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A Study of the Effect of Sewage Water Irrigation on the Elemental Composition of Soil and Plants Using Neutron Activation Analysis

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Instrumental neutron activation analysis (INAA) has allowed performing a complete characterization of the chemical composition of different soil and plant samples. Soil and plants irrigated by Nile River water and by sewage water were irradiated in the second Egyptian reactor (ETRR-2) and measured by a gamma spectroscopy system to assess the elemental concentrations in all test samples. The obtained results in soil show that there are high concentrations of some elements more than 500 ppm like Mg, K, Cl, Ca, and Na but some other elements have low concentration below 500 ppm like Mn, Al, and Fe. Trace elements have concentrations less than 1 ppm. The resulting data also showed high concentrations of some elements in soil irrigated with sewage water compared to soil irrigated with Nile River water for some elements such as Ti, Mg, Mn, Na, V, K, Al, Cl, Ca, Cr, Fe, Ce, and Zn, respectively. By comparing our results with other studies in soil, the concentrations of elements in the present work were found to be more than other studies in soil from different countries in both sample types irrigated by Nile River water or sewage water.

Keywords: Neutron activation analysis, sewage water irrigation, Nile River water irrigation, gamma spectroscopy, soil, and plants

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INTRODUCTION

Freshwater scarcity is currently the most pressing problem as the population continues to grow and freshwater becomes less important, which is why some farmers resort to irrigating agricultural land with wastewater. In addition, wastewater is the main source of many trace elements and microelements necessary for plant growth such as nitrogen, phosphorus, and potassium, which are important elements for soil and plants. The influx of nutrient-containing wastewater from watercourses into the soil rapidly leads to an increase in nutrient content and as a result, the process of time accumulation and the continuation of the irrigation process exacerbate environmental damage, depletion of dissolved oxygen, and extinction of aquatic species, which represent threats to public (Ahmed et al., 2023; Muhammad et al., 2023). Therefore, the use of wastewater for irrigation provides a great incentive for farmers in developing and low-income countries to reduce agricultural production costs by about 10-20%. On the other hand, due to the great industrial revolution of modern times, the proportion of radionuclides in wastewater is increasing as factories release waste from production processes in various forms (Jaramillo and Inés, 2017; Jiménez, 2006; Kabata-Pendias and Pendias, 2001; Khalid et al., 2022). This increases the proportion of radionuclides in the soil and has long-term harmful effects, as a high proportion of these radionuclides are transferred to plants and vegetables and high concentrations of radionuclides in the soil are associated with plant growth (Hiwa et al., 2019). Nuclear methods have proven to be very useful in environmental research for two main reasons: (1) the use of radioactive tracers to explain the behavior of specific entities in an environmental system and (2) the use of nuclear techniques to determine the concentrations of elements in the example environment. This is generally limited to the total concentration of a particular element, without distinguishing between the different chemical forms (Morrison and Nadkarni, 1973; Mahmoud et al., 2005). Instrumental neutron activation analysis (INAA) is widely used in soil samples due to its high accuracy and sensitivity (El-Taher et al., 2003; El-Taher, 2010). Trace elements present in soil play an important role in plant physiology, geochemical differentiation studies, and even mineral exploration. Some authors have used activation techniques to determine trace elements in soil, but the data are rather sparse and incomplete. Most analytical methods for determining the total content of trace element have serious disadvantages, such as lack of reliability and being expensive and time consuming (El-Taher and Mohamed, 2014). However, neutron activation analysis is useful when determining elements in many samples. Due to its

intrinsic sensitivity, it is suitable for the analysis of trace elements at concentrations below the detection limit of conventional methods (El-Taher, 2010). The high resolution of high purity germanium detectors (HPGe) for gamma spectroscopy increases the selectivity of this method and thus expands the possibilities for determining multiple elements through nondestructive analysis. However, interference caused by the complexity of the gamma spectrum of multielement soil samples can be overcome by careful selection of irradiation and decay times. The elemental composition of numerous Egyptian soils was determined, with particular emphasis on soluble elements that influence soil properties important to plants. As for trace elements, their total content in some Egyptian soils has been determined and linked to their formation and environment (El-Taher, 2010; El-Taher, 2007). The INAA k_0-standardization method was implemented in the second research reactor in Egypt using pneumatic devices for rapid irradiation of rabbits and several manual irradiation stations selected for short and long irradiation, respectively. The neutron flux parameters (f and α) at each site were determined using the Zr-Au arrays as neutron flux monitors. To validate the data, carbon reference materials NIST 1632c and IAEA-Soil 7 were analyzed and good agreement between experimental values and certified values was achieved (Mohamed et al., 2011).

- The transport and accumulation processes of minerals are influenced by the chemical properties of the elements and compounds (e.g., solubility and bioavailability), environmental factors (soil properties, climatic conditions, distance from pollution sources, and agricultural practices such as fertilization, etc.), and plant survival mechanisms (Markert, 1999; Klink et al., 2013). Since the selected medicinal plants are vascular in nature, the transfer of elements from the soil can be considered as one of the main ways of their accumulation in different compartments of the plant (Wei et al., 2020). More in-depth research is needed for the relationships between soil content and the distribution of elements between plant organs. Due to the threat of sewage, a large percentage of human-generated wastewater is discharged into rivers, oceans, and the environment without treatment, resulting in improved plant growth, but epidemics are constantly increasing, and the mortality rate is also increasing. Up to 50% of deaths of children worldwide are due to poor water quality (Li Lin et al., 2022). The cycle of nonbiological transport of radionuclides in the biosphere of the cycle of living organisms includes different main phases:
- filling material during irrigation,
- transport (transfer of various nuclides and elements into the soil),
- deposition and concentration during photosynthesis. The transport process is the main source of the presence and concentration of nuclides entering the life cycle, such as the naturally occurring uranium (^{238}U), thorium (^{232}Th), and potassium (40K) isotopes, which occur in the natural environment (Meltem et al., 2008).

As already mentioned, the enormous modern industrial revolution has led to a steady increase in the proportion of radionuclides, heavy elements, and trace elements in the environment in general and in wastewater in particular, which represents an accumulation of Renaissance industrial waste in various forms and natural human sewage waste. The article addresses the transfer of elements from sediments to plants and from roots to leaves, as well as the effects of anthropogenic pollution on wetland ecosystems in thermal zones. It is found that the element content decreases in the bottom sediments of aquatic plants, except for the halogens (Cl, Br, and I), which are 5 to 100 times higher in plants than in sediments. An elevated level of As, Mo, and Sb in some soil and sediment samples most likely indicates anthropogenic pollution. Continuous monitoring of the same area is recommended (Pavel et al., 2017). Results of instrumental neutron activation analysis of selected element concentrations in different soil samples near industrial areas in Tirupati, India, are presented. A total of 14 elements were determined including Sm, La, Cr, Co, Zn, Cs, Ce, Th, Rb, Na, K, Sr, Fe, and Eu. The induced activities were measured nondestructively by gamma spectroscopy with a high-purity germanium (HPGe) detector (Naidu et al., 2003).

MATERIALS AND METHODS

Area of Study and Samples Preparation

The samples were collected (eight soil and plants irrigated by sewage water and eight of soil and plants irrigated by Nile River water) from an area at the borders of El-Sharkia and Al-Qalyubia Governorates; see Figure (1). Note: the plant samples collected were grown in the same soil that was measured, as follows.

A. Several six samples of plants (taro, strawberry, and corn) were collected, as well as a number of two soil samples from both sides of the waste waterways, at a distance of more than 20 km along the Belbeis drainage, which is a fertile agricultural land where the cultivation of fruits and vegetables is widespread. A number of six samples of plants, two from both taro, strawberry, and corn, were collected, as well as a number of two soil samples from both sides of a canal, which is a branch stream of one of the tributaries of the Nile River, in a distance of more than 20 km along the riverbed, which is a fertile agricultural land, where the cultivation of fruits and vegetables is widespread and samples were prepared and processed in several steps:

- The drying process of the samples is done at room temperature for one week,
- Drying is done in the convection oven at a temperature of 100°C for 24 hours,
- Samples are crushed,
- They are sieved until the size is around the particle size of reference material (≤71 µm),
- The weight of each sample is set at 250 mg to be irradiated.

Study Samples and Influencing Environmental Factors

The survival period of plants in the soil and the number of irrigation times, as well as the method of irrigation, were mentioned in Table 1. The type of irrigation in all test samples is immersion and the survival periods for taro, strawberry, and corn ranged from 10 to 12, 7.0 to 8.0, and 3.5 to 4.0 months, respectively. Table 1 shows all these factors.

Instrumental Neutron Activation Analysis

The determination of trace elements in sixteen soil and plant samples was carried out in the laboratory of the second Egyptian research reactor (ETRR-2). About 250 mg dry weight of each sample was packaged separately in high-purity polyethylene vials and subjected to NAA protocols detailed in previous reports (Campbell et al., 2000). A series of subsamples enclosed in polyethylene vials were irradiated for five minutes (short time) with a well-thermalized neutron flux (3.4×10^{11} n cm^{-2} s^{-1}) in the pneumatic system of ETRR-2 to determine the elements, which could be detected by measuring the short-lived radionuclides. The samples under investigation were subjected to two irradiation/counting schemes, short-time irradiation and long-time irradiation. To determine an element producing long-lived radionuclides upon neutron irradiation, the scheme involves 1 h irradiation at thermal neutron flux of 1.8×10^{14} n cm^{-2} s^{-1} at the irradiation site using a manually loaded sample holder in the ETRR-2. The irradiated samples were counted twice after periods of approximately five and twenty-five days. For each sample set, a flow of Zr-Au 0.1% Al and a reference material (IAEA-153 for trace elements in infant milk) are monitored (Hamidatou et al., 2014). They were irradiated to estimate the neutron flux parameters or as internal quality control materials. The activities induced in the samples, flux monitors, and reference materials were measured using well-calibrated HPGe (EG and G Ortec) with 100% relative efficiency and resolution 2.1 keV at the gamma energy rays line 1332.5 keV of ^{60}Co. The gamma-ray spectra obtained were analyzed using Gamma Vision software. The concentrations of the detected elements were determined using the k_0-standardization method (De Corte and Simonits, 2003, Lin X et al., 2006).

Flounce Rate Monitor

A set consisting of approximately 20 mg of a 0.127 mm thick Zr foil (Braunschweig, purity 99.5%) together with 2 mg of the certified reference materials CRM IRMM-530 'Al–0.1%Au' (1.0 mm wire) was packed in a polyethylene capsule. The nuclear data of the three nuclear reactions ^{197}Au (*n*, *γ*) ^{198}Au and ^{94,96}Zr (*n*, *γ*) ^{95,97}Zr are summarized in Table (2) (Mohamed et al., 2011).

Gamma-Ray Spectroscopic System

After irradiation, induced activity of the samples and reference materials was measured using the coaxial p-type HPGe detector operated using gamma vision software, which has a relative efficiency of 100% and resolution of 2.1 keV, at 1332.5 keV for ^{60}Co gamma-ray energy line. The gamma-ray acquisition system consists of the Maestro multi-Channel Analyzer (MCA) emulation software card, coupled to the detector via electronic modules, all manufactured by Ortec company, Inc., USA. The knowledge of the full-energy peak efficiency is essential since it must be known for calculation of the element concentration. The HPGe detector was calibrated using two types of calibration, including energy and efficiency calibrations. The energy and efficiency curves were fitted using several suitable point sources (^{152}Eu and ^{137}Cs), which were placed at the same distance from the detector at which the samples were measured. Table 3 includes the radioisotope sources used in energy and efficiency

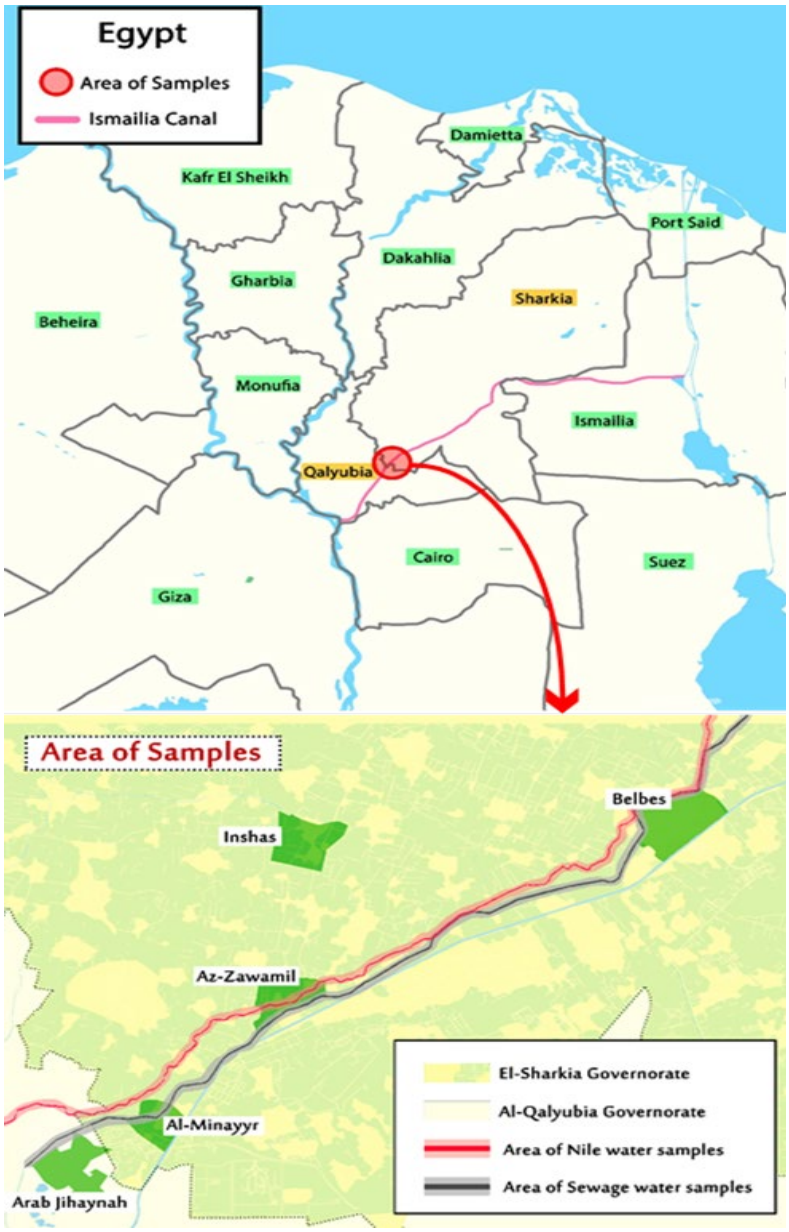

Figure 1. A map showing the places of the sample collection (soil, plant, and water samples).

Table 1. Environmental factors affecting the concentration of elements.

Plant type	The survival periods in months	Irrigation method	Number of irrigations in months
Taro	10 – 12	Immersion	11
Strawberry	7.0 - 8.0		7
Corn	3.5 - 4.0		4

Table 2. Nuclear data used in neutron flux characterization.

Nuclear reaction	Q_0 (s, %)	$\bar{E}_r$ (eV)	$t_{1/2}$	E_γ (keV)	$k_{0,Au}$ (s, %)
^{94}Zr (n, γ) ^{95}Zr	5.31 (3.3)	6260	64.02 day	724.2 +756.7	2.00E-4 (1.2)
^{96}Zr (n, γ) ^{97}Zr	251.6 (1)	338	16.74 h	743.4	1.24E-5 (0.3)
^{197}Au (n, γ) ^{198}Au	15.7	5.65	2.695 day	411.8	1

calibrations and their initial activity (remark: the activities were corrected at the time measured). It means that the true coincidence effects are negligible on these measurements (Figure 2).

Determination of the Flux Parameters

The k_0-standardization method can be interpreted as an absolute standardization with substitutions of the absolute nuclear data for experimentally determined k_0-factors (Mohamed et al., 2011). This eliminates systematic errors due to unreliability and uncertainty of nuclear data, on the condition that the experimentally determined k_0-factors are accurate. The elemental concentrations of the elements ρ_a, ppm, in samples were calculated with the following equation (Mohamed et al., 2011), and the nuclear reaction ^{197}Au (n,γ) ^{198}Au was chosen as the flux monitor:

$$\rho_{a,ppm} = \frac{A_{SP(a)}}{A_{SP(Au)}} \cdot \frac{1}{K_{0(a)}} \cdot \frac{f+Q_{0(Au)}}{f+Q_{0(a)}} \cdot \frac{\varepsilon_{p(Au)}}{\varepsilon_{p(a)}} \cdot 10^6 \quad (1)$$

where α is an analyst sample, Au is a co-irradiated comparator (monitor), A_{sp} is the specific activity, ε_p is the absolute full-energy peak efficiency of the detector for the measuring γ-line including correction for gamma-attenuation, $f = \phi_{th}/\phi_e$ is the neutron flux ratio, and $Q_0 = I_0/\sigma_0$ is the resonance integral to 2200 m s^{-1} (n,γ) cross-section, corrected for pulse losses. The specific activity (s^{-1} g^{-1}) is given by

$$A_{Sp} = \frac{N_P/t_m}{SDCW} \quad (2)$$

where N_p is the number of counts in the full-energy peak, corrected for pulse losses (dead time, random and true coincidence), t_m is the measuring time (s), S is the saturation factor ($1-e^{-\lambda t_{irr}}$), D is the decay factor ($e^{-\lambda t_d}$), t_d is the decay time, C is the measurement factor ($1-e^{-\lambda t_m}$) (with t_m in the same units as $T_{1/2}$), W is the weight of irradiated element (g), λ is the decay constant = $(1n2)/T_{1/2}$, $T_{1/2}$ is the half-life, and t_{irr} is the irradiation time. For the determination of the neutron flux parameters in the two sites of the rabbit system, two neutron flux monitor sets, one on each site, were irradiated for 30 min. The induced radioactivity was measured using the well-calibrated HPGe detector after about 2 and 5 days for Zr foils and once after about 4 days for Al–0.1%Au wires.

Estimates of *f* and *α* in both sites of the rabbit system calculated from the bare Au–Zr sets are shown in Table 3. It is found that the neutrons at the irradiation site no. 2 of the rabbit system were found to be well thermalized with *f* = 255 ± 12 and *α* = 0.206 ± 0.07. Highly thermalized neutrons are advantageous to k_0-NAA in three aspects (Markert et al., 2015): (1) because the Q_0-factor will play little role in this case, reliable k_0-NAA can be expected (in condition of reliable k_0-values) also for *(n,γ)* reactions with large Q_0-values, which may have larger uncertainties, (2) the k_0-NAA will have a large uncertainty reduction of the flux parameters α and *f*, and (3) consequently, fast neutron induced reaction interferences in NAA are negligible or much reduced. On the other hand, it is very difficult to perform epithermal or fast neutron activation analysis at this site. Site no. 1 of the rabbit system is less thermalized than Site no. 2, with average *f* = 69 ± 3 and average α = 0.109 ± 0.03 so epithermal and fast neutron activation analysis can be carried out to a small extent. Due to different locations relative to the reactor core, the available neutron fluxes in the pneumatic irradiation positions differ substantially, so that different irradiation demands can be satisfied.

For estimation of the neutron flux parameters as well as their vertical distribution in the selected positions of irradiation grid facility, one side (north or south) of each sample holder was filled with the irradiation Al cans (containing the Au–Zr sets) and irradiated for one hour. The other side was left empty except shells no. 1 and 4 to be compared with the totally filled side. The vertical distribution of *f* parameter in the two irradiation positions was investigated over the whole length of the sample holders. The *f* parameter has a minimum value near the center of the sample holder length and then increases (neutrons are more thermalized) with further moving up or down. This can be attributed to the effect of the path length of neutrons in the moderator medium. At the highest part of the sample holder, a sharp decrease in the values of *f* parameter occurred. This pattern can be attributed to the material composition and partial insertion of the control rod. To be more conservative in avoiding the effect of the control rods, shell no. 1 (north and south) of each sample holder was chosen for irradiation purposes in k_0-NAA.

RESULTS AND DISCUSSION

Verification of the k_0-Methods in INAA Procedures

The neutron flux parameters used in k_0-INAA, *f* and α, were estimated using the bare triple monitors method, according to the procedure described by Mohamed et al., 2011. In this study, Zr–Au flux monitor sets were irradiated together with each batch of the samples. The generated values of the neutron spectrum parameter, α and *f*, as well as the measured detection efficiencies were used to

calculate the concentration of the elements according to the k_0-INAA procedures established at ETRR-2 (Mohamed et al., 2011). To verify the determined parameters and the HPGe detector performance as well as the whole analysis procedure, certified reference materials IAEA soil 7 from International Atomic Energy Authority (IAEA) were irradiated together with the samples and measured with the HPGe detector used under the same conditions as internal quality control materials. In this case the certified reference materials IAEA Soil 7 have been measured as unknown samples and the concentration of elements was calculated by the k_0-method to validate this method in calculations in all unknown other samples. The results obtained showed that the relative deviation of the most determined concentration from the reference values was less than 12% while the other values were below 20% (Table 4). This relative agreement between the measured elemental concentrations of the internal quality control samples with reference elemental concentrations values was an indication of validity of the applied procedures (Mohamed et al., 2011).

Elemental analysis of soil samples

The soil samples studied using the neutron activation analysis instrument showed the presence of about 33 major and trace elements in both soils irrigated by sewage or by Nile River water, as presented in Table 5. The obtained results show that about 12 elements are either essential or beneficial to the human organism at certain concentrations, and these elements are Ca, Cl, Co, Cr, Fe, K, Mg, Mn, Na, Se, V, and Zn. Meanwhile, about six elements are potentially toxic which are Al, As, Ba, Rb, Sb, and Sr, and the rest of the elements have no biological functions (Prapamon et al., 2017). The data obtained shows that there are high concentrations of some elements in soil irrigated by sewage water rather than soil irrigated by Nile River water (Table 5). In the last table there are high concentrations of some elements in the soil irrigated by sewage water, which are 7136±199, 14605±825, 822±8.7, 6407±127, 134±2.0, 22289±2741, 56219±191, 210.22±1.0, 19236±799, 126.7±1.0, 13886±49, 52.38±0.80, and 91.43±2.75 ppm for Ti, Mg, Mn, Na, V, K, Al, Cl, Ca, Cr, Fe, Ce, and Zn, respectively. Meanwhile, the concentrations in soil irrigated by Nile River water are 11503±54, 8201±376, 588.6±8.7, 4127±95, 79.33±17.53, 7597±269, 30882±114, 120.6±0.34, 12671±214, 57.23±3.0, 9389±190, 38.19±1.32, and 274±4 ppm for the same elements, respectively (Table 5). The high concentrations of some elements in soil irrigated by sewage water were formed due to repetition of irrigation process over many years; consequently, the elements are accumulated in this soil. Some of these concentrations may be transferred to plants and then to animals and finally to the human body.

Elemental Analysis of Plant Samples

Twelve plant samples were irradiated, four samples from each type of plants, i.e., two samples from taro, strawberry, and corn plants irrigated by sewage water and two samples from the same plants but irrigated by Nile River water. The obtained results show that there are high concentrations of some elements (more than 500 ppm) like Mg, K, Cl, Ca, and Na but some other elements have low concentration (below 500 ppm) like Mn, Al, and Fe as well as trace elements that have concentrations less than 1 ppm, (Tables 6, 8). To study the effect of irrigation process by sewage water on both soil and plants (taro, strawberry, and corn), two elements, potassium (K) and calcium (Ca), were selected as major nutrients for plants, while chromium (Cr) and cobalt (Co) were selected due to their high toxicity to show the effect of irrigation by sewage water compared to irrigation by Nile River water. Figures (3) and (4) are the schematic diagrams to show this effect on both soil and different plants (for potassium and calcium). Figure (3) illustrates that the concentration ratios of K between samples irrigated by sewage water and Nile River water increased due to sewage water irrigation by 2.93, 1.29, 2.61, and 1.39 in soil, taro, strawberry, and corn, respectively. Meanwhile, Figure 4 illustrates that the concentration ratios of Ca between samples irrigated by sewage water and Nile River water increased due to sewage water irrigation by 1.52, 1.15, 1.33, and 1.03 in soil, taro, strawberry, and corn, respectively. Figures (5) and (6) are the schematic diagrams to show this effect on both soil and different plants (for chromium (Cr) and cobalt (Co)). Figure (5) illustrates that the concentration ratios of Cr between samples irrigated by sewage water and those irrigated by Nile River water increased due to sewage water irrigation by 1.21, 1.19, 2.03, and 1.13 in soil, taro, strawberry, and corn, respectively. Meanwhile, Figure (6) illustrates that the concentration ratios of Co between samples irrigated by sewage water and those irrigated by Nile River water increased due to sewage water irrigation by 1.49, 3.52, 1.13, and 1.03 in soil, taro, strawberry, and corn, respectively.

Table 3. Radioisotope sources used in energy and efficiency calibrations.

Isotope	Energy	Intensity, %	Half-life time, $T_{1/2}$	Initial activity, mCi
^{152}Eu	121.8	28.60	14y	0.9864 (manufactured on 15 July 1999)
	244.7	7.50		
	344.3	26.50		
	411.1	2.20		
	444.0	3.10		
	778.9	12.90		
	867.3	4.20		
	964.0	14.60		
	1085.8	10.00		
	1112.0	13.60		
	1408.0	21.00		
^{137}Cs	661.7	86.00	30.2y	0.9998 (manufactured on 15 Aug. 1999)

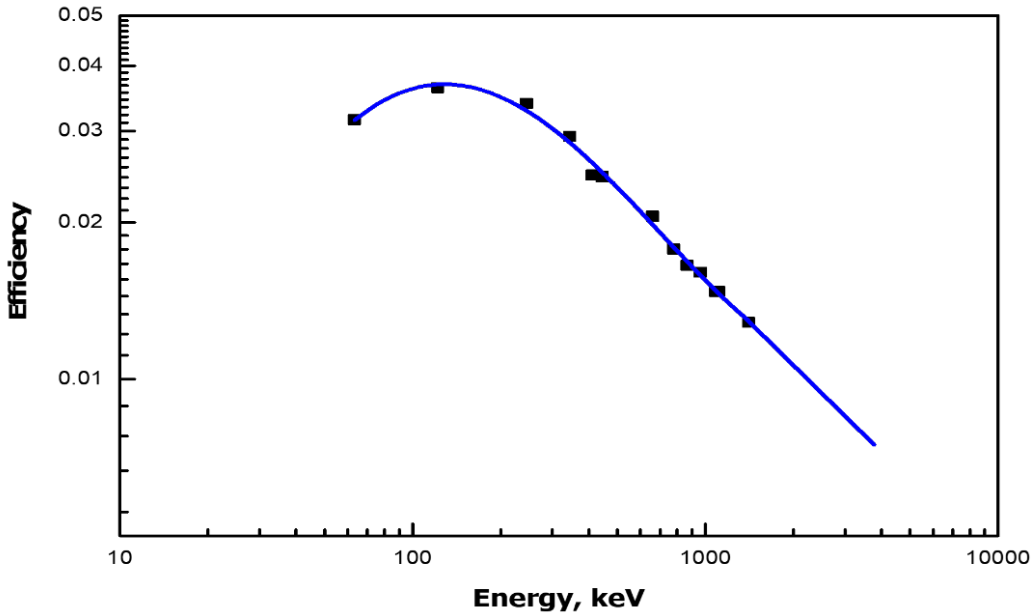

Figure 2. The full-energy peak efficiency curve for the coaxial HPGe detector fitted using different gamma point sources.

Table 4. Verification measurements by the k_0-method in INAA instruments using certified reference materials IAEA soil 7.

Element	Concentration, ppm			Element	Concentration, ppm		
	Measured values	Reference value	Err., %		Measured values	Reference value	Error, %
Ti	3415	3000	13.8	As	15.47	13.4	15.4
Mg	11432	11300	1.2	Sb	1.78	1.7	4.7
Mn	649	631	2.9	Sc	8.5025	8.3	2.4
Na	2359	2400	1.7	Fe	30154	25700	17.3
V	73	66	10.6	Co	10.24	8.9	15.1
K	11450	12100	5.4	U	2.29	2.6	11.9
Al	47995	47000	2.1	Hf	5.4	5.1	5.2
Ca	171000	163000	4.9	Ce	61.29	61	0.5
Sm	4.74	5.1	7.2	Th	9.57	8.2	16.6
Cr	70	60	16.7	Cs	6.11	5.4	13.1
Yb	2.66	2.4	10.6	Tb	0.71	0.6	18.3
Lu	0.242	0.3	19.3	Rb	58.71	51	15.1
La	22.91	28	18.2	Eu	1.06	1	6.0
Br	5.76	7	17.7	Zn	102.7	104	1.3

Table 5. Elemental concentrations in soil samples irrigated by sewage and Nile River water using neutron activation analysis technique.

Element	Irrigated by sewage water	Irrigated by Nile River water	Element	Irrigated by sewage water	Irrigated by Nile River water
	Concentration, ppm (uncertainty, %)			Concentration, ppm (uncertainty, %)	
Ti	"7136±199" (2.8)	"1503±54" (3.4)	Sb	"0.89±0.08" (9.0)	"0.6±0.08" (13.3)
Mg	"14605±825" (5.7)	"8201±376" (4.6)	Sc	"3.68±0.03" (2.5)	"7.32±0.07" (0.1)
Mn	"822±8.7" (10.6)	"588.60±8.65" (1.5)	Fe	"13886±49" (0.4)	"9389±190" (2.0)
Si	"7453±305" (4.1)	"7121±290" (4.0)	Co	"27.2±1.8" (6.6)	"18.2±0.65" (2.8)
Na	"6407±127" (2.0)	"4127±95.4" (2.9)	U	"1.32±0.12" (9.1)	"1.62±0.14" (8.6)
V	"134±2" (1.5)	"79.3±17.53" (22.1)	Gd	"15.6±1.54" (9.9)	"13.3±1.3" (9.7)
K	"22289±2741" (22.3)	"7597±269" (3.5)	Hf	"6.59±0.12" (1.8)	"5.14±0.09 (1.8)
Al	"56219±191" (0.3)	"30882±114" (0.4)	Ce	"52.4±0.80" (1.5)	"38.2±1.3" (3.5)
Cl	"210±1.0" (0.5)	"120.6±0.34" (0.3)	Th	"7.37±0.12" (1.6)	"6.04±0.26" (4.3)
Ca	"19286±799" (4.1)	"12671±214" (1.7)	Cs	"2.22±0.13" (5.9)	"1.74±0.07" (4.1)
Sm	"3.79±0.23" (5.8)	"3.17±0.23" (7.3)	Ga	"10.1±0.12" (1.2)	"5.64±0.09" (1.6)
Cr	"126.7±1.0" (0.8)	"57.23±3.0" (5.2)	Tb	"0.99±0.1" (10.1)	"0.88±0.03" (3.4)
Yb	"2.28±0.13" (5.7)	ND	Rb	"47.5±4.65" (9.8)	"48.03±3.6" (7.4)
Lu	"0.80±0.07" (8.8)	"0.37±0.11" (29.7)	Eu	"1.19±0.06" (5.0)	"0.66±0.06" (9.1)
La	"11.14±0.13" (1.2)	"8.18±0.11" (1.4)	Zn	"91.4±2.75" (3.5)	"274±4.0" (1.5)
Br	"8.55±0.46" (5.4)	"5.34±0.3" (5.6)	Ta	"3.29±0.1" (2.9)	"2.07±0.07" (3.4)
As	"1.05±0.13" (12.3)	"0.76±0.1" (13.1)	---	---	---

A. *ND: not detected.

B.

Table 6. Elemental concentrations in taro samples irrigated by sewage and Nile River water using neutron activation analysis technique.

Element	Taro	
	Concentration, ppm (uncertainty, %)	
	Irrigated by sewage water	Irrigated by Nile River water
Mg	"1804±90" (5.0)	"1795±74" (4.1)
Mn	"4.84±0.42" (5.0)	"4.13±0.25" (6.1)
Si	ND	ND
Na	"1072±33" (3.1)	"559.2±23.7" (4.2)
V	"0.20±0.02" (10.0)	"0.173±0.003" (1.7)
K	"38350±1222" (3.2)	"29690±1092" (3.7)
Al	"84.33±8.16" (9.7)	"77.6±13.4" (17.3)
Cl	"5813±55" (0.9)	"6004±69" (1.1)
Ca	"3849±144.3" (3.7)	"3350±41" (1.2)
Cr	"5.87±0.34" (5.7)	"4.95±0.25" (5.1)
La	"0.05±0.007" (14.0)	"0.054±0.012" (16.7)
Br	"2.46±0.15" (6.2)	"2.39±0.11" (4.6)
Sb	"0.92±0.14" (15.2)	"0.076±0.009" (11.8)
Sc	"0.013±0.001" (10.0)	"0.012±0.001" (8.3)
Fe	"86.73±5.9" (6.8)	"76.5±8.5" (11.1)
Co	"0.27±0.02" (7.4)	"0.077±0.005" (6.5)
U	"1.28±0.26" (15.6)	"0.965±0.165" (17.1)
Th	"9.92±1.5" (15.1)	"8.41±1.70" (16.6)
Cs	"0.08±0.013" (16.3)	"0.041±0.007" (17.2)
Rb	"3.81±0.57" (15.1)	"3.88±0.48" (12.4)
Eu	ND	ND
Zn	"54.65±0.97" (1.8)	"45.20±3.33" (7.4)

*ND: not detected.

Table 7. Elemental concentrations in strawberry samples irrigated by sewage and Nile River water using neutron activation analysis technique.

Element	Strawberry	
	Concentration, ppm (uncertainty, %)	
	Irrigated by sewage water	Irrigated by Nile River water
Mg	“2673±81” (3.0)	“2164±179” (8.3)
Mn	“49.58±1.81” (3.7)	“23.01±1.189” (5.1)
Si	“773.8±47.90” (6.2)	“728±6.6” (0.9)
Na	“434.7±25.9” (6.0)	“370.50±31.5” (8.5)
V	“0.70±0.06” (8.6)	“0.319±0.031” (9.7)
K	“30323±1468” (4.8)	“11614±958” (8.2)
Al	“295.1±3.13” (1.1)	“92.82±0.65” (0.7)
Cl	“2819±56” (2.0)	“1184±44” (3.7)
Ca	“4177±55” (1.3)	“3137±198” (6.3)
Cr	“3.73±0.37” (9.9)	“1.62±0.29” (17.9)
La	“0.08±0.01” (12.5)	“0.076±0.013” (17.1)
Br	“2.12±0.16” (7.50	“2.493±0.13” (5.2)
Sb	“0.12±0.02” (16.7)	“0.11±0.019” (17.3)
Sc	“0.055±0.003” (5.5)	“0.021±0.002” (9.5)
Fe	“264.0±22.4” (8.5)	“113.8±17.9” (15.7)
Co	“0.49±0.038” (7.8)	“0.434±0.036” (8.3)
U	“0.64±0.07” (10.9)	“0.781±0.145” (18.6)
Th	“17.83±2.29” (12.8)	“9.49±1.7” (17.9)
Cs	“0.13±0.003” (2.3)	“0.071±0.012” (16.9)
Rb	“13.95±1.29” (9.2)	“6.99±1.16” (16.6)
Eu	0.”022±0.003” (13.6)	ND
Zn	“48.76±2.72” (5.6)	“44.6±2.1” (4.7)

*ND: not detected.

Table 8. Elemental concentrations in corn samples irrigated by sewage and Nile River water using neutron activation analysis technique

Element	Corn	
	Concentration, ppm (uncertainty, %)	
	Irrigated by sewage water	Irrigated by Nile River water
Mg	“1631±66” (4.0)	“1527±77” (5.0)
Mn	“7.97±0.1” (1.3)	“7.01±0.55” (7.9)
Si	“166.7±5.1” (3.1)	“106±18.32” (17.3)
Na	“35.57±1.75” (4.9)	“25.37±2.7” (10.6)
V	“0.078±0.009” (11.5)	“0.059±0.006” (10.2)
K	“5990±473” (7.9)	“4325±572” (13.2)
Al	“48.60±0.48” (1.0)	“44.42±0.9” (2.0)
Cl	"730.1±11.68” (1.6)	“698.7±26.56” (3.8)
Ca	“249.9±44.98” (18.0)	“242.5±29.5” (12.2)
Cr	“0.93±0.12” (12.9)	“0.821±0.109” (13.3)
La	“0.022±0.003” (13.6)	“0.011±0.001” (9.1)
Br	“0.152±0.007” (4.6)	“0.128±0.017” (2.3)
Sb	ND	ND
Sc	“0.006±0.001” (16.7)	“0.006±0.001” (14.30
Fe	“58.16±7.97” (13.7)	“56.13±7.6” (13.5)
Co	“0.218±0.021” (9.6)	“0.212±0.024” (11.3)
U	“0.579±0.09” (15.6)	“0.531±0.071” (13.4)
Th	“6.94±1.12” (16.1)	“6.7±0.86” (12.8)
Cs	“0.076±0.007” (9.2)	“0.049±0.008” (16.3)
Rb	“2.69±0.39” (14.5)	“1.65±0.249” (14.5)
Eu	ND	ND
Zn	“83.61±2.59” (3.1)	“73.26±2.04” (2.8)

*ND: not detected.

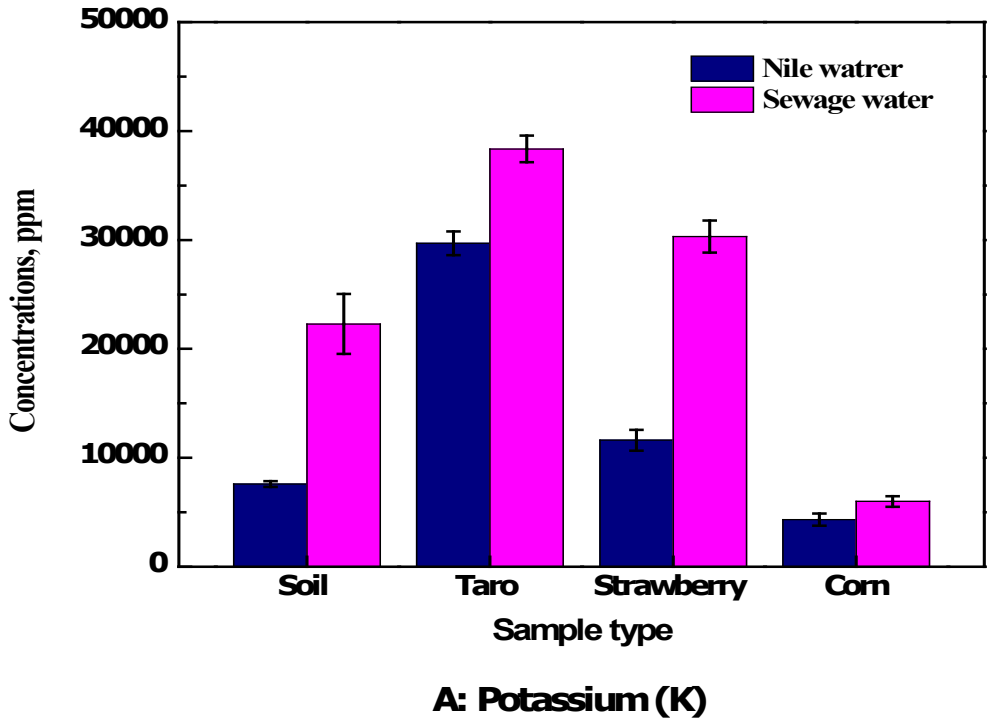

Figure 3. A schematic diagram that shows the effect of sewage water irrigation on both soil and plants for potassium.

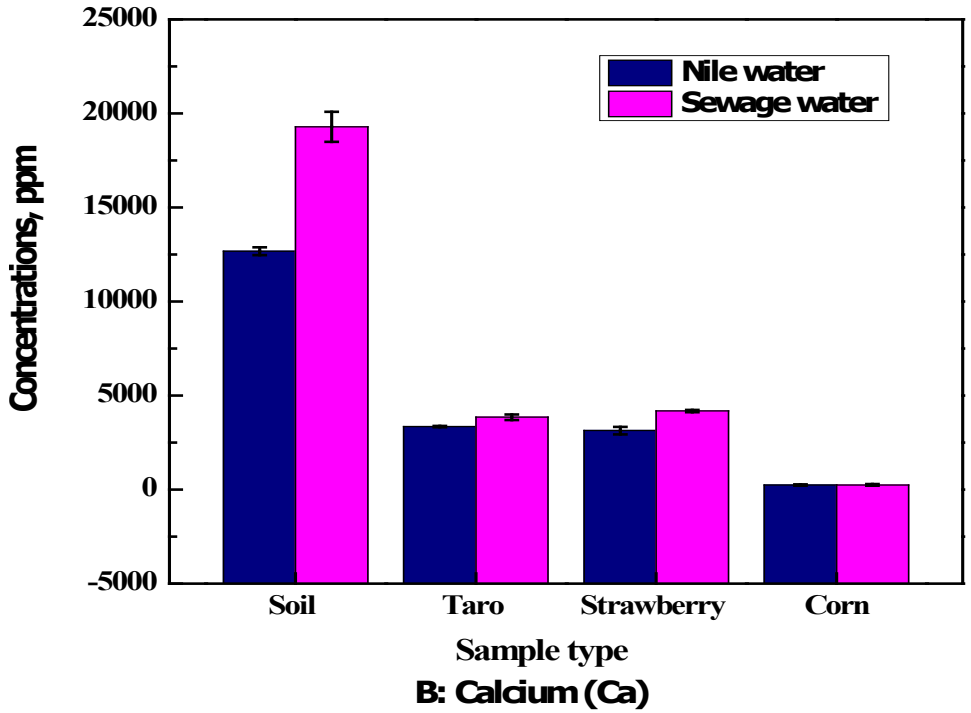

Figure 4. A schematic diagram that shows the effect of sewage water irrigation on both soil and plants for calcium

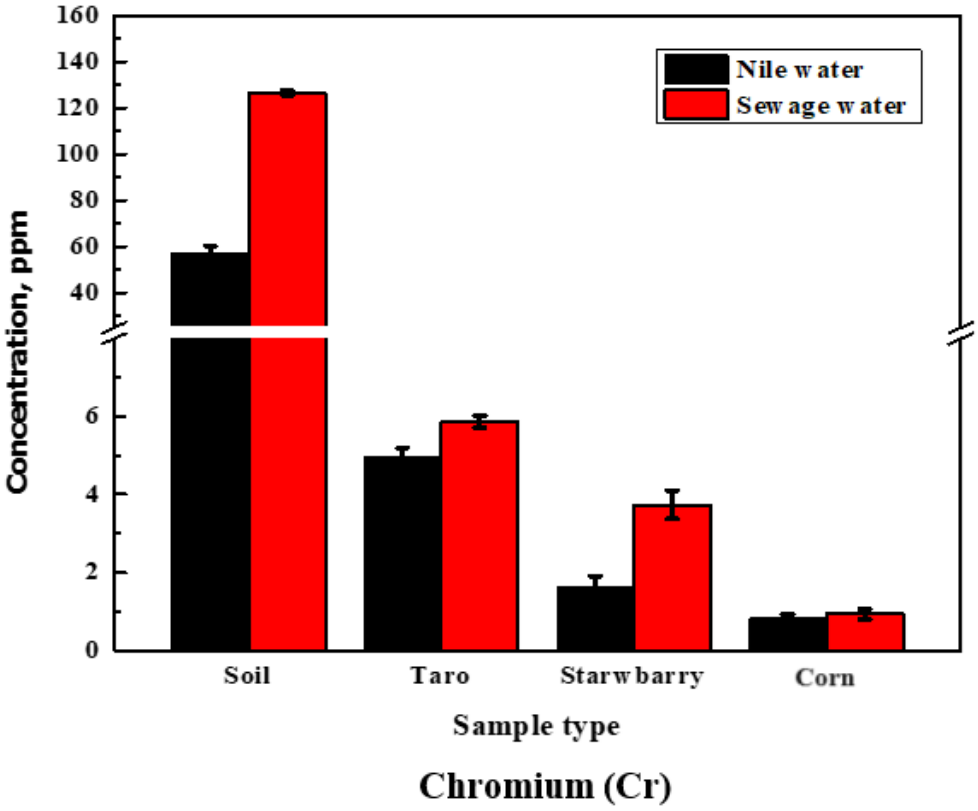

Figure 5. A schematic diagram that shows the effect of sewage water irrigation on both soil and plants for chromium

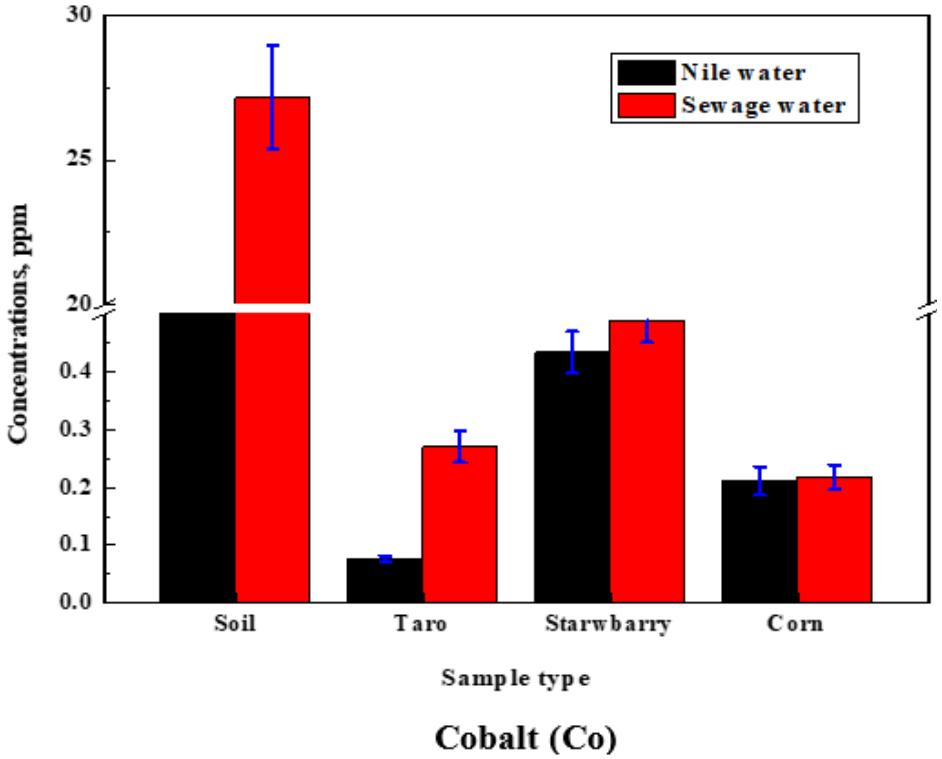

Figure 6. A schematic diagram shows the effect of sewage water irrigation on both soil and plants for cobalt.

Table 9. Elemental concentrations comparison in soil between the results of the present study and other studies.

Element	Present study	Egypt (El-Taher and Mohamed, 2014)	Thailand (Prapamon et al., 2017)	Nigeria SOKTSO2 (Essiett et al., 2011)	India Tirupati (Naidu et al., 2003)	Russia Anapa (Pavel et al., 2017)
		Concentration, ppm				
Ti	1503	C. 19000	ND	1.47	ND	ND
Mg	8201	D. 45000	ND	ND	ND	ND
Mn	588.6	E. 1000	479600	9.05	ND	370
Si	7121	ND	ND	ND	ND	ND
Na	4127	F. 7000	ND	1.47	17730	ND
V	79.33	ND	ND	1.87	ND	30.0
K	7597	10000	11800	1.72	11000	ND
Al	30882	172000	ND	1.94	ND	ND
Cl	120.66	ND	ND	ND	ND	ND
Ca	12671	228000	ND	ND	ND	ND
Sm	3.17	ND	ND	1.14	6.12	ND
Cr	57.23	G. 167	70110	ND	30	30.0
Lu	0.37	1	ND	NP	ND	ND
La	8.18	63	36760	2.83	61.34	ND
Br	5.34	ND	ND	5.85	ND	ND
As	0.76	H. 6.6	23560	7.45	ND	7
Sb	0.60	ND	3340	3.14	ND	0.6
Sc	7.32	ND	12010	ND	ND	ND
Fe	9389	55000	35100	4.28	36820	ND
Co	18.23	I. 13	15120	ND	17.1	4
U	1.62	ND	11350	ND	ND	ND
Gd	13.31	ND	ND	ND	ND	ND
Hf	5.14	J. 62	16660	ND	ND	ND
Ce	38.19	K. 120	ND	ND	55.61	ND
Th	6.04	ND	ND	ND	29.7	ND
Cs	1.74	L. 0.3	15590	ND	2.10	ND
Ga	5.64	M. 14	ND	1.48	ND	ND
Tb	0.88	ND	ND	ND	ND	ND
Rb	48.03	ND	ND	ND	145.4	ND
Eu	0.66	N. 2	ND	ND	0.61	ND
Zn	274.1	ND	82560	ND	0.0022	50
Ta	2.07	ND	ND	ND	ND	ND

*ND: not detected; the values in the original reference were converted to the unit of ppm.

Comparison of Our Results with Other Studies

The results obtained for the concentration of elements in natural soil by the INAA technique were compared with other studies in some countries, as tabulated in Table 9. The results obtained show that the concentrations of some elements are approximately close to the values obtained by others from different countries, while the concentrations of other elements are less than those in other results. However, the concentrations of different elements in soil which is irrigated by sewage water in the present study are much higher compared with the values of the same elements in other countries.

CONCLUSIONS

Instrumental neutron activation analysis (INAA) is an advanced tool for quantifying the elemental concentration in different samples especially in case of trace concentrations. The data obtained in the present study show that the concentrations of different elements in soil and plants irrigated by sewage water are more than those irrigated by Nile River water. The elemental concentration ratio between samples irrigated by sewage water and irrigated by Nile River water increased by about 2.93 in case of K in soil, while the elemental concentration ratio is less than that for other elements. As a result of irrigation of plants by sewage water, this has led to the accumulation and increased the concentration of some elements in soil and plants and consequently in humans. However, we recommend that the irrigation process using sewage water should be under control or supervision of the Ministry of Agriculture, Ministry of Environment and Ministry of Health & Population to avoid an excessive increase in the concentration of some elements that may be toxic or harm human health.

DECLARATIONS

The authors have no relevant financial or nonfinancial interests to disclose.

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