Transfer of ^{40}K, ^{226}Ra and ^{210}Pb from soil to plants in various locations of El-Jadida agricultural area (north-western Morocco)

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Abstract. The present study examines the radionuclides (^{40}K, ^{226}Ra and ^{210}Pb) concentrations in soil and plants collected from El Jadida agricultural area. The transfer factors of radionuclides from the soil to different components of the plants (stems, roots, leaves, and fruits) was also determined and assessed. The plants include various vegetable crops, including pumpkin, zucchini, beans, fennel, potato, sunflower, broccoli, onion, carrot, cabbage, tomato, and mallow from three different locations. A wide-range HPGe gamma-ray spectrometer is used for radionuclide activity measurement. The radionuclides activities of soil samples display a wide range of variability from one location to another. The concentrations of ^{226}Ra vary between 18 ± 1 Bq.Kg^{-1} and 80 ± 4 Bq.Kg^{-1}, the concentrations of ^{210}Pb range from 49.7 ± 4.4 Bq.Kg^{-1} to 269 ± 16 Bq.Kg^{-1}, and the ^{40}K values fluctuate between 94,1 ± 6,5 and 286,1 ± 15,3 Bq.Kg^{-1}. The study showed that the transfer factor for K-40 is more significant than Pb-210 and Ra-226, mainly related to the use of fertilizers rich in potassium in the agricultural areas, leading to its concentrations increase.
Keywords: Transfer factor; Soil; Plant; Potassium-40; Radium-226; Lead-210; Gamma spectroscopy; El Jadida region; Morocco

1. Introduction

Radionuclides occur naturally in Earth's crust. This naturally occurring radioactive element is part of the biosphere and is present in the soil, sediment, air, water, food, biota, and human bodies [1]. Soil and air are known as pathways to the transfer of radionuclide to the plant. The Transfer factor (TF) soil-to-plant is widely utilized for measuring radiological human dose through the ingestion pathway [2] and as a convenient and useful approach allowing to define the number of radionuclides estimated to enter a plant from the soil [3-4]. Otherwise, TF is considered one of the important parameters utilized for the environmental safety assessment required for nuclear facilities [5].

Up to date, many studies have investigated the transfer of radionuclides from soil to plants [6, 7, 8, 9, 10, 11, 12, 13]. In the El Jadida region of northwest Morocco, almost all soil research has focused on evaluating the concentration of heavy metals and soil quality [14-15]. In contrast, studies focusing on the analysis of radionuclide concentrations in the El Jadida area and surrounding areas use sediments as quantification of the concentration of radioactive elements (such as Pb-210; K-40; Cs-137, Ra-228) and for establishing The pollution history of these elements, heavy metals and rare earth elements [16, 17, 18, 19, 20, 21, 22, 23]. Thus, the present study is the first assessment of radionuclides concentrations in El Jadida's agricultural areas aiming at identifying and quantifying the radionuclides concentration and their Tfs from soil to plant.

Therefore, this study aims to analyze soil quality by determining the concentration of radionuclides in soil samples and determining the transfer factors of ^{40}K, ^{226}Ra, and ^{210}Pb from the soil to vegetables grown in the El Jadida agricultural area.

2. Materials and methods

2.1 Study area, Sample collection and physical preparation

Soil and plant samples were collected at six locations at different distances from the phosphate complex of Jorf-Lasfar (at 17 km from El Jadida city) in Morocco. Two locations in the Jorf-Lasfer area, three in Sidi Moussa and one in Ouled Ganem (Figure 1 and Table 1). The study area is characterized by a climate semi-arid Mediterranean, with fresh and humid winters and hot and dry summers. The average annual temperature is between 14°C and 21°C, and the average annual rainfall is about 389 mm; November, December, and January are the rainiest months (from 68 to 75 mm). The less rainy months are June, July, August and September (El Jadida weather station). The soil in the study area is generally sandy clay [24]. Thirteen samples were collected from the plant [pumpkin (Cucurbita moschata D.), courgette (Cucurbita pepo L.), fennel (Fœniculum Vulgare), bean (Vicia faba L. var major Harz), sunflower (Helianthus annuus L.), potato (Solanum tuberosum L.), broccoli (Brassica oleacera var. Italica L.), carrot (Daucus carota L.), onion (Allium cepa L.), cabbage (Brassica oleracea L.), turnip (Brassica rapa L.), mallow (Malva sylvestris), and tomato (Lycopersicon Lycopersicum L.)]. Six soil samples (depth of 0–5 cm) were retrieved as well from six locations in February 2019.

In the laboratory, we used deionized water to wash vegetables in order to remove all observable soil particles. Before being ground into powder, all collected plant parts and soil samples are dried at 85°C for 72 hours to constant weight. The soil samples were passed through a 2 mm mesh sieve. Non-soil particles, stones, woodblocks, rocks, gravel, and/or organic debris have been removed. The chemical and physical properties of the soil (e.g organic matter, pH, conductivity) are also analyzed.

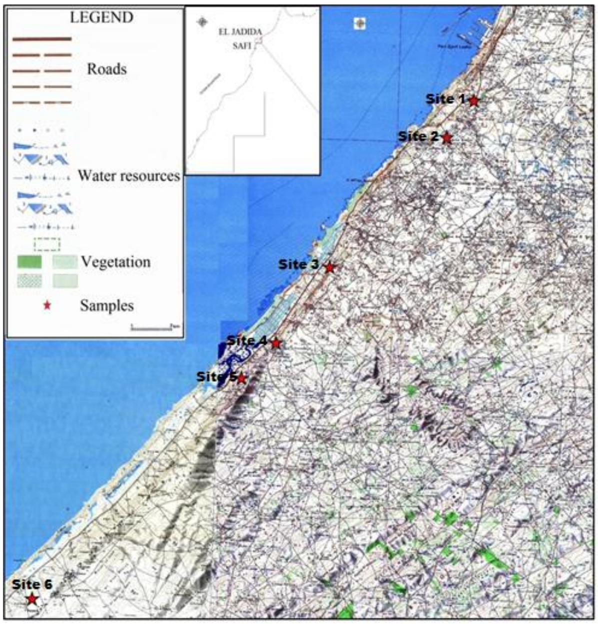

Fig. 1. Location of sampling sites.

Table 1. Positions of retrieved samples along with their longitude and latitude.

Site number	Collection location	GPS location
1	Jorf Lasfar	N 33°6'3.16"/ W 8°37' 48.44"
2	Jorf Lasfar	N 33°5'8.19"/ W 8°38' 33.57"
3	Sidi Moussa	N 33°1'53.95"/ W 8°41'49.89"
4	Sidi Moussa	N 33°0'0.65"/ W 8°43'19.03"
5	Sidi Moussa	N 32°59'7.78"/ W 8°44'16.89"
6	Ouled Ghanem	N 32°53'35.95"/ W 8°50'7.34"

2.2 Determination of radionuclides concentrations

The samples (plants and soil) were analyzed using high-resolution gamma-ray spectrometry to determine the activity concentrations of ^{226}Ra, ^{40}K and ^{210}Pb. The detector used is a low background CANBERRA high purity coaxial germanium (50% efficiency), and the resolution was 2 keV for the 1332 keV ^{60}Co γ-peak, housed in a 10-cm-thick high-purity lead shield. The gamma spectra delivered by the detector are analyzed by Genie 2000 gamma analysis software. ^{226}Ra was determined by measuring their gamma emitter daughters ^{214}Pb (351.9 keV) and ^{214}Bi (609 keV). The photopeaks used for ^{40}K are 1460.82 keV and for ^{210}Pb are 46.5 keV.

2.3 Determination of transfer factors (TFs)

The transfer factor is calculated as the ratio of the radionuclide activity concentration measured in the plant (A_{plant}) divided by the activity concentration in the corresponding soil sample (A_{soil}), as shown in Equation (1).

$$TF = \frac{\text{radionuclide activity in plant } (Bq.Kg-1\,, dry\ weight)}{\text{radionuclide activity in soil } \ (Bq.Kg-1\,, dry\ weight)}$$

3. Results and discussion

3.1 Soil characteristics

Table 2 shows the physicochemical parameters of soil samples collected from the Jorf-Lasfar phosphate complex at different distances. The pH value of the soil sample is between 8.16 and 8.63, with an average value of 8.48, signifying that it is alkaline. The soil EC (the standard measure of salinity) ranges from 0.12 to 0.32, with an average of 0.19 mS cm^{-1}. The organic matter in the soil ranges from 2.04% to 7.25%. Sites 1, 2, and 5 are characterized by high organic matter content. However, sites 3, 4, and 6 show low OM content.

Table 2. Mean of physical and chemical properties of the analyzed soils

Site number	1	2	3	4	5	6
pH (in H2O)	8.16	8.33	8.58	8.63	8.55	8.61
ECE (mS cm^{-1})	0.27	0.15	0.14	0.15	0.32	0.12
OM (%)	7.25	4.35	2.31	2.04	5	3.05

3.2 Radionuclide concentrations in soil

The determined activity concentrations of ^{226}Ra are ranged from 18.05±1.05 to 78.95±4.05 Bq kg^{-1}. The highest activity value was detected in site 1. The ^{40}K mean activity ranged from 94.1±6.5 to 286.1 ± 15.3 Bg kg^{-1}, while the maximum activity was found in site 2. The obtained values are similar to the worldwide average values of studied radionuclides stated for soil by UNSCEAR (2000), which are 35 (16–110) Bq kg^{-1} for ^{226}Ra and 400 (140–850) Bq kg^{-1} for ^{40}K. The concentrations of ^{210}Pb are ranged from 49.7±4.4 to 117.5±8.6 Bg kg^{-1}, while the highest activity was detected in site 2. The obtained values for Pb-210 are higher than those described in soil analyzed in other regions in the world (e.g. South of Syria: 15 to 43 Bq kg^{-1}; India: 10.4 to 75.9 Bq kg^{-1}) [12-13].

The highest activities of ^{226}Ra, ^{40}K, and ^{210}Pb recorded in sampling sites 1 or 2 can be explained by the proximity to industrial activities practised nearby El-Jadida city.

3.3 Radionuclide concentrations in plants

Results revealed that the concentration of ^{226}Ra varied between 2.25±0.6 and 7.15±0.52 Bq.kg^{-1} with an average value of 4.54±0.59 Bq.kg^{-1}. The maximum activity of ^{226}Ra was found in mallow root (site 1) (7.15 ± 0.52 Bq.kg^{-1}), and the minimum activity was found in carrot fruit (site 3) (2.25±0.6 Bq kg^{-1}). The activity of ^{210}Pb ranged from 3.44±0.55 to 37.76± 0.42

Bq kg^{-1} with an average value of 15.00±0.59 Bq kg^{-1}. The lowest activity for ^{210}Pb was found in cabbage fruit (site 4) (3.44±0.55 Bq kg^{-1}), while the highest activity for ^{210}Pb was found in mallow root (site 1) (37.76±0.42 Bq kg^{-1}). The mean concentrations of ^{40}K varied between 379.2±27.54 and 1094.3±57.75 Bq kg^{-1} with an average value of 891.67±50.33 Bq kg^{-1}, in all the vegetable samples with a highest recorded in courgette fruit (site 6), while the lowest activity for ^{40}K was registered in cabbage root (site 4). The activity concentrations of ^{40}K in all plant species were more significant than those of ^{210}Pb and ^{226}Ra. This is probably related to potassium being an essential component of crop growth [25].

3.4 Transfer factor of radionuclides from soil to plants

The TF values calculated for ^{210}Pb, ^{226}Ra and ^{40}K to various agricultural products are presented in Table 3. The transfer factor for ^{210}Pb ranges from 0.06 to 0.47, with an average of 0.23. The highest and lowest TF of ^{210}Pb was found in mallow root (site 1) and in cabbage fruit (site 4). The results of ^{226}Ra showed that the transfer factor for ^{226}Ra ranged from 0.09 to 0.34 with an average of 0.19. The sunflower root (site 6) displayed the highest value (0.34), while the lowest value (0.09) was found both in mallow root and (stem+leaves) (site 1). The bean root (site 2) indicated the lowest TF (2.07), whereas tomato (root+stem+leaves) presented the highest TF (10.96) (Table 3). The Tfs values calculated for ^{40}K are considerably higher than those of ^{226}Ra and ^{210}Pb, suggesting higher uptake levels of ^{40}K. It is worthily noting that although some plants are grown in soils of similar Physico-chemical characteristics and similar concentrations of ^{210}Pb, ^{226}Ra and ^{40}K, the transfer factors are dissimilar for different species. The transfer factors of ^{210}Pb reported for fruit vegetables vary from 0.01-0.34 [26] and from BDL-0.80 for medicinal plants [11]. The transfer factors of ^{226}Ra ranged from 0.097-0.504 with an average of 0.17 for grass pasture [26]. Manigandan & Chandrashekar [27] reported that the transfer factor for ^{40}K varied from 0.128 to 0.954 for six different plants. The ^{210}Pb and ^{226}Ra transfer factors observed in the present study are comparable to the values of the studies mentioned above [11, 26, 27]. The transfer factors for ^{40}K are relatively higher than the values found in Manigandan & Chandrashekar [28]. This high TF of ^{40}K is probably linked to the excessive use of fertilizers rich in potassium in the studied sites.

Table 3. The TF values for ^{210}Pb, ^{226}Ra, and ^{40}K to various agricultural products.

Plant species	Site	Sample type	Transfer factor		
			^{210}Pb	^{226}Ra	^{40}K
Mallow	1	Root	0.47	0.09	4.98
		Leaves+Stem	0.30	0.09	6.56
Bean	2	Root	0.16	0.16	2.07
		Leaves+Stem	0.20	0.21	2.73
Carrot	3	Fruit	0.17	0.12	4.08
Cabbage	4	Root	0.27	0.23	4.03
		Fruit	0.06	0.15	10.37
Courgette	5	Fruit	0.09	0.15	9.37
Courgette	6	Fruit	0.20	0.17	7.45
Sunflower	-	Root	0.40	0.34	5.42
		Stem	0.16	0.16	4.41
		Flower head	0.10	0.25	5.66
		Leaves	0.28	0.23	3.48
		Seeds	0.15	0.25	4.09
Turnip	-	Stem + leaves	0.22	0.13	6.12
		Fruit	0.21	0.12	4.61
Broccoli	-	Root	0.23	0.26	7.07
		Stem + leaves	0.12	0.20	5.99
Pumpkin	-	Root+stem+leaves	0.29	0.21	9.08
Tomato	-	Root+stem+leaves	0.22	0.23	10.96
Fennel	-	Whole plant	0.27	0.22	6.05

4. Conclusions

The concentrations of naturally occurring radionuclides in various locations of El-Jadida agricultural area in soil, vegetables, and TFs for soil-to-plants were determined.

The measured concentrations of radionuclides (Pb-210 & Ra-226) were similar to the soil guideline values reported by UNSCEAR (2000) and relatively low for plants samples as well. K-40 exhibited higher values in analyzed samples (soil and plants), which is probably linked to the application of fertilizers rich in potassium in the study area. The transfer factor of radionuclides from soil to plant is relatively low for Pb-210 and Ra-226 compared to K-40, which showed higher values.

Further investigations need to be developed to assess the distribution of radionuclides in El Jadida agricultural areas and accurately quantify their transfer factor to plants. This work contributes to establishing a database on the concentration of radioactive elements (Ra- 226, Pb-210, and K-40) in soils and plants and their soil-plant transfer factor in the semi-arid environment of Morocco.

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References

1. M.S. Aswood, MS Jaafar, S. Bauk, Appl. Phys. Res. **5**, 85–92 (2013).
2. Sh. R. Chakraborty, R. Azim, A. K. M. Rezaur Rahman, and R. Sarker, J. Phys. Sci., **24**(1), (2013).

3. International Atomic Energy Agency, (IAEA-TECDOC-1616) Vienna International Atomic Energy Agency (2009)
4. United Nations Scientific Committee on the Effects of Atomic Radiation Sources and effects of ionizing radiation New York United Nations (2000)
5. International Atomic Energy Agency, Technical Reports Series No. 364, IAEA, Vienna (1994).
6. H. Duong Van, T. Duong Nguyen, A. Peka, M. Hegedus, A. Csordas, T. Kovacs, J. Envir. Rad, 223–224 (2020).
7. HH. Azeez, H.H. Mansour, S.T. Ahmad, J Appl Radiat Isot . **147,** 152-158 (2019)
8. T. Adjirackor, EO. Darko, F. Sam, , Radiat Prot Environ **40**, 34-43 (2017)
9. R. Kritsananuwat, S. Chanyotha, C. Kranrodand, P. Pengvanich, J. Phys., Conf. Ser. **860** 012008 (2017).
10. M. Haque & M. J. Ferdous, Transfer of natural radionuclides from soil to plants in Savar Dhaka. Spanish Journal Of Soil Science **7** (2017)
11. K. Chandrashekaraa & H.M. Somashekarappa,. J. Radiat Res. Appl. Sci, 68-77 (2016).
12. N. Karunakara, Ch. Rao, P. Ujwal, I. Yashodhara, S. Kumara, P.M. Ravi, J. Envir. Rad. **118**, 80–92 (2013)
13. M.S. Al-Masri, B. Al-Akel, A. Nashawani, Y. Amin, K.H. Khalifa, F. Al-Ain, J. Envir. Rad. **99**, 322–331 (2008)
14. H. Mohcine, N. Saber, K. Moustarhfer, Inter. J. Sci. Eng. Res. **7**, 6, ISSN 2229-5518(2016).
15. S. Kanmani and R. Gandhimathi, Appl Water Sci **3**, 193–205 (2013)
16. A. Benmhammed, A. Laissaoui, N. Mejjad, N. Ziad, El. Chakir, A. Benkdad, H. Ait Bouh, A. El Yahyaoui, J. Envi. Radioa. **227**, 106464 (2020).
17. N. Mejjad, A. Laissaoui, O. El-Hammoumi, A. Fekri, H. Amsil, A. El-Yahyaoui, A. Benkdad, Environ. Res. Pollut. Res. **25**, 22872–22888 (2018).
18. N. Mejjad, A. Laissaoui, O. El-Hammoumi, M. Benmansour, S. Benbrahim, H. Bounouira, A. Benkdad, FZ. Bouthir, A. Fekri, M. Bounakhla, J. Radioanal. Nucl. Chem. **309**, 1133–1143 (2016).
19. A. Laissaoui, N. Mejjad, O. El Hammoumi, A. Benkdad, A. Fekri, M. Ghazi, II International conference on radioecological concentration processes (50 years later) Seville, Spain, November 2016, book of proceedings (2016)
20. A. Laissaoui, N. Mejjad, N. Ziad, H. Ait Bouh, O. El Hammoumi, A. Benkdad, A. Fekri, Envi. Monit. Assess. **190,** 642 (2018)
21. M. Maanan, A.C. Ruiz-Fernández, M. Maanan, P. Fattal, B. Zourarah, M. Sahabi, Inter. J. Sed. Res. **29**, 1-10 (2014)
22. B. Zourarah, M. Maanan, C. Carruesco, A. Aajjane, K. Mehdi, M. Conceiçao Freitas, Estuar Coast Shelf S **72**, 359–369 (2007).
23. A. Benmhammed, A. Laissaoui, N. Mejjad, El M. Chakir, N. Ziad, A. Benkdad, A. El Yahyaoui, H. Ait Bouh. j. environ. ecol. res. **9**, 4, 186-195 (2021).
24. G. Bryssine, Al Awamia **33,** 45 (1969).
25. Rao. Chethan, (Ph.D.thesis), Mangalore University (2012)
26. K. Prajapati, H.A. Modi, Ind. J. Plant Sci. **1**,177-186 (2012)
27. F. Vera Tome, M.P. Blanco Rodríguez, J.C. Lozano,J. Environ. Radioact. **65** (2), 161-175 (2003).
28. P.K. Manigandan, B. Chandar Shekar, J. Envir.lRadioa. **130,** 63-67 (2014).