 0.0751 µSv y^{-1}, while the minimum dose was found in Bird's Eye chilli fertilized with natural fertilizer of about 0.0466 µSv y^{-1}.

DISCUSSION

This study examined the activity concentrations of K-40, Th-232, and Ra-226 in chemical and natural fertilizers and their transfer to bird's eye chillies plants. Results showed that Ra-226 exhibited the highest activity concentration in all samples, followed by K-40, while Th-232 recorded the lowest. Chemical fertilizers consistently showed higher radionuclide concentrations than natural fertilizers.

The elevated levels in chemical fertilizers are mainly attributed to the phosphate rocks used in their production, which naturally contain uranium and thorium series radionuclides that persist in the final product (Ahmad et al., 2015). Similarly, the higher K-40 concentration is linked to potash, a potassium-rich compound used in many chemical fertilizers that inherently contains radioactive isotopes of potassium (Ogundele et al., 2026). In contrast, natural fertilizers derived from organic matter and animal manure showed much lower radionuclide activity.

Other than that, bird's eye chillies plants grown with chemical fertilizers displayed higher activity concentrations of K-40, Th-232, and Ra-226 than those treated with natural fertilizers, with Ra-226 being dominant. This enrichment reflects the transfer of radionuclides from fertilizers to plants, consistent with findings that phosphate-based fertilizers enhance radionuclide uptake due to their inherent radioactivity (Mankala et al., 2025).

The mobility and bioavailability of radionuclides in soil play a crucial role in their uptake. Chemical fertilizers can alter soil pH and introduce complexing agents that increase radionuclide solubility that facilitating root absorption. The elevated K-40 concentrations are further explained by potassium's essential role in plant nutrition and its uptake regardless of isotope form.

These findings have important environmental and health implications. Continuous application of phosphate-based fertilizers may lead to radionuclide accumulation in soil and their subsequent transfer to crops, increasing radiation exposure through the food chain (Sahu et al., 2014).

CONCLUSION

This study aims to measure and compare the radioactivity level of K-40, Th- 232, and Ra-226 in chemical fertilizer and natural fertilizer and their influence on the radioactivity level of bird's eye chillies. This experimental study was conducted using High Sensitivity Gamma Spectrometer GDM 10C. The findings reveal that the activity concentration of K-40, Th-232, and Ra-226 is higher in chemical fertilizer and Bird's Eye chilli treated with chemical fertilizer than natural fertilizer and Bird's Eye chilli fertilized with natural fertilizer.

For radiological health hazard, the Radium equivalent activity, absorbed dose rate, and annual effective dose of K-40, Th-232, and Ra-226 for chemical fertilizers gives higher values than natural fertilizers. On the other hand, the annual ingestion dose of K-40, Th-232, and Ra-226 for bird's eye chillies fertilized with chemical fertilizers is higher than fertilized with natural fertilizers. However, the values are still considered safe.

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