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Evaluation of Natural Radioactivity and Chemical Elements in Soil Fertilized with Phosphate in Delta Egypt

Atta H. Zaki[1], Ahmed M. Shabasy [1], M. H. Khedr[2], F. S. Tawfik[1], H. M. Diab[1], Asmaa S. Hamouda[2]

[1] *Egyptian Atomic Energy Authority (EAEA), Nuclear and Radiological Safety Research Centre, Egypt*

[2] *Faculty of Postgraduate Studies for Advances Science PSAS, Beni Suef University, Egypt*

THE APPLICATION of phosphate fertilizers in agricultural soils can lead to the accumulation of natural radionuclides and trace elements, posing potential environmental and health risks. This study aims to investigates the levels of natural radioactivity and associated chemical elements in soils fertilized with phosphate in the East Delta region of Egypt. Phosphate fertilizers, commonly used in intensive agricultural practices, are known to contain naturally occurring radionuclides such as uranium-238, thorium-232, and potassium-40**.** Soil samples were collected from various agricultural sites fertilized by phosphate fertilizer. Gamma spectrometry was employed to quantify radionuclide concentrations, and using activation with the thermal neutrons to assess the presence of trace and heavy elements., The study examined the distribution of essential and toxic trace elements (Cd, Pb, As, Zn, Cu) in the soil and their correlation with fertilizer use. The radiological hazard indices were evaluated and found to comply with international safety standards, although some areas neared the upper safety threshold. In clay soil, the activity concentrations were 38.94 Bq/kg for 238U in Colocasia esculenta 2, 17.55 Bq/kg for ^{232}Th in Abelmoschus esculentus, and 242.4 Bq/kg for ^{40}K in Triticum. In sandy soil, the values were 12.39 Bq/kg for 238U in Triticum, 19.82 Bq/kg for ^{232}Th in Capsicum annuum, and 266.29 Bq/kg for ^{40}K in Capsicum annuum. These results underscore the importance of ongoing environmental monitoring and adopting sustainable farming practices to reduce potential long-term ecological and health risks.

Keywords: Natural radioactivity, phosphate fertilizers, radiological hazards, trace elements, soil contamination, Delta Egypt.

1. Introduction

Soil is essential for agriculture and plant development, serving as a source of nutrients and water, while also providing a habitat for microorganisms. It is formed through the weathering of rocks, which supplies minerals such as sand, silt, and clay key factors influencing soil composition and nutrient retention. Among the naturally occurring substances in soil are radionuclides, primarily from the decay chains of uranium-238, thorium-232, and potassium-40. Human activities, especially the use of phosphate-based fertilizers containing these radionuclides, can increase soil radioactivity. When crops grow in such environments, radionuclides can accumulate in plant tissues, raising concerns about food safety and agricultural sustainability. Therefore, understanding the distribution and behavior of natural radionuclides in soil is vital for assessing radiation exposure and safeguarding both environmental and human health (Mohamed A. El-Zohry, 2023).

Phosphorus is one of substantial nutrients required for growth and development of plant and ranked second after nitrogen element (Emad eldeen Rashwan (2019)). the hardest nutrients to be absorbed by plants, it is necessary for plant growth, nucleus formation and cell division. Phosphorus compounds are involved in the transfer and storage of energy within plants. In the recapitulation, it plays an important function in all plant growth stages like root growth, photosynthesis, flowering and seed set, so its deficiency leads to reduction in plant growth (Emad eldeen Rashwan (2019). The efficiency of phosphate fertilizers depended on several factors, such as the particle sizes of the fertilizer (Mohammed I. Sayed Ahmed (2025).

Phosphorus is a critical macronutrient for plants, playing a central role in energy transfer, genetic material structure, and metabolic functions. It is crucial for photosynthesis, cellular development, protein synthesis, and inheritance, as it forms part of

*Corresponding author email: omaratta2024@gmail.com
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the backbone of DNA and RNA. Moreover, it is a key component of ATP (adenosine triphosphate), the molecule that drives energy processes throughout a plant's lifecycle from germination to maturity (Hesham M. H. Zakaly, 2024).

Proper phosphorus availability supports various aspects of plant health, including: Enhanced root development. Stronger stems and stalks. Improved flowering and seed formation. More uniform and earlier crop maturity. Greater resistance to disease. Increased nitrogen fixation in legumes. Better nutrient and water uptake. As one of the three primary macronutrients, phosphorus is vital in modern agriculture. Fertilizers rich in phosphorus significantly contribute to energy transfer, photosynthesis, nutrient uptake, and overall crop performance. Their use leads to stronger root systems, better stress tolerance, improved yield, and higher crop quality (Hesham M. H. Zakaly, 2024; Nadarajan, 2021). Globally, Egypt is the second-largest producer of phosphate after Morocco, with reserves estimated at 2.8 billion metric tons in 2024—well below Morocco's 50 billion tons (World Population Review.com). Approximately 95% of Egypt's phosphate output is used in agriculture, including fertilizers and animal feedstocks (Elmaadawy et al., 2015). While artificial radionuclides have been extensively studied since the mid-20th century, natural radionuclides have recently attracted attention for their effects on arable soil, plant health, and human exposure (Shtangeeva, 2010). Despite its importance, phosphorus availability in soils faces three key limitations: Low natural abundance – Soil phosphorus levels are significantly lower than those of nitrogen or potassium. Low solubility – A large proportion of phosphorus exists in forms that are not easily absorbed by plants. Fixation – Much of the phosphorus applied through fertilizers becomes unavailable quickly, with plants absorbing only 10–15% in the first year. As a result, farmers often apply double or quadruple the actual requirement (Mahdi et al., 2018). The efficiency of phosphate fertilizers depended on several factors, such as the particle sizes of the fertilizer (Mohammed I. Sayed Ahmed (2025).

Three difficulties with phosphorus affect soil fertility. First, soils typically have low levels of phosphorus overall between one-tenth and one-fourth that of nitrogen and one-twentieth that of potassium. In the top 15 cm of surface soil, phosphorus concentrations range from 200 to 2000 kg, with an average of about 1000 kg P/ha. Second, because they are frequently highly insoluble, the phosphorus compounds that are frequently found in soils are generally not available for plant uptake. Third, soluble sources of phosphorus, like those found in fertilizers, are fixed (converted to unavailable forms) when they are added to soils, eventually forming very insoluble compounds.2 Only a limited portion (10 to 15%) of the phosphorus in fertilizers and manure may be absorbed by plants in the year after application due to fixation reactions in soils. As a result, those farmers who can afford to do so add two to four times as much phosphorus to their soil as they anticipate taking it out during crop harvest 3- or 2 (Mahdi et al. 2018). The efficiency of phosphate fertilizers depended on several factors, such as the particle sizes of the fertilizer (Mohammed I. Sayed Ahmed (2025). When fertilizing with manufactured P fertilizers, only 25-30% of the added P is available to absorb the plant and the rest is converted into un-available and insoluble form, the release of which depends on the characteristics of the soil (Aziz et al., 2015). Tricalcium phosphate (Ca3 (PO4)2), as insoluble inorganic form of P that is impossible for plants to utilize, accumulates in Egyptian soils (Mohammed I. Sayed Ahmed (2025). The ratio of activity concentrations of specific radionuclides in plant and soil samples is known as the soil-to-plant transfer factor (TF), and it is one of the crucial elements for radiological evaluation (Kassab, (2025)). The plant species, soil type, radionuclide availability, and climate conditions are only a few of the variables that can affect the TF value ((Kassab, (2025).

The specific application of this work is for determining natural radioactivity and chemical elements in soils and plants fertilized by phosphate fertilizer in the east delta of Egypt.

This study investigates the concentration of natural radionuclides and chemical elements in soils and plants fertilized with phosphate fertilizers in Egypt's East Delta region. Radioactivity levels were assessed using a high-purity germanium (HPGe) detector, while elemental analysis was conducted via neutron activation analysis. Phosphate fertilizers may introduce heavy metals and radionuclides into agricultural systems (De Souza Braz et al., 2021; Imseng et al., 2021). Although a single application may have limited impact, repeated use can lead to substantial contamination over time (Abed et al., 2022).

Elevated radionuclide concentrations can degrade soil quality and contaminate adjacent environments, increasing radiological and chemical hazards for humans (Asaduzzaman et al., 2015). Factors such as soil uranium content, plant type, and local climate influence radionuclide uptake. While most food crops exhibit low absorption of uranium-238, thorium-232, and potassium-40, tobacco plants are known for hyperaccumulating these elements (Stojanovic et al., 2012; Kadhim et al., 2019; John et al., 2022; Nriagu, 1988).

2.1 Geological Setting

The study area covers an area of 22000 k m^2 which is the most highly populated governorate in Egypt. Around 63 of the total agricultural land is prevalent in the region due to the nature of the fertile alluvial soil and an irrigation system in this area The River Nile Delta is characterized by rich silt soil which is considered the most fertile soil in all of Africa the depth of topsoil in the Nile delta varies from 1524 to 2286 m while it is measured in many places in the world in mere inches 18 figure 1 shows the map in which the samples were collected.

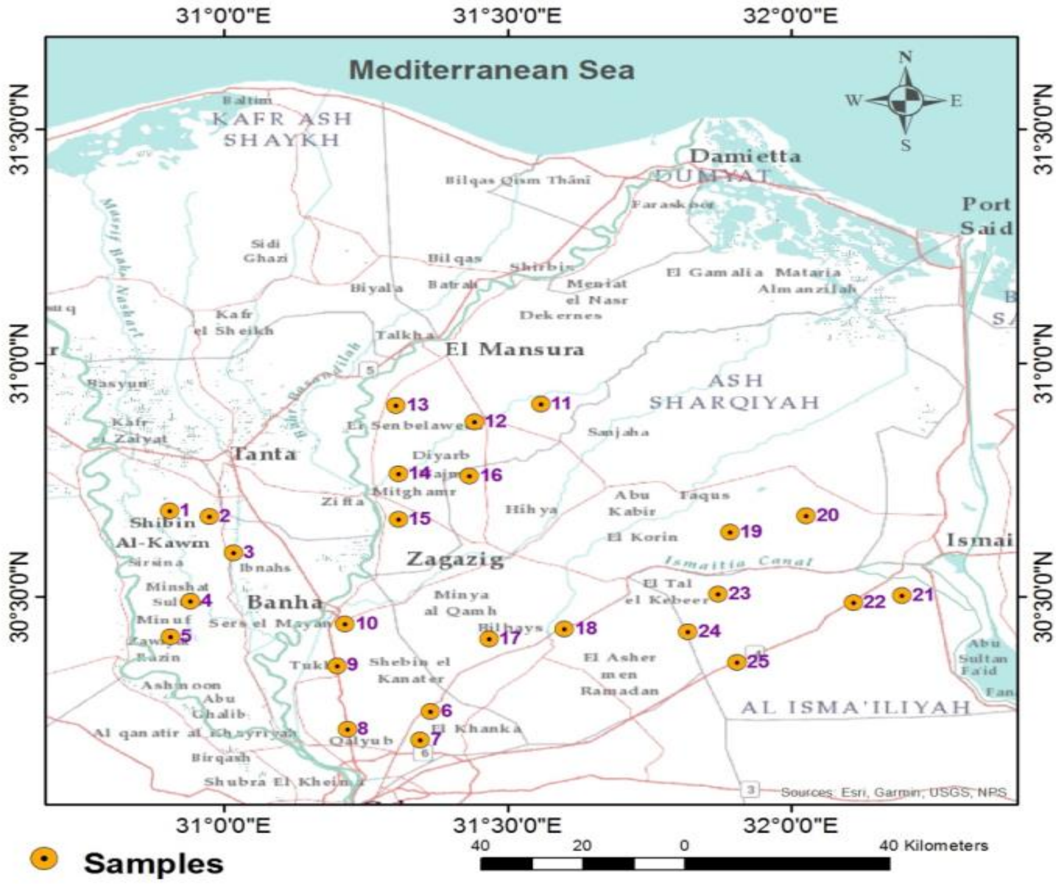

Fig. 1. The study area and sample map.

2.2. Samples collection and preparatio

Twenty-five surfaces soil samples were collected to represent the predominant characteristics of the geomorphological units. They were subjected chemical analysis, physical, Neutron activation analysis and radiological analysis.

Corresponding Twenty-five plant samples were collected from the aforementioned soil sites, elements, Neutron activation analysis, radiological.to measure the samples the Soil.

After sampling, using the previously mentioned methods, the samples were weighed. The sample was dried in an oven at 115 ^{0}C. The sample was mechanically crushed, and sieved through a 0.8 mm sieve. The sieved portion of the sample is weighed, for gamma spectrometry measurement; the required volume of the sample was transferred to a Marinelli beaker of 100 mL capacity, Then Marinelli beakers were sealed for about four weeks in order to ensure secular equilibrium between the long-lived radioisotopes uranium, thorium and radium content of the sample and their daughters. It is assumed that radon gas could not escape from the sealed Marinelli beaker (Amuri N. Aet al 20172.2. HPGe detector and γ-ray spectrometry.

The samples were analysed using high-purity germanium HPGe detector. The detector has a relative efficiency of approximately 40% of the 3″×3″ NaI (Tl) crystal efficiency, with a resolution of 1.9 keV and a peak/Compton ratio of 69.9:1 at the 1.33 MeV gamma-ray transition of 60 Co. The detector is shielded from the background radiation, using a 4 mm Pb, 1 mm Cd and 1 mm Cu. The counting time for each sample was 80.000s then peak area analysis and was carried out using the Genie 2000 software. The activity concentration (C) in units of Bq.kg-1 for each radionuclides using the following expression was determined (Amuri N. Aet al 2017).

$$\mathbf{C}\left(\mathbf{Bq\ Kg^{-1}}\right) = \frac{C_n}{\varepsilon P_\gamma M_S} \qquad (1)$$

Where Cn is the count rate under each photo-peak due to each radionuclide, ε is the detector efficiency for the specific γ-ray, Pγ is the absolute transition probability of the specific γ-ray, and Ms is the mass of the sample (kg).

3. Soil classification

The soil classification and the physical-chemical properties of the collected samples are shown in Table 1

2.4. Neutron activation analysis

This method is predicated on induced radioactivity and the subsequent analysis of that activity. The method is used for determination of multi-trace elements in ppm and ppb levels Generally, in activation analysis, an element is bombarded with neutrons; this induces a nuclear reaction and an exited intermediate is formed by emitting prompt x-rays. the emitted radiation is monitored to obtain both qualitative and quantitative analytical information via characterization of the particle or ray energies and intensities for samples irradiated for short-term and long-term radiation, 100 mg of soil were covered in polyethylene and aluminium foils, respectively. The correctness of the analyses was verified once data processing and element concentration determination were completed.

3. Results

3.1. Clay soil samples results

The activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the collected clay samples were determined and illustrated in Figures 2 and 3. The results of ^{238}U, ^{232}Th and ^{40}K obtained were ranged between12.12 Bq.kg-1 and 37.24 Bq.kg-1, between 5.35 Bq.kg-1 and 17.55 Bq.kg-1and between 77.17Bq.kg-1and 242.4 Bq.kg-1 respectively. All measurements fell within permissible limits, except for a single sample Colocasia esculenta, collected from front the industrial facility—which showed significantly elevated specific activities ^{238}U, ^{232}Th and ^{40}K. This increase is attributed to the accumulation of phosphate particles released during the fertilizer grinding process.

Table 1. soil classification, Physical chemical.

no	Sand %	Silt %	Clay %	Texture	CEC	EC (dS/m)	pH	OM (%)
1	35.1	29	35.9	Sandy Clay	29	0.4	8.3	1.9
2	37	30	33	Sandy Clay	30	0.4	8	2
3	40	21	39	Sandy Clay	31	0.4	7.9	1.5
4	47	25	28	Sandy Clay Loam	29.1	1	8.7	0.3
5	45	24	31	Sandy Clay Loam	29.3	1	8.8	0.4
6	43	21	36	Sandy Clay	30.5	0.6	8.3	1.8
7	40	24	36	Sandy Clay	28.5	0.8	8	1.8
8	35	28	37	Sandy Clay	34.8	1.1	7.6	0.7
9	31.38	30.23	38.39	Clay Loam	35	0.7	7.8	1.4
10	33	32	35	Clay Loam	33	0.8	7.5	1.6
11	29.16	23.42	47.42	Clay	39	0.8	7.7	1.9
12	21	38	41	Silty Clay	36	2.4	7.8	2.4
13	25	34	41	Clay Loam	38	2.5	7.5	2.5
14	51	25	24	Clay Loam	23	1.5	8.4	1.9
15	62.77	8.48	28.75	Sandy Clay Loam	20.6	0.4	7.9	1.9
16	50	30	20	Sandy Clay Loam	20.7	0.5	7.5	1.8
17	35.48	29.72	34.8	Clay Loam	31	0.2	7.7	1.5
18	33.97	30.23	35.8	Clay Loam	23.5	0.4	7.9	1.2
19	33	30	37	Clay Loam	24.7	0.4	7.2	1.4
20	50.55	22.15	27.3	Sandy Clay Loam	20.2	2.3	7.9	1.4
21	92.02	2.41	5.57	Sand	3.2	1	7.8	1.3
22	73.37	3.3	23.33	Sandy Clay	13.4	0.3	8.2	2.2
23	75	5	20	Sandy	4	0 .2	7.9	0.5
24	92.22	3.25	4.53	Sand	3.4	0.3	8.1	0.8
25	90.05	5.71	4.24	Sand	5	0.3	8	0.4

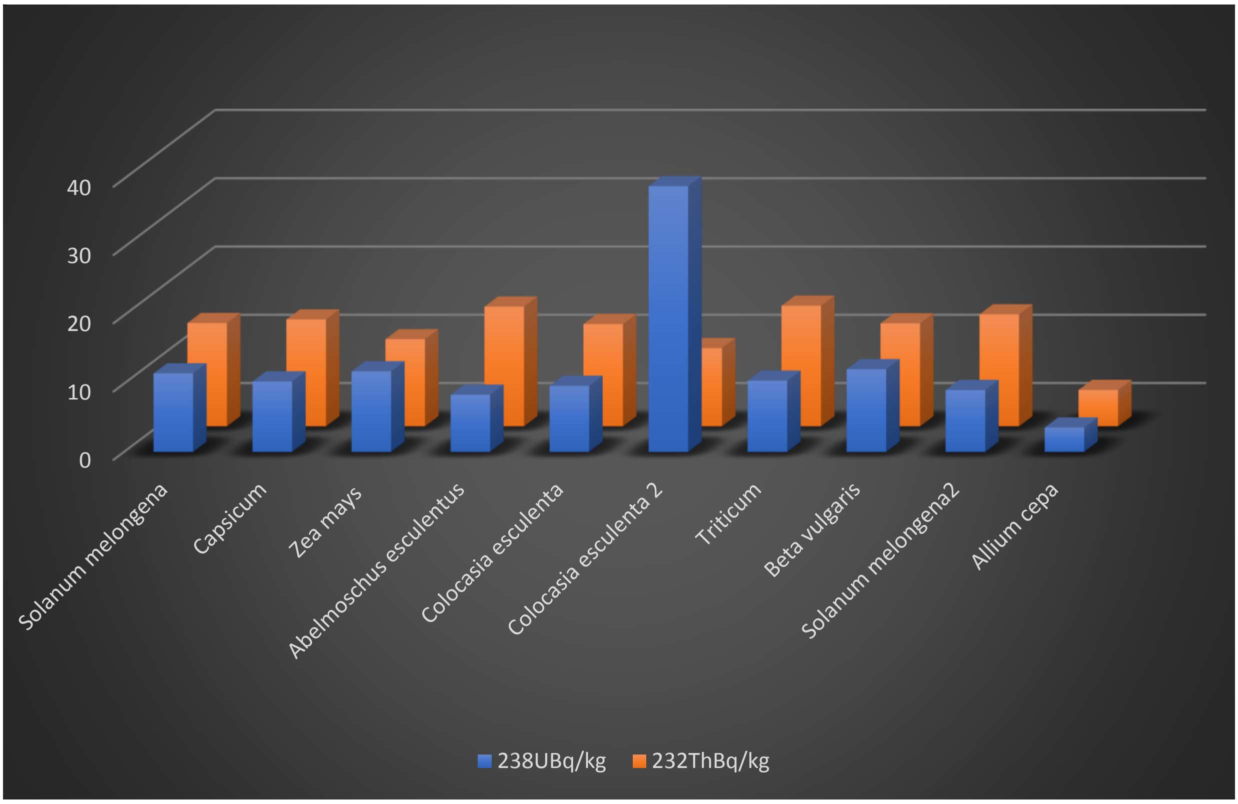

Fig. 2. The activity concentrations of ^{238}U and ^{232}Th in the collected clay soil samples.

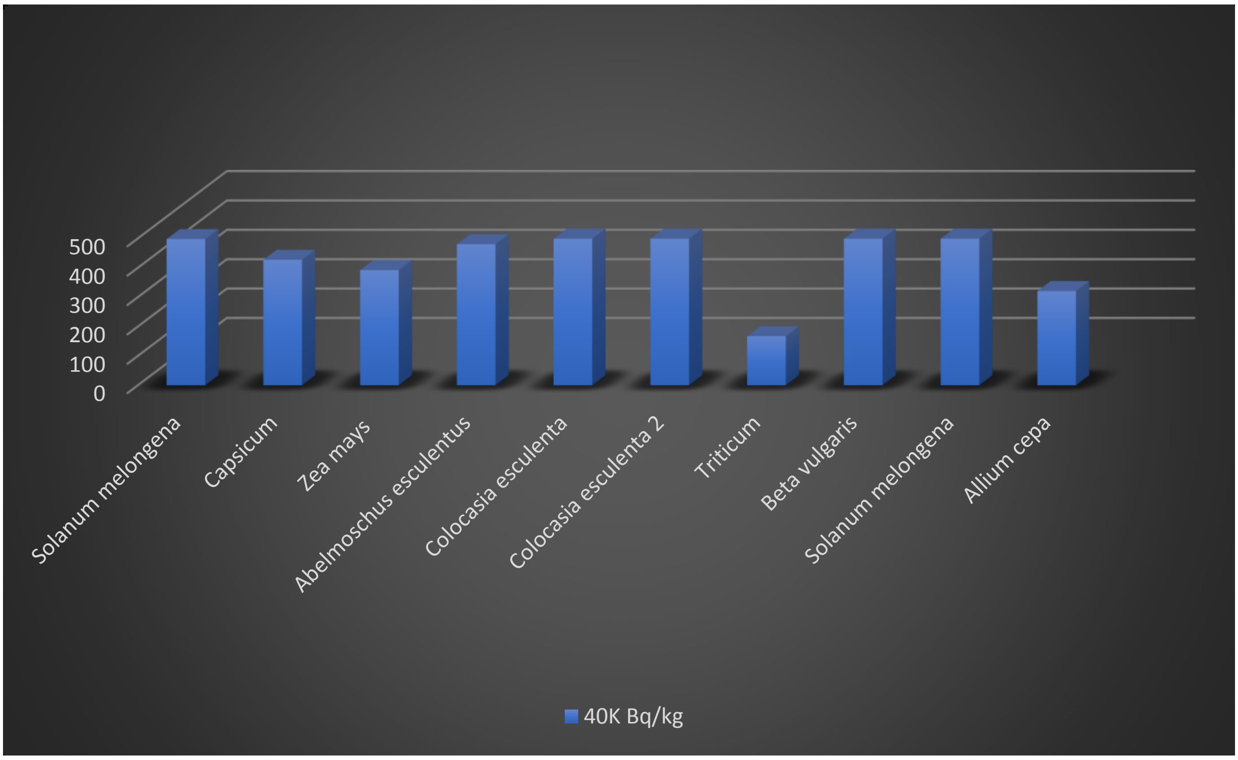

Fig. 3. The activity concentrations of ^{40}K in the collected clay soil samples.

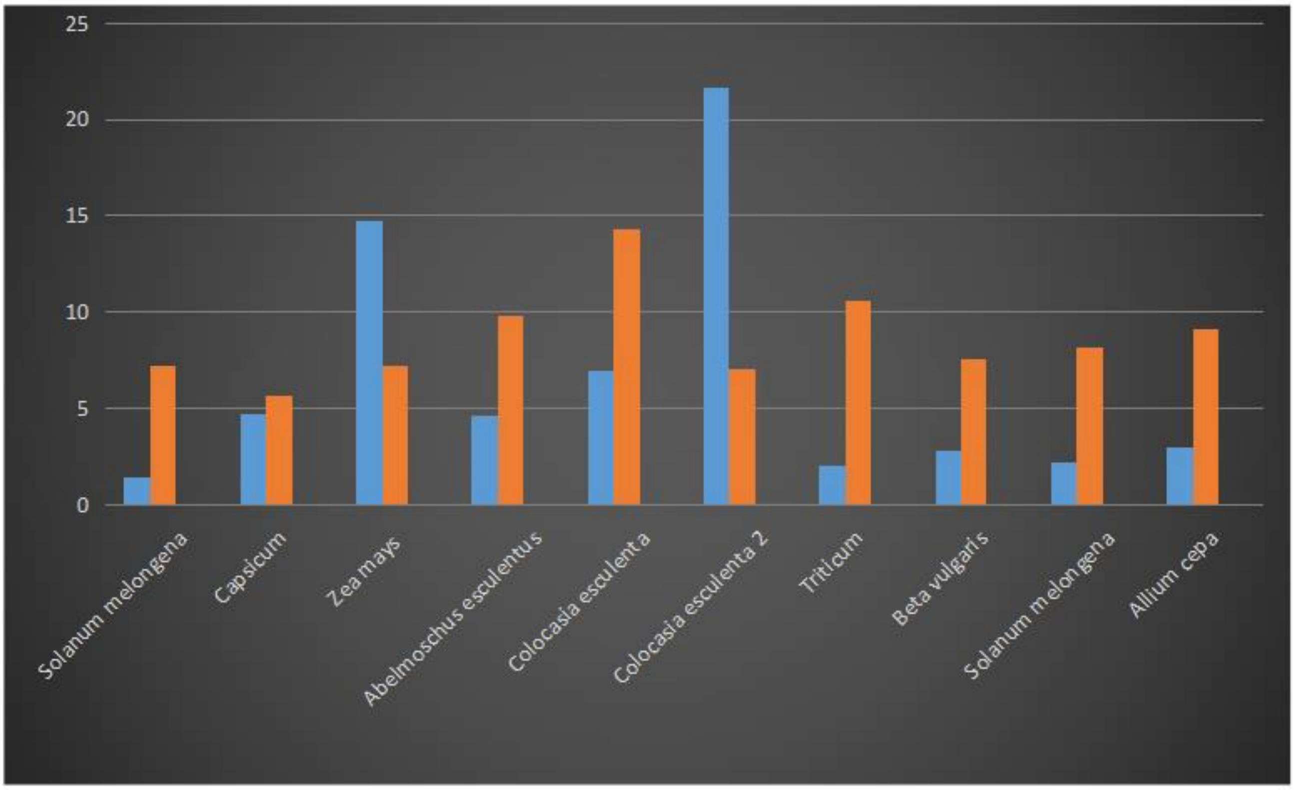

Fig. 4. The activity concentrations of ^{238}U and ^{232}Th in the collected clay Vegetables samples.

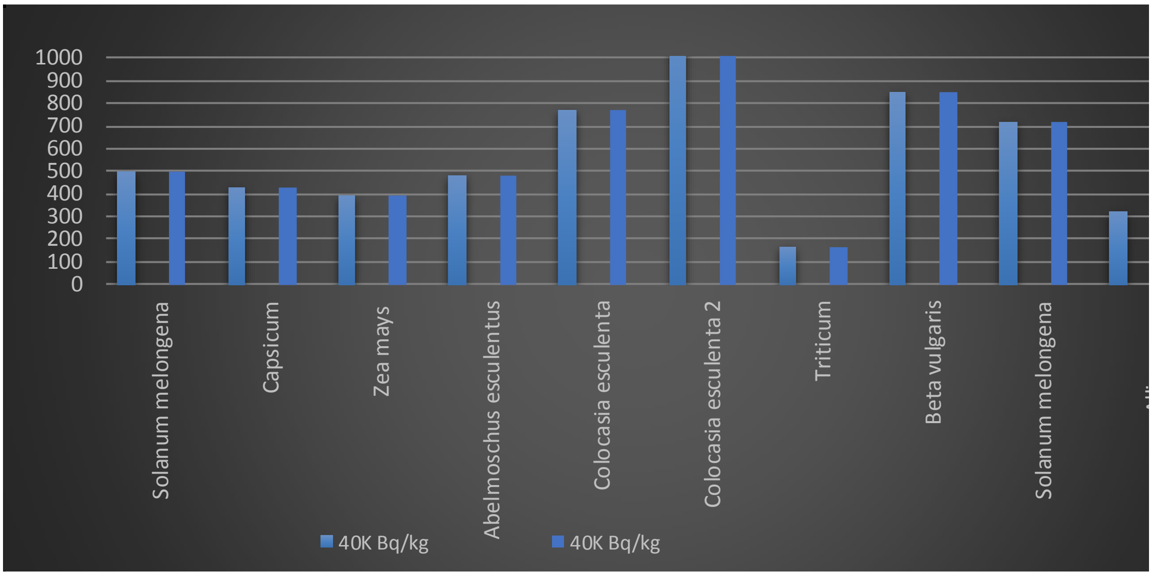

Fig. 5.The activity concentrations of ^{40}K in the collected clay Vegetables samples.

3.2. Soil-Plant Transfer factor

The transfer factors of 40K from soil to plant samples were calculated and tabulated in the Table 2. The transfer factors for ^{40}K the clay soil to plan transfer.

Table 2. The transfer factors for ^{40}K the Clay soil to plan transfer.

Clay soil plant	TFk
Solanum melongena	2.33
Capsicum	2.02
Zea mays	2.23
Abelmoschus esculentus	2.05
Colocasia esculenta	4.38
Colocasia esculenta2	8.54
Beta vulgaris	3.51
Solanum melongena2	3.02
Allium cepa	1.83

3.3. Sandy Soil Samples Results

The activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the collected sand samples were determined and illustreted in figures 6 and 7.The results obtained of ^{238}U, ^{232}Th and 40K were ranged between4 Bq.kg-1 and 24 Bq.kg-1, between 5 Bq.kg-1 and 25 Bq.kg-1and between 50 Bq.kg-1and 280 Bq.kg-1, respectively. The activity concentrations in the collected vegetables samples were lower than the detection limit of the detector for ^{238}U and ^{232}Th, while ranged between 38 Bq.kg-1 and 848 Bq.kg-1 for ^{40}K as shown figures 8 and 9.

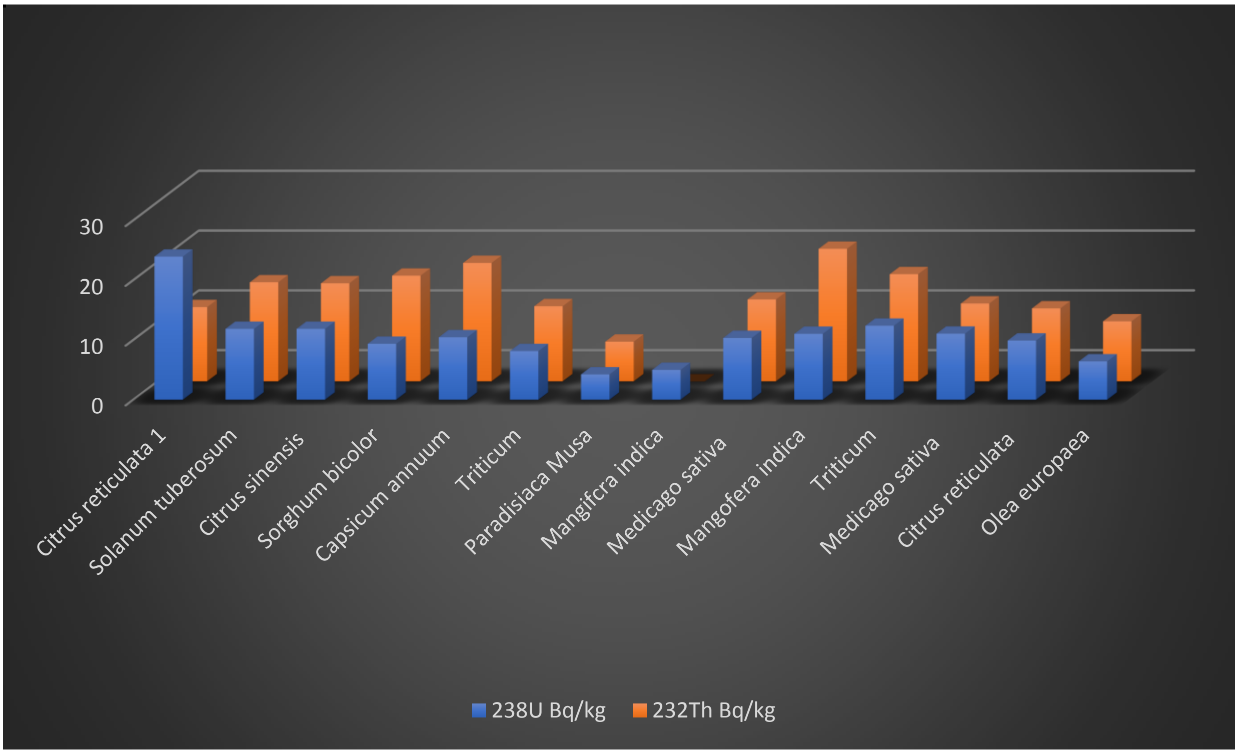

Fig. 6. The activity concentrations of ^{238}U and ^{232}Th in the sandy soil samples.

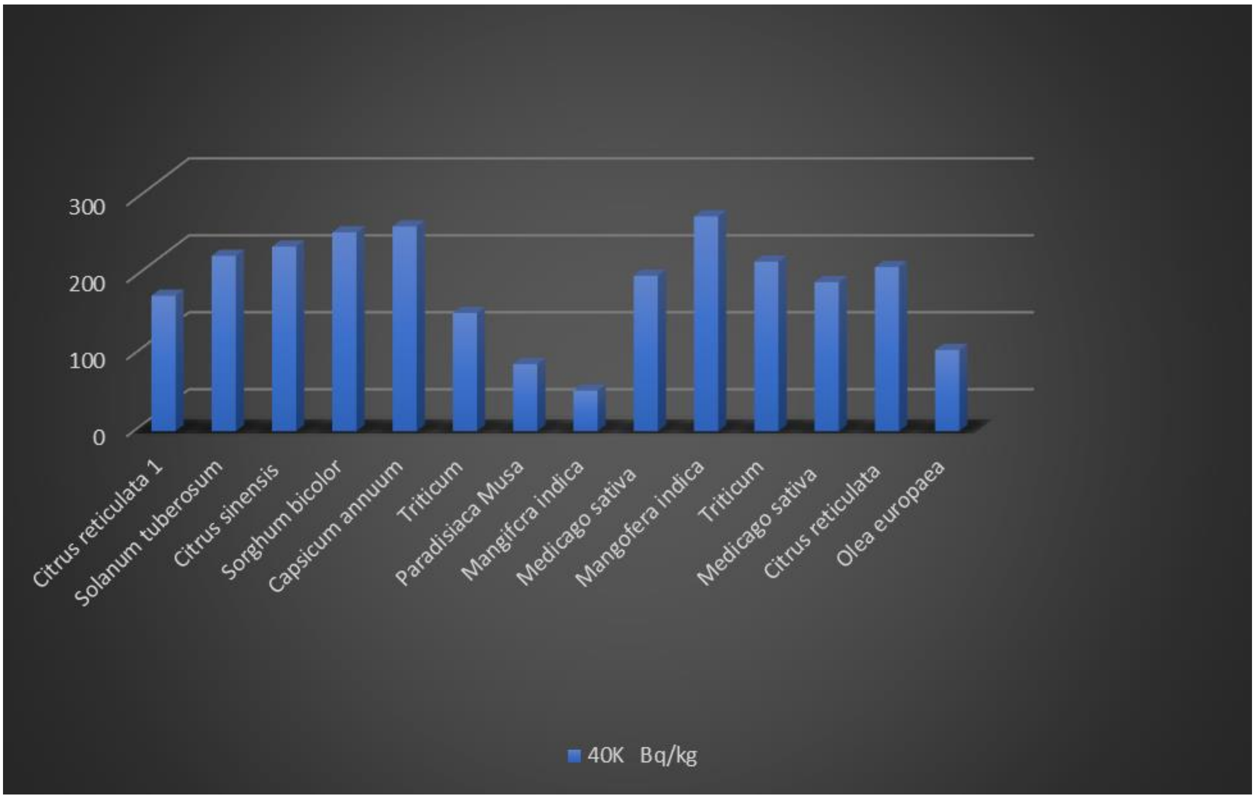

Fig. 7. The activity concentrations of ^{40}K in the soil samples.

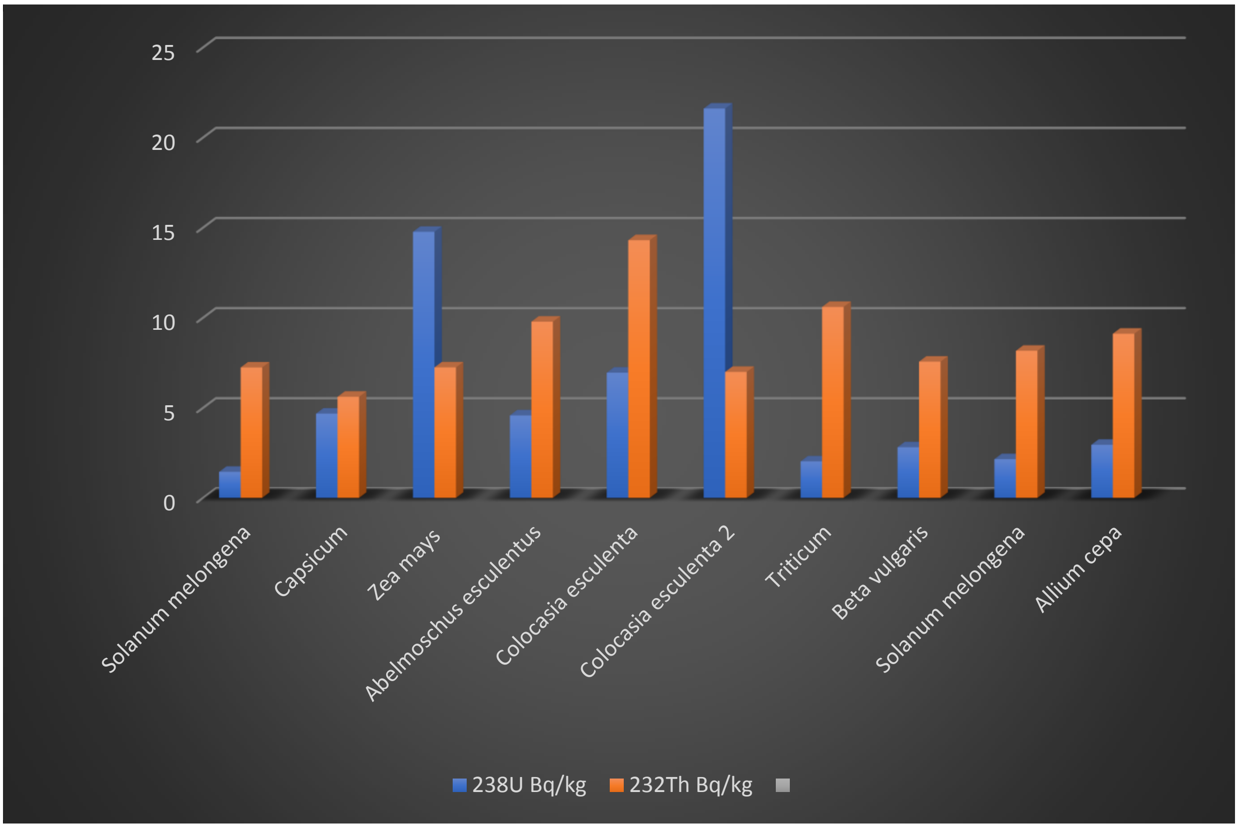

Fig. 8. The activity concentrations of ^{238} U and ^{232}Th in the plant sandy soil samples.

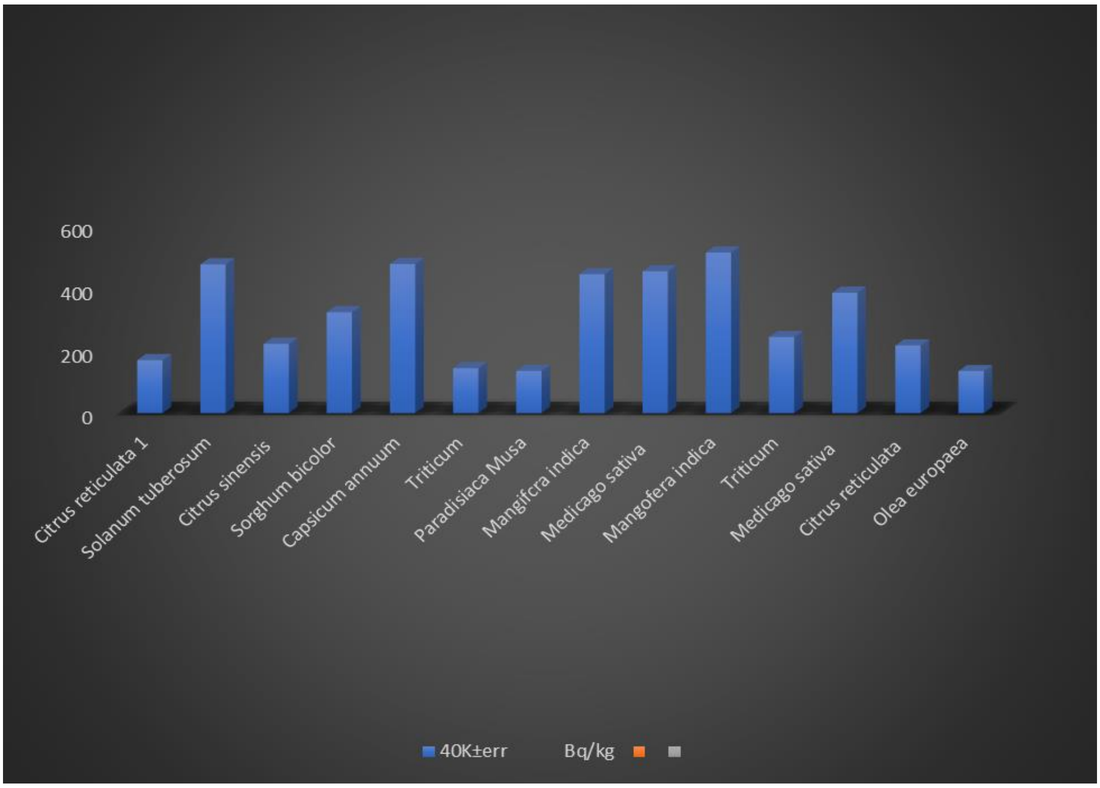

Fig. 9. The activity concentrations of ^{40}K in the collected Vegetables samples.

Radionuclide Soil-Plant Transfer Behaviour

The transfer factors of ^{40}K from soil to plant samples were calculated and tabulated in the Table 3.

Table 3. The transfer factors for ^{40}K the sandy soil to plan transfer.

Sandy soil plant	TFk
Citrus reticulata	0.96
Solanum tuberosum	2.09
Citrus sinensis	0.92
Zea mays	1.25
Triticum	0.63
Triticum	0.94
Paradisiaca Musa	1.55
Mangifera indica	8.41
Medicago sativa	2.24
Mangifera indica	1.84
Triticum	1.11
Medicago sativa	1.99
Citrus reticulata	1.01
Olea europaea	1.28

3.4. Neutron Activation Analysis Result

In the current study, neutron activation analysis was used to measure 31 elements in soil and plant material, and the results were reviewed. The elements in question are those that could be found using this technique, and they included both necessary elements for plant growth (such C1, K, Ca, Mn, Fe, Cu, Zn, Na, and Mo) and unnecessary elements in the present the study, measuring 31 elements in soil and plant plants were determined by neutron activation analysis and discussed. The elements concerned are those that could be detected by this method, which included both essential elements for plant growth, such as C1, K, Ca, Mn, Fe, Cu, Zn Na and Mo, and nonessential elements, such as , Sc, Ti, V ,Cr, Co, Ni, As, Se, Br, Sr, Zr, Cd, Sb, I, Cs, Ba, La, Ce, Au, Th and U .Samples of 14 agricultural plants including root crops, fruit vegetables green vegetables were collected from a total of five governmental farm fields (Table 4,5) The neutron activation analysis approach was also used to analyses two IAEA reference materials, SOIL-7 and V-10 HAY. Tables 4 and 5 present the results in relation to the reported values. 31 elements found in plants and soil were analysed. Table 4.5. All plant species had extremely high quantities of the key components for plants. The amounts of various components, including Ca, Na, Sr, La, and Sc, were dependent upon the species of plant. Some elements in plants showed relatively similar concentrations independent of the species of plant.

Table 4. Elemental composition of the soil samples..

clay Soil	Zea mays	Citrus reticulata	Solanum tuberosum	Abelmoschus esculentus	Colocasia esculenta	Colocasia esculenta2	Triticum
Ce	5.93E-2	888.9267	9.64E-1	1035.3	820.3989	23.73886	125.305
Se	5.81E-01	0.265759	7.51E-02	0.722653	0.087278	0	0.941262
Th	1.14E-03	4.6139	2.77E-02	5.393354	4.27036	0.561178	7.181258
Cr	1.09E-01	120.9338	4.18E-01	82.50649	79.49226	8.739124	102.2668
Hf	0.000674	5.426169	0.628227	5.024895	7.764288	0.347706	5.345178
Sr	1.98E-01	69.53174	1.13E-01	31.95017	0	16.63717	111.6951
Zr	2.03E-02	300.9417	2.47E-02	365.0399	370.409	0	195.0878
Cs	1.48E-02	1.151794	1.91E-02	1.102561	0.927571	0	1.2419
Ni	1.66E-01	131.5231	1.08E-01	302.7635	63.98786	28.25893	323.5384
Sc	1.18E-01	11.72846	4.94E-02	15.239	9.583502	0.272397	18.5535
Fe	4.21E-01	368.5229	5.18E-02	46868.62	30248.43	10640.37	56363.66
Zn	1.40E-02	11.576	8.44E-02	197.885	126.319	570.8145	233.109
Ta	6.37E-02	1.14313	4.79E-02	1.301123	0.714777	0	1.410187
Co	2.25E-2	19.76877	2.46E-2	24.63388	15.80897	2.014504	29.7511
Pb	0.001749	0.001285	3.74E-2	0.006841	0.003656	0.000605	0.010441
Cd	0.000113	10.60702	2.76E-02	16.10087	11.2714	0	20.64165
Ti	404.355	617.076	867.505	6292.047	3019.672	2172.87	887.566
Mg	572.542	383.102	315.7763	102.22	932.845	307.312	583.406
Na	285.933	183.947	459.115	395.274	368.182	182.148	701.783
V	22.77059	37.03144	54.17249	37.46881	28.46914	15.77792	54.17632
Mn	374.79	410.3264	487.621	463.3066	237.6233	215.1806	496.648
Ca	114.17	108.29	707.89	229.11	117.08	273.41	367.24
Sm	0.006487	0.774283	0.724792	35.20086	25.89503	3.080847	7.64023
Lu	0.352787	5.083659	4.758715	31.36487	22.29555	1.658236	0.447682
U	0.132873	0.582395	0.545169	13.22778	5.610494	4..959858	2.54537
Yb	12.83577	2.26145	2.1169	166.378	960.8996	118.3666	225.7765
Br	0.061649	1.362862	1.275749	106.474	5.812228	1.162743	9.88478
Sb	0.060385	0.388058	0.363253	9.195859	7.714855	0.868632	0
Na	0.146435	5.825395	5.45304	13.7243	172.5	405.543	14.66
K	9.649125	47.15014	44.13633	19.0531	17.1365	17.424	37.5116
La	0.037702	0.030323	0.028384	286.4344	236.4092	14.92687	32.40142

Table 5. Elemental composition of the plant's samples.

Sandy Soil	Triticum	Allium cepa	Capsicum annuum	Mangifera indica	Triticum	Medicago sativa	Citrus reticulata	Olea europaea
Ce	155.092	147.732	142.1202	71.8405	61.5816	91.8632	11.93764	9.6413
Se	0.611935	0.583269	0.753532	0.506768	0.23923	0.090755	1.110062	7.5007
Th	8.712955	8.964551	7.811462	5.901371	3.31091	4.522743	0.38965	2.7607
Cr	107.3667	113.9408	122.2978	74.8176	77.9545	74.0507	1.238943	4.18
Hf	6.581158	6.830572	9.385874	10.49314	8.45599	5.325106	2.584905	2.97
Sr	143.828	111.26	43.67778	105.2531	46.6936	134.9168	1.310714	1.1306
Zr	252.55	81.5687	305.7492	415.7295	266.655	191.4042	2.624389	2.4706
Cs	1.143815	1.845542	1.588364	0.820663	0.70461	0.838595	0.1169	1.9109
Ni	148.6745	215.7089	151.4704	187.3942	81.1573	0	2.839359	1.0805
Sc	20.69815	21.91389	19.5498	8.444474	7.06751	11.52078	0.954669	4.9409
Fe	51.03	57.87	62.64	26.22	61.9	35.068	0.935749	5.1708
Zn	29.003	23.411	26.561	104.342	90.359	145.704	9.737485	8.409
Ta	1.775416	1.703918	1.308572	0.877809	0.75892	0.945031	1.296966	4.7907
Co	32.8476	34.24936	32.41449	13.06451	10.7736	18.09398	1.386423	2.461
Cd	13.55288	42.43988	43.92246	42.62014	13.8165	19.30102	0.88935	2.7308
Ti	70.82	90.805	99.5753	9.540447	221.562	600.293	591.811	412.8
Mg	130.01	48.356	243.5514	42.49377	31.77	33.092	19.413	11.5
Na	75.926	28.492	44.5138	11.67732	32.404	24.889	31.703	62.7
V	47.84582	64.59648	93.057	0.01131	19.08938	44.66637	23.00657	16.896
Mn	40.97	22.9	101.6088	174.5824	129.24	11.81	138.38	88.1
Ca	203.3507	44.47033	118.2506	215.8832	72.56749	54.3339	12.33	109.7002
Sm	10.44781	8.724614	7.347203	4.146793	0.182555	4.986894	4.237044	0. 2578
Lu	1.945278	0.951456	0	0.28812	1.273653	0.171571	0.790648	0. 1425
U	3.909553	0	1.472064	0.555573	1.085431	1.136392	0.168718	0. 2339
Yb	228.5008	236.6324	199.9205	23.26247	112.8868	91.76159	120.5139	0.288167
Br	17.39748	12.76948	11.58297	6.048492	0.236473	1.450622	6.439984	0. 1327
Sb	0	0	0.186349	0	0.145188	0	0.511207	0. 2151
Na	166.25	121.71	193.77	86.615	62.829	77.933	86.76	0. 1652
K	707.332	289.37	135.84	192.33	89.707	105.72	196.9	10.71
La	45.08692	0	31.87218	19.81547	15.64473	22.39273	24.38393	0.8842

4. Discussion

The results of this study highlight the presence of natural radionuclides, including uranium-238 (^{238}U), thorium-232 (^{232}Th), and potassium-40 (^{40}K), in soil fertilized with phosphate fertilizers. These radionuclides contribute to the background radiation levels in agricultural environments and may have implications for soil quality, plant uptake, and human health.

The measured activity concentrations of ^{238}U, ^{232}Th, and ^{40}K were within internationally accepted safety limits, indicating that the application of phosphate fertilizers does not pose immediate radiological hazards. The computed radiological hazard indices, and excess lifetime cancer risk (ELCR), were all found to be below the global safety thresholds. This suggests that while these fertilizers contribute to soil radioactivity, the exposure risk remains minimal under current agricultural practices.

The study also examined the transfer of radionuclides from soil to plants, a key factor in assessing potential food chain contamination. The transfer factors (TFs) varied among different plant species and soil types. In general, the uptake of uranium and thorium by plants was low, confirming findings from previous studies that most crops do not readily accumulate these radionuclides. However, certain plant species, such as Nicotiana tabacum (tobacco), exhibited higher radionuclide absorption rates, consistent with its classification as a hyper accumulator. These findings suggest that plant-specific factors, soil chemistry, and environmental conditions play a crucial role in radionuclide mobility and uptake.

Additionally, elemental analysis using neutron activation revealed the presence of essential nutrients such as potassium (K), calcium (Ca), and magnesium (Mg), which support plant growth. However, the detection of heavy metals such as lead (Pb) and cadmium (Cd) raises concerns regarding long-term soil contamination and potential bioaccumulation in crops. These elements, if present in significant concentrations, could pose ecological and human health risks through prolonged exposure and food chain transfer.

While the findings indicate that current phosphate fertilizer use does not present an immediate health hazard, continuous monitoring is recommended to evaluate long-term effects. Future research should focus on refining soil remediation techniques, exploring alternative fertilizers with lower radionuclide content, and investigating agricultural management practices that reduce radionuclide uptake by crops. Additionally, strategies for mitigating heavy metal accumulation should be explored to prevent potential adverse environmental impacts.

So, this study underscores the need for a balanced approach to agricultural productivity and environmental safety. By implementing proper monitoring and risk assessment strategies, the use of phosphate fertilizers can be optimized to ensure both soil fertility and ecological sustainability while minimizing radiological and chemical risks.

The provided table 4 presents the concentrations of various elements in clay soil and their respective uptake by different crops, including Zea mays (corn), Citrus reticulata (mandarin), Solanum tuberosum (potato), Abelmoschus esculentus (okra), Colocasia esculenta (taro), and Triticum (wheat). The variations in element concentrations highlight important trends in soil chemistry, plant uptake, and potential environmental or agricultural implications.

1. Heavy Metals and Toxic Elements

Uranium (U): The highest uranium concentration is found in Solanum tuberosum (13.22 mg/kg), indicating a potential risk of bioaccumulation in potatoes. Other crops show lower uranium uptake, with wheat (2.54 mg/kg) and taro (4.96 mg/kg) containing moderate levels.

Lead (Pb) and Cadmium (Cd): The concentrations of Pb and Cd are generally low across all crops, with minor uptake seen in Solanum tuberosum (Cd = 16.10 mg/kg, Pb = 0.0068 mg/kg). These heavy metals are known contaminants in agricultural soils and should be monitored for food safety concerns.

Chromium (Cr) and Nickel (Ni): Both elements show significantly higher concentrations in Solanum tuberosum (Cr = 82.50 mg/kg, Ni = 302.76 mg/kg) and Triticum (Cr = 102.26 mg/kg, Ni = 323.54 mg/kg). These metals, while essential in trace amounts, can be toxic in high concentrations, affecting crop health and posing human health risks.

2. Nutrient Elements and Essential Minerals

Potassium (K), Calcium (Ca), and Magnesium (Mg): These elements are vital for plant growth. Solanum tuberosum has high Ca (707.89 mg/kg) and Mg (102.22 mg/kg) content, indicating its high nutrient demand. Wheat shows a significant potassium level (37.51 mg/kg), essential for crop yield and quality.

Iron (Fe): Found in exceptionally high concentrations in Solanum tuberosum (46,868.62 mg/kg) and Triticum (56,363.66 mg/kg), confirming that these crops are effective iron accumulators, which may have implications for biofortification strategies.

3. Rare Earth and Trace Elements

Cerium (Ce), Thorium (Th), and Hafnium (Hf): The highest concentrations of these elements are observed in Solanum tuberosum (Ce = 1035.3 mg/kg, Th = 5.39 mg/kg, Hf = 5.02 mg/kg) and Citrus reticulata (Ce = 888.92 mg/kg, Th = 4.61 mg/kg, Hf = 5.42 mg/kg). These elements are often associated with phosphate fertilizers, suggesting possible contamination pathways.

Strontium (Sr) and Zirconium (Zr): High Sr levels are found in Triticum (111.69 mg/kg), while Zr is abundant in Solanum tuberosum (365.03 mg/kg) and Citrus reticulata (300.94 mg/kg). These elements are typically linked to soil mineralogy and may influence plant uptake through soil-plant interactions.

4. Variability in Element Uptake Across Crops

Solanum tuberosum shows the highest accumulation for multiple elements, including U, Fe, Ca, Mg, Cr, Ni, and rare earth elements. This suggests that potatoes could be more prone to absorbing contaminants from the soil.

Triticum (wheat) exhibits high levels of Fe, Sr, and Ni, indicating its potential role in metal cycling in agricultural systems.

Citrus reticulata accumulates significant amounts of Ce, Th, and Zr, which may impact its long-term cultivation in contaminated soils.

5. Agricultural and Environmental Implications

The presence of radionuclides (U and Th) in edible crops suggests the need for long-term monitoring to assess potential radiological risks.

High levels of Fe, Ca, and Mg in certain crops suggest possible benefits for biofortification but may also indicate soil composition variations that influence nutrient availability.

Heavy metal contamination, particularly in Solanum tuberosum and Triticum, suggests the need for soil remediation strategies to minimize toxic metal accumulation in food crops.

The given table presents elemental concentrations in sandy soil and their uptake by different crops, including Triticum (wheat), Allium cepa (onion), Capsicum annuum (pepper), Mangifera indica (mango), Medicago sativa (alfalfa), Citrus reticulata (mandarin), and Olea europaea (olive). The variations in element concentrations highlight the differences in soil-plant interactions, nutrient uptake efficiency, and potential contamination risks.

1. Heavy Metals

Uranium (U): The highest uranium concentration is observed in Triticum (3.90 mg/kg), while other crops have significantly lower uptake. This suggests that wheat may have a higher tendency to absorb uranium from sandy soil, requiring further investigation into bioaccumulation risks.

Cadmium (Cd): The highest Cd concentrations appear in Capsicum annuum (43.92 mg/kg), Allium cepa (42.43 mg/kg), and Mangifera indica (42.62 mg/kg). These levels indicate potential risks of heavy metal accumulation in edible crops, which could have food safety implications (Yefeng Wang, (2019)).

Nickel (Ni) and Chromium (Cr): High levels of Ni are detected in Allium cepa (215.70 mg/kg) and Mangifera indica (187.39 mg/kg). Capsicum annuum also shows high Cr levels (122.29 mg/kg), suggesting that some vegetables have a greater affinity for metal uptake.

2. Essential Nutrients and Minerals

Potassium (K), Calcium (Ca), and Magnesium (Mg)

Potassium (K) is highest in Triticum (707.33 mg/kg), which is expected as wheat requires high potassium levels for optimal growth. (Fujuan Zang, 2024)

Calcium (Ca) is most concentrated in Mang/

ifera indica (215.88 mg/kg), which aligns with the calcium demand of fruit-bearing trees. (Wainwright & Burbage 1989)

Magnesium (Mg) is notably high in Capsicum annuum (243.55 mg/kg), reinforcing its essential role in plant metabolism. (Nazir Ahmed 1, 2023)

Iron (Fe): The highest Fe concentration appears in Capsicum annuum (602.64 mg/kg), indicating its strong uptake ability for this essential micronutrient It can be excess iron caused a drastic reduction in the accumulation of total dry mass in plant (Fánor Casierra-Posada, 2018).

3. Rare Earth and Trace Elements

Cerium (Ce) and Thorium (Th): Ce is highly concentrated in Triticum (155.09 mg/kg) and Allium cepa (147.73 mg/kg), while Th levels follow a similar pattern. The presence of these rare earth elements suggests possible associations with phosphate-based fertilizers or natural geological deposits.

Strontium (Sr) and Zirconium (Zr): The highest Zr concentration is found in Mangifera indica (415.72 mg/kg), while Sr is most prominent in Triticum (143.82 mg/kg). These elements, though less commonly discussed in agriculture, could influence plant structural development.

Scandium (Sc) and Ytterbium (Yb): High concentrations of Yb (236.63 mg/kg in Allium cepa) suggest that onions may have a higher uptake potential for certain rare earth elements.

4. Variability in Element Uptake Among Crops

Triticum (wheat) exhibits the highest levels of potassium, strontium, and uranium, suggesting it plays a significant role in soil nutrient cycling and potential contaminant accumulation.

Capsicum annuum (pepper) shows elevated concentrations of Cr, Cd, Fe, and Mg, making it both a nutrient-rich and metal-accumulating crop.

Mangifera indica (mango) demonstrates strong uptake of zirconium, calcium, and thorium, indicating its sensitivity to trace elements.

5. Agricultural and Environmental Implications Heavy metal contamination risks are evident, particularly for crops such as Capsicum annuum, Allium cepa, and Mangifera indica, which accumulate high levels of Cd, Ni, and Cr. Regular soil testing is recommended to prevent long-term contamination.

Essential nutrient availability appears adequate, with high K, Ca, and Mg levels supporting crop growth. However, the presence of rare earth elements (Ce, Th, Zr) raises concerns about potential bioavailability and environmental persistence.

Food safety concerns arise from crops with high Pb, Cd, and U concentrations. Additional research on metal bioavailability and human health impact assessments would be beneficial.4.

4. Conclusion

This study provides an in-depth assessment of natural radioactivity and elemental composition in soils fertilized with phosphate fertilizers in Delta Egypt. The findings indicate that the activity concentrations of naturally occurring radionuclides, including ^{238}U, ^{232}Th, and ^{40}K, are within globally accepted safety limits. However, continuous monitoring is recommended to ensure long-term environmental and human safety and Regular washing is necessary because additional fertilizer frequently causes an accumulation dose rate from heavy metal and radionuclide-active material. The soil-to-plant transfer of radionuclides varies across different crops, with some plants exhibiting higher accumulation tendencies. The presence of essential nutrients such as potassium, calcium, and magnesium supports plant growth, but trace amounts of heavy metals, including lead and cadmium, highlight the need for careful soil management. While phosphate fertilizers contribute valuable nutrients to agricultural soils, they also introduce trace levels of radionuclides and heavy metals. Implementing sustainable agricultural practices, such as controlled fertilizer application and soil remediation strategies, can help mitigate potential contamination risks. Future research should focus on improving radionuclide mobility assessments, developing effective soil amendments to reduce metal uptake, and evaluating long-term radiological impacts on ecosystems.

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