World Applied Sciences Journal 35 (11): 2341-2347, 2017
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2017.2341.2347

Activity Concentration and Soil-Plant Transfer Factor of Naturally Occurring Radionuclides Around Charcoal Kilns in Egypt

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Abstract: The study was performed around traditional charcoal kilns in Egypt which based on earth pit designs. In this study, radiological assessment of soil and plants around kilns were performed to investigate dispersion of charcoal dust through the environment. A simple comparison is carried out between soils under kiln and other fields to compute the relative change of the soil activity concentration. The soil to plant transfer factors (TF) of natural radionuclides were evaluated and investigated. Different plants and corresponding soil samples were collected around kilns. Samples were analyzed using HPGe detector. The highest activity values within all the radionuclides in different samples were found for K-40 which was ranged between 90.5 to 251.8 Bq/kg with average of 148.9 Bq/kg for soil and 159.4 to 394.6 Bq/kg with average of 320 Bq/kg for plant. Average activity concentration of U-238 was 6.1 Bq/kg and 6.7 Bq/kg for soil and plant respectively, for Th-232 it was 6.8 Bq/kg and 3.4 Bq/kg for soil and plant respectively. It can be conclude that the activity concentrations of these radionuclides in plants and their plant transfer factors seem to depend on the activity concentrations of the same radionuclides in corresponding soil. The soil to plant transfer factors for K-40 was found to be much higher than those of U-238 and Th-232. This may be due to due to higher uptake of plant from soil which depends on many factors as bioavailability, presence of organic matter and application of phosphorus fertilizers in agricultural fields.

Key words: Activity Concentrations · Gamma Spectroscopy · Transfer Factor · NORM

INTRODUCTION

More than 2, 000 traditional charcoal kilns distributed through different governorate in Egypt. Most of these kilns based on old technique of earth pit designs that use low-cost but inefficient conversional techniques [1, 2]. Coal dusts due to charcoal production are dispersed through the surrounding environment. Also, naturally occurring radionuclides (U-238, Th-232 and K-40) are distributed in the environment (air, water and soil) [3, 4]. These radionuclides in soils are frequently transferred to different plant tissues by direct transfer via the root system, or by aerial deposition radionuclides and resuspension of contaminated soil followed by deposition on plant leaves. Most of the internal radiation doses received by human beings are due to the consumption of food contaminated with different radionuclides. The uptake of radionuclides from soil to plant is characterized by the transfer factor (TF) which can be defined as the ratio of radionuclide concentration in plant to soil per unit mass. The TF is usually used for assessing the impact of radionuclide releases into the environment [5-7]. Soil-to-plant transfer of radionuclides depends on soil type, pH, solid/liquid distribution coefficient, exchangeable K^+, organic matter content, climatic change and application of phosphorus fertilizers in agricultural fields [8-11].

In this study, a simple comparison is carried out between soils under kiln and other fields to compute the relative change of the soil activity concentration due to dispersion of charcoal dust through the environment. The soil-plant transfer factor of natural radionuclides is studied to evaluate human risk.

MATERIALS AND METHODS

Samples Collection: Six soil samples (25 centimeters depth soil cores) and twelve plant samples (two plant samples for each soil sample) were collected from the

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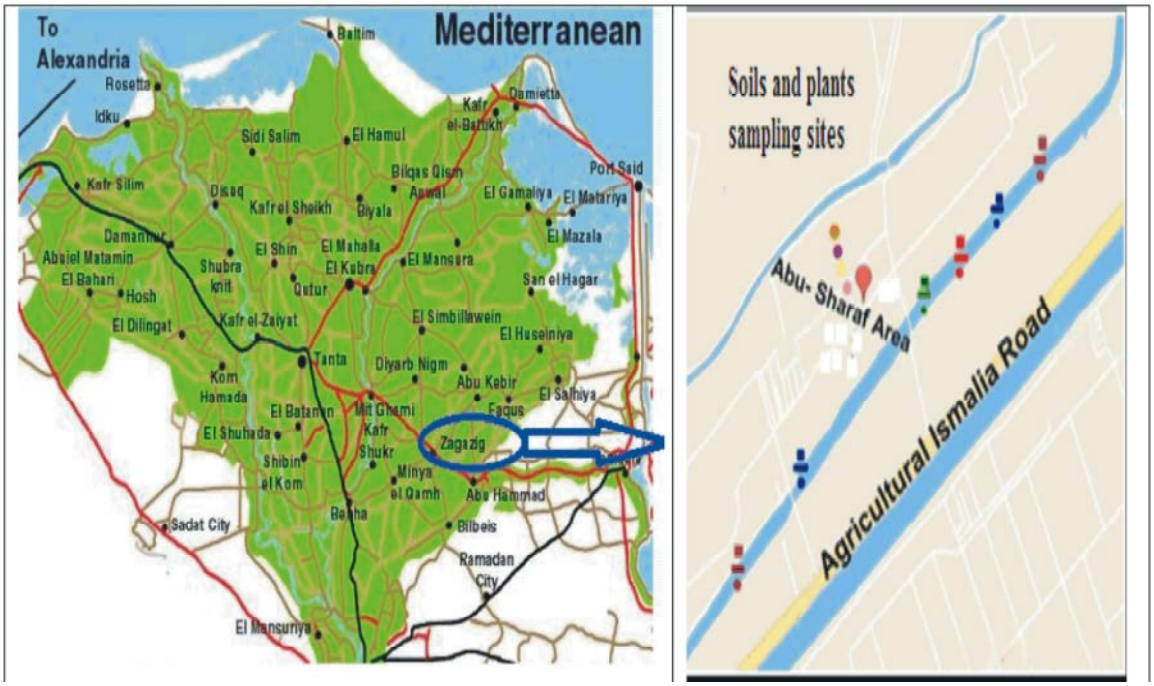

Fig. 1: Map of sampling locations

surrounding farming land of traditional charcoal kiln at different distances. Three soil samples and three plant samples were collected from farms far from kiln as shown in Figure 1.

Sampling Collection Sites: The study area is widely enough for collecting, storing and drying wood that used as a raw material for charcoal production. The emissions of charcoal dust flow in all directions, especially through the farming land from where plant and soil samples were collected at different distances from the kiln. For a simple comparison plant samples and corresponding soils were collected from farms far from kiln.

Samples Preparation and Measurement: Plant samples were cleared by fresh water for removing the dust and mud, cut into small pieces and primarily dried by spreading in air for about 3 days. Then they were dried in an electric oven at 60°C until friable stage. By using a grinder dried samples were ground to powder. .Soil samples were well mixed after removing extraneous materials such as pieces of stone, mat portions and roots. Then, they dried in an oven at 378 °K (105°C) for about 24 hours to remove the water and moisture until a constant dry mass was obtained and hence, they manually grinded. Soil and plant samples were mixed thoroughly and weighed using a digital balance and packed in plastic cylindrical containers of uniform size (The mass of the soil and plant samples varied because of the varying density of the sample material).

The plastic containers sealed tightly with caps and wrapped with thick cellotape around their screw necks to make them air tight to ensure that Rn-222 and Rn-220 is confined within the volume. All samples kept for more than four weeks to attain secular equilibrium between Ra -226 and its progenies to be achieved before gamma spectroscopy. For Gamma spectrometry HPGe detector, Canberra model no. CPVD 30-3020 (with specific characteristics shown in Table 1) was used. The main advantages required for such detector is high efficiency, high-energy resolution, very low background and non-destructive analytical. Especially the background features of the system are of considerable importance, as they must be known in order to get an estimate of the detection limits and the minimum detectable activity. Efficiency calibration of the system was carried out by using secondary standard sources (RGU-1, 400 μg/g of U-238) and (RGTh-1, 800 μg/g of Th-232) produced from IAEA. The activity of U-238 and Th-232 was determined via their decay products as shown in table 2 [12-15]. For background measurements pure silica was also poured to similar jar up to the same height as sample. Gamma spectrum for each sample and background were accumulated for about 24 hours.

Table 1: Specific characteristics of HPGe detector used for the measurements

Detector type	P-type coaxial
Shield (Pb)	10 cm
Cadmium (Inner shield coated)	1 mm
Copper (Inner shield coated)	1 mm
Resolution (FWHM) at 1.33 MeV, Co-60	2.1 keV
Accessories	a preamplifier, a linear amplifier, high voltage power supply, , multi-channel analyzer (MCA) and software program Genie 2000
Relative Efficiency	30%

Table 2: Main energies and branching ratio of U-238, Th -232 and K-40

	Uranium-238 series	
Nuclide	Energy (keV)	Photons per disintegration (%)
Ra-226	186.1	3.3
Pb214	295.1	19.2
	352.1	37.1
Bi-214	609.3	46.1
	1120.3	15.1
	1765	15.9
	Thorium-232series	
Nuclide	Energy (keV)	Photons per disintegration (%)
	338.4	12.4
	911.2	29.1
	966.6	23.2
Tl-208	583.1	30.9
	2614	35.8
	Potassium	
K-40	1460	10.74

Soil Bulk Density: The bulk density is the mass of unit volume of an air-dried sample, which includes all solid particles and all voids. It is expressed as:

$$\rho = M / V \ (gm/cm^3) \quad (1)$$

where; ρ = bulk density (gm/cm^3),
M= mass of air-dried sample (gm),
V= volume (cm^3) of predetermined mass (M), it was measured using a graduated cylinder [7].

Activity Concentrations: Activity concentrations of mentioned radionuclides in the measured samples were then computed by using Eq. (2) and expressed in (Bq /kg) as:

$$A = \frac{Netc/s}{\varepsilon(\%) * I * m} * 100 \ (Bq/kg) \quad (2)$$

where net c/s is the net counts per second, I is the branching ratio for the specific energy, ε (%) is the absolute photo peak efficiency of the detector at specific energy, m, is the mass of the sample in kg.

Handle of Errors: Standard deviation was calculated for each result due to measurement replication and the average and standard deviation were calculated for all results.

Data Treatment: The transfer factor (concentration ratios) is a tool in the form of a mathematical equation that is used to express the uptake of radionuclides from soil by the plants. It is defined as the ratio of the activity concentration in the edible part of the plants (Bq kg^{-1} dry weight) divided by the activity concentration of the specific soil (Bq kg^{-1} dry weight) [9, 16-18]. For our samples it is obtained by the activity of dry plant matter divided by the activity of dry soil matter.

$$TF = \frac{Activity\ of\ radionuclides\ in\ plant\ (Bq\ kg^{-1}\ dry\ weight)}{Activity\ of\ radionuclides\ in\ soil\ (Bq\ kg^{-1}\ dry\ weight)} \quad (3)$$

where, TF is the transfer coefficient of the radionuclides [19-20]

RESULTS AND DISCUSSION

Tables (3-4) show the average activity concentrations of plants and corresponding soil samples. The average activity concentrations of U-238, Th-232 and K-40 for plants were 6.7, 3.4 and 320 Bq/kg respectively. Soil samples have activity concentrations ranged between 3.2-10.2, 1.6-11.4 and 90.5-251.8 Bq/kg for U-238, Th-232 and K-40 respectively.

From Tables (3 & 4) we can conclude that the average activity concentration of U-238, Th-232 and K-40 are higher for plant samples compared with soil samples, this may be due to due to higher uptake from soils which depends on many factors as bioavailability, presence of organic matter and application of phosphorus fertilizers in agricultural fields. From these results soil –to- plant transfer factors were calculated as shown in Table (5). Results show that transfer factors of K-40 always more than unity due to high uptake of it by plants.

Table 3: Average activity concentration of plant samples around kiln (Bq/kg)

Samples	U-238	Th-232	K-40
P1	7.0±3.6	4.6±2.9	374.7±9.9
P2	1.0±0.3	BDL*	260.6±7.8
P3	BDL	BDL	189.1±7.6
P4	BDL	BDL	312.9±6.3
P5	13.1±3.9	5.1±2.1	340.5±6.8
P6	BDL	BDL	159.4±3.2
P7	18.0±2.3	12.4±2.2	343.6±6.9
P8	BDL	BDL	394.6±11.8
P9	BDL	3.2±0.9	359.4±7.2
P10	20.1±3.8	7.2±3.8	383.5±11.5
P11	3.5±1.0	1.5±0.5	340.8±6.8
P12	18.2±5.5	6.8±2.1	381.4±7.6
Average	6.7	3.4	320.0
Range	1-20.1	1.5-12.4	159.4-394.6

*Note: BDL – Below detection limit,

Table 4: Average activity concentration of soil samples around kiln (Bq/kg)

Samples	U-238	Th-232	K-40
S1	6.4±2.4	5.7±1.8	251.8±12.6
S2	5.8±1.8	7.3±2.6	115.9±2.3
S3	6.4±2.9	11.4±6.0	161.6±8.1
S4	10.2±2.9	9.2±3.8	130.2±6.5
S5	7.2±2.3	7.3±2.2	143.3±8.6
S6	3.2±0.9	1.6±0.4	90.5±6.3
Average	6.5	7.1	148.9
Range	3.2-10.2	1.6-11.4	90.5-251.6

Table 5: Transfer factors for different samples around kiln

Sample	U-238	Th-232	K-40
P1	1.09	0.81	1.49
P2	0.17	-	2.25
P3	-	-	1.17
P4	-	-	2.40
P5	1.82	0.7	2.38
P6	-	-	1.76
P7	2.81	2.18	1.37
P8	-	-	3.40
P9	-	0.28	2.22
P10	1.97	0.78	2.95
P11	0.48	0.21	2.38
P12	5.68	3.48	4.21
Average	2.0	1.2	2.3

Table 6: Average activity concentration of soil and plant samples far from kiln (Bq/kg)

Soil	U-238	Th-232	K-40	Plant	U-238	Th-232	K-40
S7	24.0±4.8	17.4±4.2	94.0±9.7	P13	1.5±0.6	1.1±0.4	3.3±1.4
S8	16.2±4.0	16.5±4.1	79.4±8.9	P14	1.0±0.4	0.6±0.1	3.6±1.4
S9	19.1±4.4	16.1±4.0	86.2±9.3	P15	1.3±0.6	0.9±0.4	3.3±1.3
Average	19.8±4.0	16.7±0.7	86.5±7.3	Average	1.3±0.3	0.8±0.2	3.4±0.2
Range	16.2-24.0	16.1-17.4	79.4- 94.0	Range	1.0-1.5	0.6-1.1	3.3-3.6

Table 7: Transfer factors for different samples far from kiln

Sample	U-238	Th-232	K-40
P13	0.06	0.06	0.04
P14	0.06	0.04	0.05
P15	0.07	0.05	0.04
Average	0.06	0.05	0.04

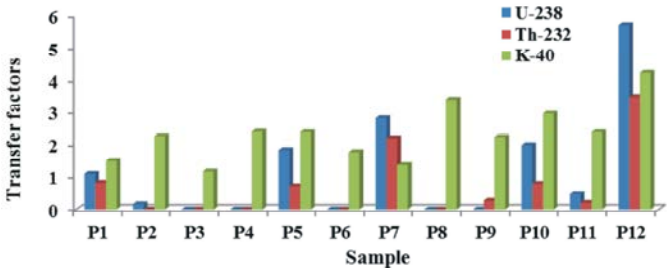

Fig 2: Transfer factors for plants around kiln

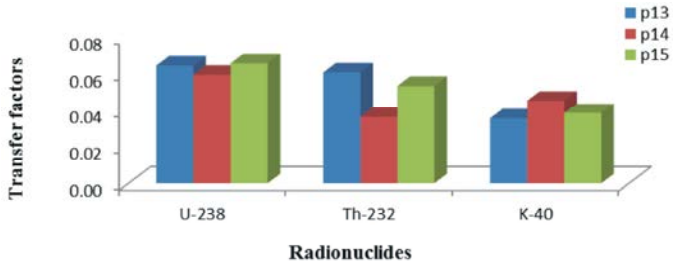

Fig. 3: Transfer factors for plants far from kiln

Table 8: Comparison of mean activity concentrations in soil samples (Bq/kg) of naturally occurring radionuclides with published results from other countries

Country /samples	Ra-226	U-238	Th-232	K-40
Egypt:	Soil activity			
Our study:				
Around kiln	-	6.5	7.1	148.9
Far from kiln	-	19.8	16.7	86.5
Inshas city [7]	-	19.6	16.9	87.2
Cairo [21]	-	65.3	23.7	146.3
Qena [22]	13.7	-	12.3	1233
Sweden [9]:				
Möjsjövik	33	593	32	76
Lövstalöt	49	307	50	849
Skogsvallen	65	-	63	1040
Myrviken	259	426	31	697
Hallen	49	-	31	681
Backfors	249	478	37	845
Vikdrolet	411	631	34	872
Nigeria [23]:				
Lokoja	41.3	-	18.9	508.9
Ibaji	9.8	-	12.0	633.5
Bangladesh:				
Manikganj[5]	26	-	-	404
Savar [5]	24	-	-	408
Chittagong [8]	22.1	-	38.5	451.9
Palestine [6]:	69.3	39.2	21.4	109.0
Saudi Arabia:				
Qassim [3]	13.0	-	16.6	618
World average[24]	35	-	30	400

Table 9: Comparison of mean transfer factors of naturally occurring radionuclides with published results from other countries

Country /samples	Ra-226	U-238	Th-232	K-40
Egypt	Transfer factors			
Our study				
Around kilns	-	2.0	1.2	2.3
Far from kilns	-	0.06	0.05	0.04
Inshas city [7]	-	0.07	0.05	0.04
Sweden [9]				
Möjsjövik	1.3	-	0.3	4.3
Lövstalöt	-	1.6	0.4	0.9
Skogsvallen	1.0	-	-	0.5
Myrviken	0.7	1.7	0.9	1.6
Hallen	-	-	-	1.3
Backfors	0.5	0.8	0.6	0.6
Vikdrolet	0.5	0.8	0.8	0.6
Nigeria				
Lokoja	0.31	-	0.59	0.08
Ibaji	0.81	-	0.87	0.10
Canada [18]	0.06	-	0.03	-
Bangladesh:				
Manikganj [5]	0.25	-	-	1.58
Savar [5]	0.40	-	-	1.63
Chittagong [8]	0.06	-	0.89	0.28
Palestine [6]	0.6	0.5	0.31	1.7
Saudi Arabia:				
Qassim [3]	0.12	-	-	0.16
World average [25]	0.04	0.02	0.04	-

Tables (6 & 7) show the activity concentrations of soil and plant samples collected far from the kiln to investigate the difference between it and samples which collected around the kiln. Results show that the transfer factors for plants around kiln were higher.

Figures (2 & 3) show the calculated transfer factors for plant around kiln and that far from it. From a comparison between them we can conclude that transfer factors for plants far from the kiln were very low compared that for around kiln this may be due to the aerial deposition of charcoal dust on plants and the higher activity concentration of k-40 in soil around kiln.

Tables (8 & 9) show a simple comparison between our results and that of other countries and the world average values for soil and plant [24, 25] it can be concluded that our results show higher transfer factors due to the high activity concentrations of k-40 and due to the pollution of environment by charcoal dust.

CONCLUSIONS

Maximum activity concentration in soil samples around kiln were 10.2 Bq/kg for U-238 and 11.4 Bq/kg for Th-232 and 251.8 Bq/kg for K-40. While soil samples from another field which located far from the kiln have activity concentrations of 24 Bq/kg, 17.4 Bq/kg and 94 Bq/kg for U-238, Th-232 and K-40 respectively. These concentrations of natural radionuclides were within the range of the world average [24]. Hence we can conclude that the close charcoal kilns haven't any affect on the nearby fields. So there is no hazard to human in these areas. Transfer factors values for plants from the far field were low and were within the world average [25]. While for plants around the kiln the uptake of K-40 is higher than those for the other two radionuclides. This may be due to higher uptake of plant from soil which depends on many factors as bioavailability, presence of organic matter and application of phosphorus fertilizers in agricultural fields, competition with major ions present in the soil-plant system, the effects of rhizosphere processes and soil micro-organisms on bioavailability, recent novel electrophysiological and genetic techniques [26]. It is important to understand that although the activity concentrations of naturally occurring radionuclides still within the world limits but continuous intake of radionuclides through the food-chain may lead to dangerous health effects on individuals in the long term. So, investigations should be undertaken to detect the concentration of radionuclides in soil and their transfer to plants in order to take necessary radiological and dosimetric measures with the aim of minimizing the harmful effects of ionizing radiation.

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