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ACCUMULATION AND SOIL-TO-PLANT TRANSFER OF RADIONUCLIDES IN THE NILE DELTA COASTAL BLACK SAND HABITATS

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***The radionuclide content was estimated in the soil of three black sand habitats in the Mediterranean coast of Egypt, namely, sand mounds and coastal sand planes and dunes. In addition, a total of 14 heavy minerals found in the soils were characterized. The soil to plant transfer of uranium and thorium was tested on three black sand species, namely,* Cakile maritima *Scop.,* Senecio glaucus *L. and* Rumex Pictus *Forssk. The transfer of thorium and uranium radionuclides from the soil to plant is complex process that is subjected to many variables; among which are the organic matter and clay content of the soil, the type of radionuclides and plant species. The study revealed a strong negative relationship between uranium and thorium uptake by* S. glaucus *and* R. pictus *and the clay and organic matter content of soil. Concentration of thorium in the soil has a negative correlation with soil-to-plant transfer factor. The study results suggest the possibility of using black sand species for phytoremediation of soils contaminated with radioactive elements. The potentiality of* S. glaucus *as phytoremediator of radionuclides polluted soils is greater than* R. pictus *which in turn outweigh* C. maritima.**

KEY WORDS: uranium, thorium, transfer factor, phytoremediation, Mediterranean, Egypt

INTRODUCTION

Black sands are deposits from River Nile silt and clay suspensions and gain its color due to the increased concentration of heavy dark minerals. Accumulation of black sands along large stretches of Mediterranean coast in Egypt extend from Abu Qir Bay in the west to Rafaa on the east between longitudes 30 12/ and 34 10 E/ (El-Hadry, 1998). This part of the Mediterranean coast reaches about 500 km length (Figure 1). Black sands originally derived as erosional products of the crystalline igneous rocks from the mountain ranges in Sudan and Abyssinian and carried down the courses of the River Nile. Rosetta promontory is the area with the highest black sand placers in Egypt (Seddeek, 2005). Even though, in comparison with the generally known coastal sands in the Middle East, black sand habitats are rich in radioactive minerals several sites are not devoid of vegetation. Tomsett and Thurman (1988) reported that although contaminated soils drastically affect the growth of plant and soil–living microbes, these environments are not totally devoid of flora and fauna as many species are adapted to tolerate the increased mineral concentrations.

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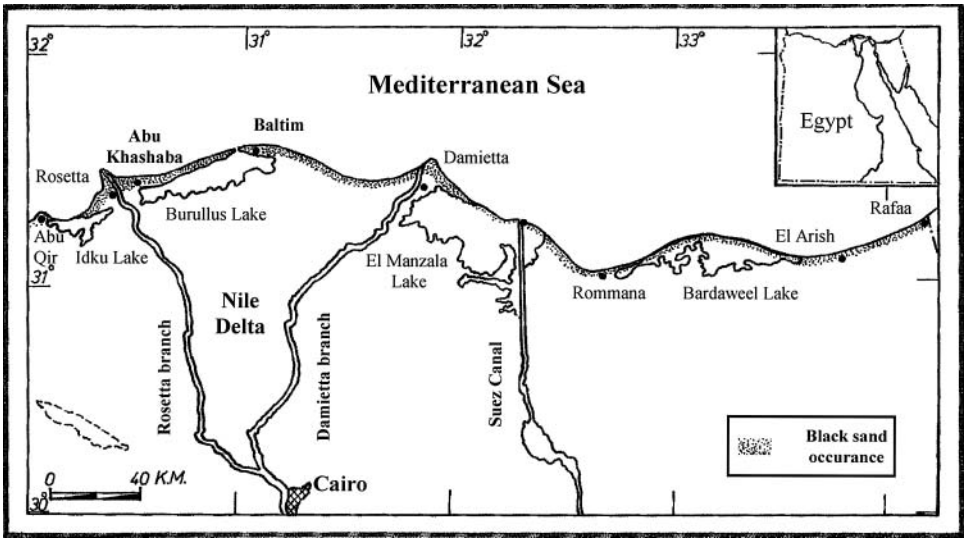

Figure 1 Map of northern part of Egypt showing the black sand deposits (dotted coastal strip) and the study sites location in Abu Khashaba and Baltim.

There are many radionuclides naturally occurring in the environment, including the isotopes of uranium and thorium and their decay products. In environmental samples with a harmful concentration of uranium and thorium, determination of radionuclides is important in the view of radiation protection (Hou and Roos, 2008). Radionuclides existing in soil can be dissolved in solution, or ion exchanged in reaction, complexed with soil organics or precipitate as pure or mixed solids. They can move into the water, air and the food supply. The immobility of these radioactive elements in uppermost soil layers represents a problem for environment and human health, since they can be easily integrated in the food chain. As a consequence, a risk for coastal ecosystems, agro-systems and health could be induced (Gavrilescu *et al.*, 2009).

The study on transfer of natural radionuclides like uranium and thorium along with their daughter products through the biosphere is important on account of their ubiquitous presence and persistence in the environment (Pulhani *et al.*, 2005). Predicting the cycling of radionuclides in the environment is essential to the development of reliable transport, dose, and risk assessment models (Fresquez *et al.*, 1998). An assessment of impact caused by a given contaminant in the ecosystem usually includes the estimation of plant uptake from the soil (Blanco Rodriguez 2002). Once radionuclides enter the soil, their fate is determined by their own and the soil physical and chemical properties, as well as by other factors including climate and vegetation. Understanding the geochemical cycle of radionuclides in soil-plant systems is of critical importance for the modeling of their transport and retention in soils, transfer from soil to plants and hence into the food chain, and phytoremediation potentialities (Ebbs *et al.*, 1998).

Previous studies on consumption of agricultural products contaminated with radionuclides presented the principal route of internal intake of radionuclides for humans. It is for this reason that plant uptake of radionuclides has been widely studied from the early 1940s (Zhu and Shaw, 2000). Accumulation of radionuclides was investigated on a wide array of plants and results varied greatly among different habitats and species (Broadley and Willey,

1997). Information gathered on plant uptake of radionuclides has primarily been used for radiological assessment and radioecological research. This kind of information has now become more important for the purpose of phytoremediation of sites contaminated with high levels of radionuclides (Zhu and Shaw, 2000). Problems such as how to screen different plant species having appropriate biological characteristics that can rapidly accumulate significant quantities of radionuclides, and how to find a way to enhance the bioavailability of radionuclides to the plants need to be addressed (Tang *et al.*, 2003; Vera Tome *et al.*, 2003).

The present study provides an assessment of the transfer of radionuclides from the soil to plants as an important asset to understand the cycling of natural radionuclides in the environment. The main objective is to estimate the soil content of radioactive minerals and the soil-to-plant transfer of radionuclides.

MATERIALS AND METHODS

Study Area

The present study was conducted in two localities; Abu Khashaba (Rosetta) and Baltim (Figure 1). Two sites were selected in Abu Khashaba; coastal sand plain, sand mounds, and one site in Baltim called Al Narreges coastal sand dunes (Figure 5). Abu Khashaba area is situated about 5 km to the north of Rosetta and lies on the eastern side of Rosetta branch of the River Nile. Abu Khashaba area is bounded to the west by Rosetta branch of the River Nile and to the east by the Mediterranean Sea and occupies about 8 km^2 (Said, 1990). The topography of the area is almost flat where the coastal plain occupies most of the surface except the southern part where accumulations from eolian sands occur as small dune belts and sand bars (Hassan, 1993). Shallow lagoons lie behind the shoreline, which partially dries out in the summer season, but is replenished with water in winter. The altitude of the area is slightly higher than sea level. Baltim is located in the north of Kafr El-Sheikh Governorate facing the Mediterranean Sea, El Burullus Lake from the south, Al Hammul town to the east, and El-Sheikh Mabrouk and Al-Raba villages to the west.

Soil Characteristics

From the study sites soil samples were taken along the depth of 0–30 cm. Five samples (about two kilogram each) were randomly collected from different five stands in every study site. Samples were pooled together in one composite sample (about 10 kg) for all sampling stands per site. Soil samples were air dried, sieved through 2 mm sieve and stored in paper bags until analysis. For soil texture analysis, the fractions were separated by sieve method. A known weight (50 g) of soil were passed through a series of sieves of 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.063 mm, 0.04 mm, and < 0.04 mm diameter to separate gravel (>2 mm), very coarse sand (2–1 mm), coarse sand (1–0.5 mm), medium sand (0.5–0.25 mm), fine sand (0.25–0.125 mm), very fine sand (0.125–0.063 mm), silt (0.063–0.04 mm) and clay (< 0.04 mm). The amount of each fraction was expressed as percentage of the original soil weight (Allen *et al.*, 1974). Organic matter in the soil samples was determined by loss on ignition method (Allen *et al.*, 1974). The percentage of $CaCO_3$ was estimated by titration against 1N HCL (Jackson, 1962).

Soil/water extracts 1:5 were prepared and used for determination of total dissolved salts, soil reaction (pH), bicarbonate (HCO_3^1-), chloride (Cl^1-) and sulfates ($SO\,HCO_4^2-$).

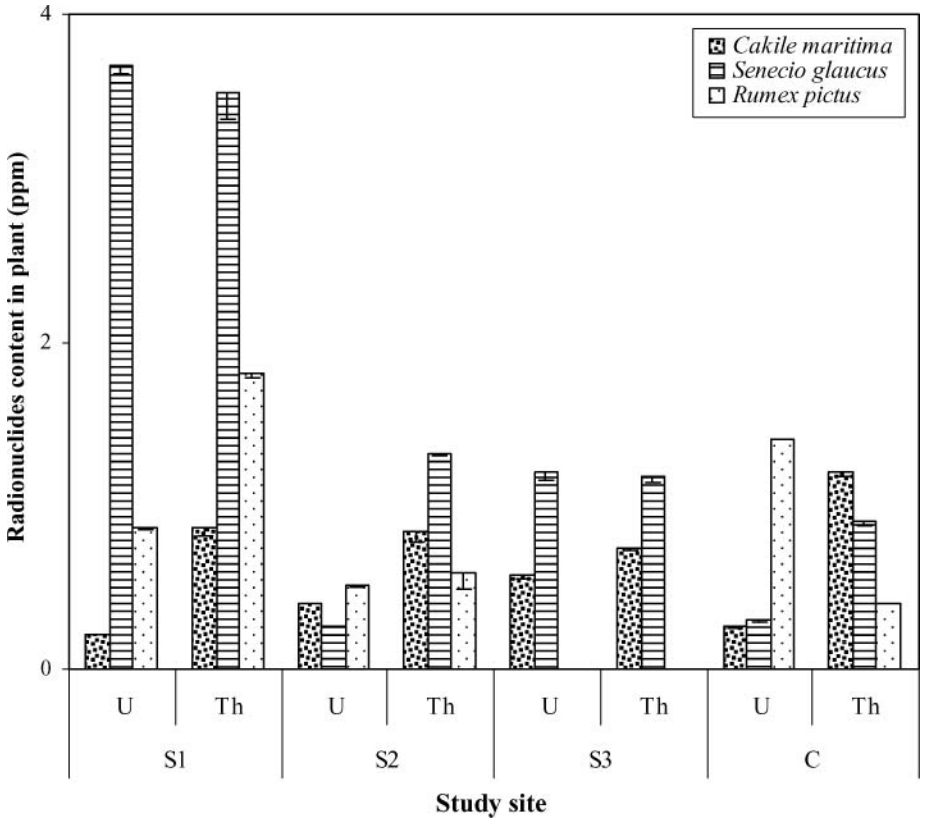

Figure 2 Uranium and thorium content in *Cakile maritima*, *Senecio glaucus* and *Rumex pictus* grown in soils from three black sand sites. S1 = Al Narreges coastal sand dunes in Baltim; S2 = Sand mounds in Abu Khashaba; and S3 = Coastal sand plain in Abu Khashaba and the control soil (C). U = uranium; and Th = thorium.

Three replicates were made for each sample. The total dissolved salts were measured by conductivity meter (Model-DAI Lamotte Chemical). Soil reaction was determined by a glass electrode PH meter (Model 206 Lutron Corporation). Bicarbonate was estimated by titration with 0.1 N HCl using methyl orange as indicator(Jackson, 1962). Determination of chloride was carried out by titration against silver nitrate using potassium chromate as indicator (Hazen, 1989). Sulfates were determined turbidimetrically as barium sulfate at 500 nm (Harrison and Perry, 1986). The heavy minerals in the soil samples were identified according to Tucker (Tucker, 1988). The soil samples were subjected to disaggregation, sieve analysis and heavy minerals separation for preparation of heavy fraction which were mounted and examined by polarized microscope for identification of light and heavy minerals.

Radionuclide Content

For estimation of the soil radionuclide content, the concentration of uranium and thorium was chemically determined using spectrophotometric technique (Marczenko, 1986) at Uranium & Thorium Laboratory, Central Labs, Nuclear Materials Authority, Anshas.

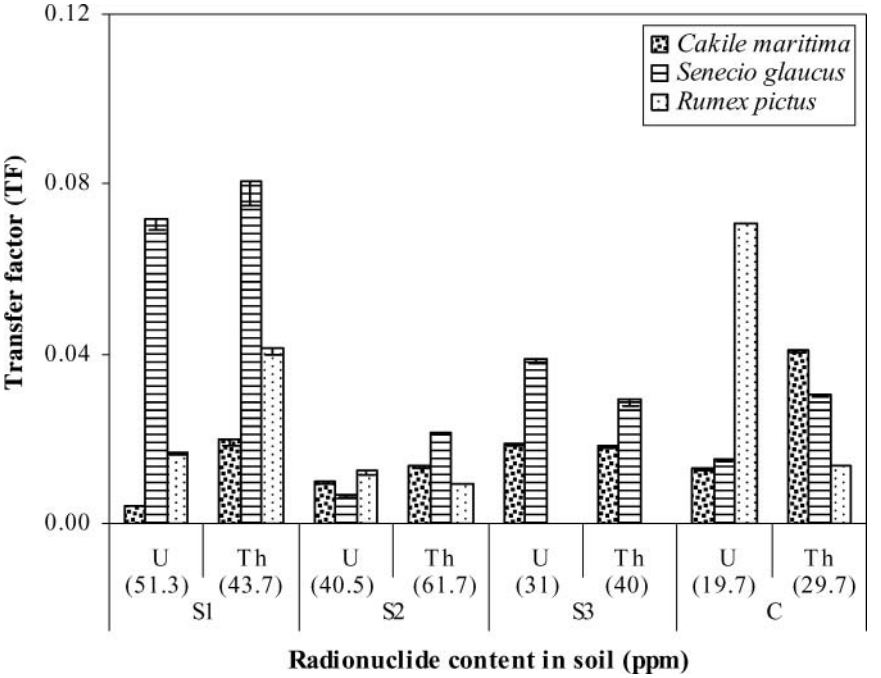

Figure 3 Transfer factor (TF) for uranium and thorium in the study species *Cakile maritima*, *Senecio glaucus* and *Rumex pictus* grown in soils from three black sand sites, S1 = Al Narreges coastal sand dunes in Baltim. S2 = Sand mounds in Abu Khashaba and S3 = Coastal sand plain in Abu Khashaba, and the control soil (C). U = uranium, Th = thorium. Values between bracts on x-axis represent the radionuclides content (ppm) of soil.

Three plant species namely *Cakile maritima*, *Senecio glaucus* and *Rumex pictus* were used for radiochemical analysis. Plants were raised from seeds collected by hand from naturally growing populations in the study sites. The soil collected from the plants natural habitat shortly before the start of the experiment was excavated between 5- and 30-cm depths. Control soil was collected from Cairo-Alexandria desert road near Wadi El Natron about 120 km south of the Mediterranean coast. The control soil is not black, and it is a product of processes other than those producing the black sand and has lower heavy mineral content than the coastal sands. The plants were raised in open greenhouse in plastic pots, 18 cm in diameter. About 3.5 kg soil were used per pot. Seeds were sown at a 1-cm depth (15 seeds per pot) and watered regularly with tap water. After seedling establishment, they were thinned to five individuals per pot. At the flowering/fruiting stage the plants were harvested by cutting with scissors at soil surface and placed in polyethylene bags, kept in an icebox and transferred to the laboratory. Plant shoots were used because the low contribution of roots to the total plant biomass and the mobility character of radionuclides which accumulate in the shoot system. In the laboratory, plants were rinsed in distilled water to remove any adhering detritus and soil particles then oven dried at 80°C until constant weight. Plant material harvest was taken after 60 days growth period (seed to flowering-fruiting stage). The average dry weight of an individual plant at time of harvest ranged from 1.6 to 2.8 g. Uranium and thorium content of the plant samples was determined by inductively coupled plasma mass spectrometer (ICP-MS technique) model JEOL JMS-Plasma X2 high

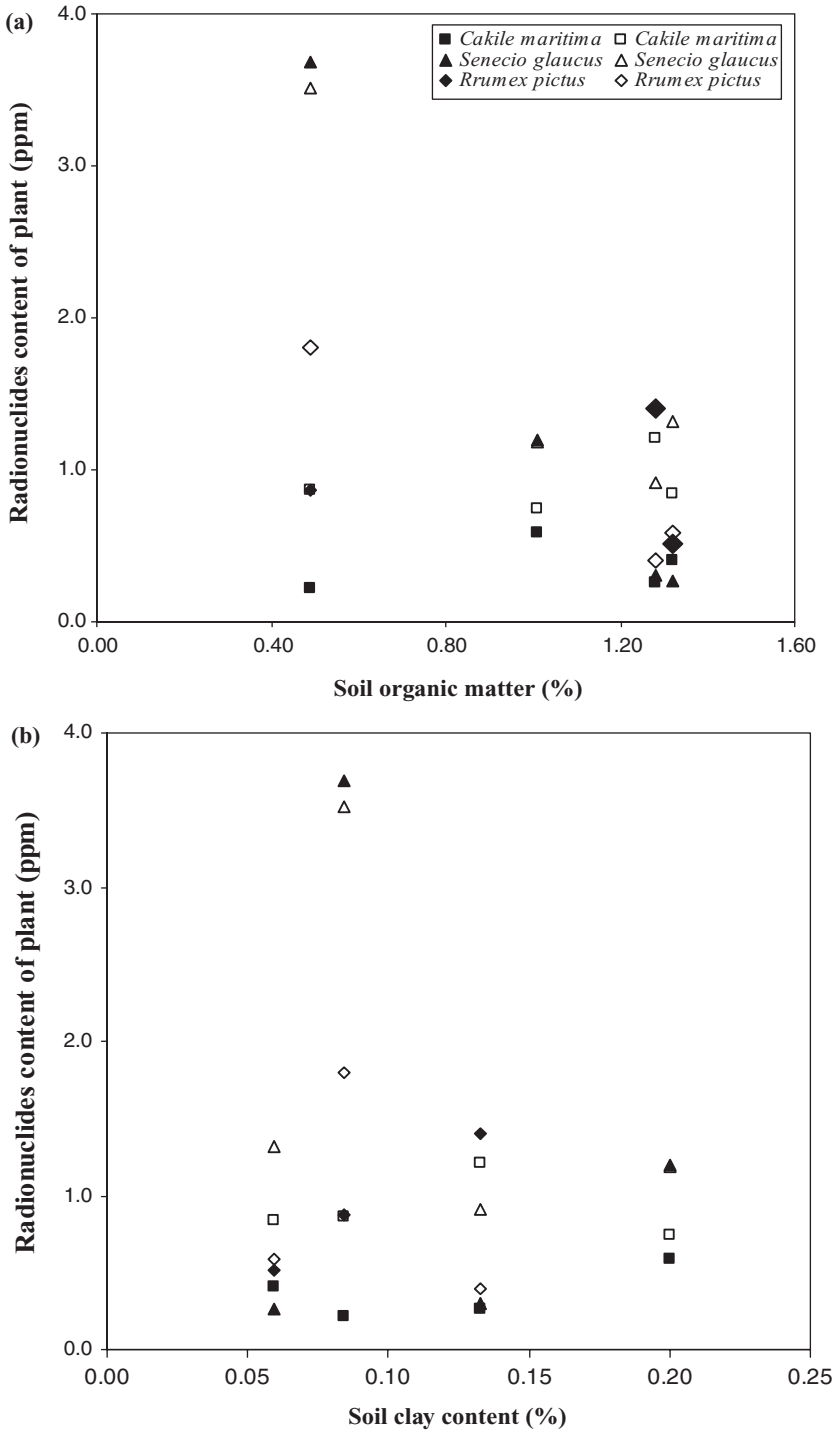

Figure 4 Scatter diagram of uranium and thorium content in *Cakile maritima*, *Senecio glaucus* and *Rumex pictus* grown in soils from three black sand sites with different organic matter content (a) and clay content (b). Solid symbols represent uranium content and hollow symbols represent thorium content.

Figure 5 The study black sand sites: (a) coastal sand dune in Baltim, (b) coastal sand plain in Abu Khashaba, and (c) sand mounds in Abu Khashaba. (Figure available in color online.)

resolution ICP-MS. The apparatus is installed at Central Laboratory for Elemental and Isotopic Analysis, Nuclear Research Center, Atomic Energy Authority, Egypt.

From the measured radionuclide content in the soil and plant samples, transfer factor was determined as follows:

$$\text{Transferfactor} = \text{Radionuclidecontentinplant}/\text{Radionuclidecontentinsoil}.$$

Data were statistically processed by one-way ANOVA to test the significance between radionuclide content in soils of the study sites, and the significance between radionuclide taken up by the plants from soils of the study sites and control site.

RESULTS

Soil Characteristics

The results in Table 1 indicate significant differences in soil texture among the study sites.

Soil in the three study sites is mainly sandy where the total medium, fine, and very fine sand represent more than 90% of soil texture. The coarse sand, silt and clay represent small fractions of soil texture. The soil reaction is slightly alkaline and calcareous with calcium carbonate content attained more than 55% in all study sites. Soil salinity is higher

Table 1 Soil characteristics in the study black sand sites

	Black sand sites			
	Baltim	Abu Khashaba		
Soil variable	Coastal sand dune	Coastal sand plain	Sand mounds	Control soil
Physical properties				
Gravel (%)	0.05 ± 0.07^{a}	0.26 ± 0.02^{b}	0.02 ± 0.04^{a}	0.00 ± 0.00^{a}
Very coarse sand (%)	0.17 ± 0.18^{ab}	0.28 ± 0.02^{b}	0.07 ± 0.01^{a}	0.16 ± 0.02^{ab}
Coarse sand (%)	2.22 ± 0.87^{b}	2.03 ± 0.00^{b}	0.11 ± 0.05^{a}	$0.61 \pm 0.18a$
Medium sand (%)	44.67 ± 10.46^{c}	37.83 ± 0.00^{c}	8.58 ± 4.57^{a}	25.68 ± 0.02^{b}
Fine sand (%)	49.05 ± 10.28^{a}	54.20 ± 0.00^{a}	78.67 ± 2.32^{b}	48.29 ± 0.15^{a}
Very fine sand (%)	3.72 ± 0.85^{a}	4.60 ± 0.00^{a}	12.00 ± 6.20^{b}	24.67 ± 0.00^{b}
Silt (%)	0.09 ± 0.04^{a}	0.60 ± 0.00^{b}	0.49 ± 0.20^{b}	0.47 ± 0.00^{b}
Clay (%)	0.08 ± 0.12^{ab}	0.20 ± 0.00^{b}	0.06 ± 0.05^{a}	0.13 ± 0.00^{ab}
Chemical properties				
PH	7.74 ± 0.07^{ab}	7.93 ± 0.04^{b}	7.65 ± 0.26^{a}	7.93 ± 0.03^{b}
T.D.S (%)	0.00 ± 0.00^{a}	0.03 ± 0.00^{ab}	0.06 ± 0.06^{b}	0.03 ± 0.00^{ab}
Cl^{-} (%)	0.01 ± 0.00^{a}	0.11 ± 0.00^{a}	0.26 ± 0.42^{a}	0.04 ± 0.00^{a}
$SO_4{}^{-}$ (%)	0.02 ± 0.00^{a}	0.02 ± 0.00^{a}	0.90 ± 0.75^{b}	0.23 ± 0.32^{a}
$HCO_3{}^{-}$ (%)	0.02 ± 0.00^{a}	0.02 ± 0.00^{a}	0.03 ± 0.01^{b}	0.03 ± 0.00^{c}
$CaCO_3$ (%)	59.52 ± 0.34^{c}	57.48 ± 0.92^{ab}	57.92 ± 0.16^{b}	56.18 ± 1.05^{a}
OM (%)	0.49 ± 0.13^{a}	1.01 ± 0.25^{b}	1.32 ± 0.56^{b}	1.28 ± 0.09^{b}

Values are means followed by standard deviation. T.D.S = Total dissolved salts; HCO31- = Bicarbonate; Cl1- = Chloride; SO42- = Sulfate; CaCO3 = Calcium carbonate; and OM = Organic matter. Different superscript letters in the same raw indicate significant difference at p = 0.05 level.

in the coastal sand plains and sand mounds than in the sand dunes, while organic matter content demonstrated lower values in the coastal sand dune site than in the other sites.

Heavy Mineral Association

Microscopic examination of soil heavy minerals are identified and summarized in Table 2. The shape of some important radioactive minerals are shown in Figure 6. Soil of the coastal sand plain in Abu Khashaba showed the highest heavy mineral association and content, while garnet, muscovite, pyroxene and andalusite were not recorded in the soil of sand mounds of Abu Khashaba. Monazite, rutile, and epidote are important radioactive minerals recorded in the black sand sites but not recorded in the control soil. Monazite is the most important minerals identified in the black sand soils due to its high content of uranium and thorium.

Plant-Soil Radionuclides Relationship

The radionuclide content of the soil in the study sites is varied. Uranium and thorium concentration attained the lowest values of 19.67 ppm and 29.67 ppm, respectively in the control soil. The maximum concentration of uranium reached 51.33 ppm in soil of the coastal sand dunes in which thorium concentration attained 43.67 ppm. The highest concentration of thorium was 61.67 ppm in soil of the sand mounds in Abu Khashaba, where as uranium concentration reached 40.5 ppm. Uranium and thorium concentrations

Table 2 Heavy minerals and their chemical composition identified by microscopic examination in soils of the black sand sites

	The soil of				
		Abu Khashaba			
Mineral	Al Narreges	Coastal sand plain	Sand mounds	Control	Chemical composition
Zircon	+	+	+	+	$Zr^*O_2.SiO_2$
Tourmaline	+	+	+	+	$Na_2O.8FeO.8Al_2O_3.4B_2O_3.16SiO_2.5H_2O$
Garnet	+	+	−	+	$(Fe, Ca)O.3Al_2Si_3O_{12}$
Muscovite	+	+	−	+	$(K_2Na)_2\ O.3Al_2O_3.6SiO_2.2H_2O$
Biotite	+	+	+	+	$K_2O.4(Fe, Mg)O.2(Al, Fe)_2O_3.6SiO_2.H_2O$
Hornblende	+	+	+	+	$Ca_3Na_2(Mg, Fe)_8\ (Al, Fe)_4Si_{14}O_{44}(OH)_4$
Apatite	+	+	+	+	$(U^*, Mn, Dy^*, Ce^*, As^*)Ca_4\ (CaF, Cl)\ (PO_4)_3$
Monazite	+	+	+	−	$(U^*, Ce^*, La^*, Dy^*)\ _2O_3.\ P_2O_5.Th^*O_2.SiO_2$
Stourolite	++	++	+	++	$2FeO.5Al_2O_3.4SiO_2.H_2O$
Rutile	+	+	+	−	TiO_2
Epidote	++	++	+	−	$4CaO.3(Al, Fe)_2O_3,6SiO_2.H_2O$
Kyanite	+	++	++	++	$Zr^*O_2.SiO_2$
Pyroxene	+	+	−	+	$Na_2O.8FeO.8Al_2O_3.4B_2O_3.16SiO_2.5H_2O$
Andalusite	−	+	−	−	$(Fe, Ca)O.3Al_2Si_3O_{12}$

+ = the mineral is present, ++ = the mineral is present with high amount,− = the mineral is absent. *: refers to radioactive element.

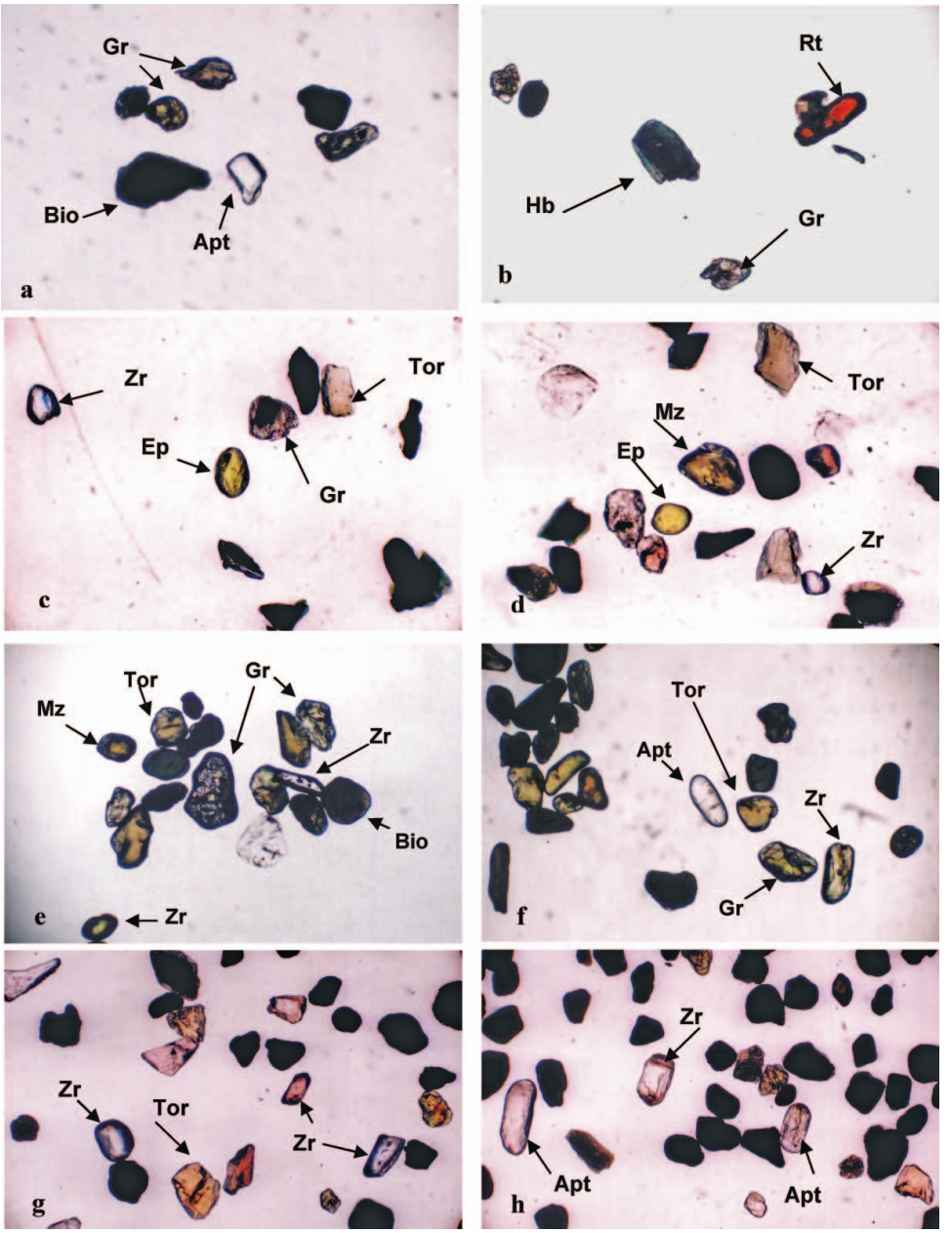

Figure 6 Photomicrograph showing some heavy mineral associations in the soil of the study black sand sites. (a & b) sand mounds in Abu Khashaba, (c & d) coastal sand plain in Abu Khashaba and (e & f) costal sand dune in Baltim, and (g & h) minerals in the control soil. Gr = Garnet; Ep = Epidote; Rt = Rutile; Hb = Hornblende; Apt = Apatite; Bio = Biotite; Zr = Zircon; Tor = Tourmaline; and Mz = Monazite. (Figure available in color online.)

in the soil of Abu Khashaba coastal sand plain exhibited the values 31.0 and 40.0 ppm, respectively. In general, the levels of thorium concentrations are slightly above the uranium concentrations in the soils of the three study sites.

Radionuclides content in the study species are shown in Figure 2. The level of uranium attained the minimum value 0.21 ppm in the shoot of *Cakile maritima* grown in the soil of Al Narreges coastal sand dunes, followed by 0.26 ppm in plants grown in the control soil. The highest concentration of uranium (0.58 ppm) was detected in *C. maritima* grown in the soil of the coastal sand plain in Abu Khashaba. With respect to thorium concentration in *C. maritima*, it attained the highest concentration 1.21 ppm in plants grown in the control soil. Thorium was accumulated with low concentration 0.74 ppm in plants grown in the coastal sand plain soil of Abu Khashaba. With respect to *S. glaucus,* the plants grown in the soil collected from the coastal sand dunes contain the highest concentrations of both uranium and thorium reaching 3.69 and 3.52 ppm, respectively; while the minimum concentration of uranium and thorium (0.3 and 0.9 ppm, respectively) were observed in plants grown in the control soil. In case of *R. pictus*, uranium, and thorium concentrations showed higher levels in plants grown in the soil from its natural habitats than the control. The concentrations of both uranium and thorium attained higher values amounted 0.87 and 1.82 ppm, respectively, in plants grown in the coastal sand dune soil than that grown in the sand mound soil of Abu Khashaba where the concentration of uranium reached 0.51 and thorium 0.59, ppm. The uranium and thorium content in soil is given in Figure 3. The highest soil content of uranium was found in the coastal sand dunes and the lowest content in the control soil with values 51.3 and 19.7 ppm, respectively. As for thorium, the highest value 61.7 ppm and the lowest value 29.7 ppm was found in the sand mounds and control soil, respectively. In general, the three study species have accumulated thorium with concentrations higher than uranium. *S. glaucus* accumulated the highest concentrations of both uranium and thorium in comparison to *C. maritima* and *R. pictus*.

The soil-to-plant transfer of radionuclides is shown in Figure 3. The transfer factor for uranium in *C. maritima* showed the lowest value 0.004 for plants grown in the coastal sand dune soil of Baltim, while attained the highest value 0.02 when raised in soil transferred from the coastal sand plain in Abu Khashaba. Transfer factor for uranium in plants grown in the control soil and that of sand mounds in Abu Khashaba attained the same value 0.01. The soil to plant transfer factor for thorium in *C. maritima* exhibited the maximum value 0.04 when grown in the control soil and attained the minimum value 0.01 in plants grown in the soil of the sand mounds in Abu Khashaba. As for *S. glaucus*, plants attained the highest transfer factor values 0.07 and 0.08 for uranium and thorium respectively when grown in soil of the coastal sand dunes in Baltim, while the lowest values 0.01 and 0.02 for uranium and thorium respectively were obtained for plant grown in soil of the sand mounds in Abu Khashaba. The transfer factor for uranium in plants grown in soil of the coastal sand plain in Abu Khashaba reached 0.04, compared to the value 0.02 for the plants grown in the control soil. The soil-to-plant transfer factor for both uranium and thorium in *R. pictus* was significantly higher in the plants grown in the control soil than in the plants grown in the soils from its natural habitat. The transfer factor for both uranium and thorium in the plants grown in soil of the coastal sand dunes attained values 0.02 and 0.04, respectively, while a lower value 0.01 attained by the plants grown in soil of the sand mounds in Abu Khashaba. The transfer of both uranium and thorium from the soil to plants is generally higher in *S. glaucus* than in *C. maritima* and *R. pictus*—especially for plants grown in the soil of their natural habitat.

Table 3 Multiple regression equations of radionuclides uptake against clay and organic matter content of the soil

Species	Radionuclide	R^2	Equation
Cakile maritima	Uranium	0.49	U conc. = 0.04 + 1.63 Clay + 0.13 OM
	Thorium	0.15	Th conc. = 0.76 − 0.46 Clay + 0.20 OM
Senecio glaucus	Uranium	1.00	U conc. = 5.93 − 2.58 Clay − 4.16** OM
	Thorium	1.00	Th conc. 5.49 − 7.27** Clay − 2.83** OM
Rumex pictus	Uranium	1.00	U conc. = −0.08 + 12.64* Clay − 0.13* OM
	Thorium	1.00	Th conc. = 2.85 − 3.60* Clay − 1.55* OM

*P < 0.05, **P < 0.01, OM = organic matter.

Soil Variables-Radionuclide Relationship

The effect of clay and organic matter content of soil on the uptake of uranium and thorium by plants is represented in the scatter diagrams (Figure 4a,b). Uranium and thorium content of the three study species generally decrease with the increased clay and organic matter content of the soil. *S. glaucus* accumulated the highest amount of uranium and thorium (3.69 and 3.52 ppm, respectively) when plants grown in soil containing low organic matter content 0.49% (Figure 4a). The similar trend is observed in the other two species. The radionuclides absorption by *S. glaucus* was more affected by the increased organic matter and clay content in soil than both *C. maritima* and *R. pictus*.

Relationship between soil characteristics and radionuclides uptake by plants is shown in Table 3. Multiple regressions of data gave R^2 values showing the variation in the radionuclide uptake as explained by equations for the study species in relation to clay and organic matter content. There is a strong negative relationship between radionuclides (uranium and thorium) uptake and organic matter content of the soil for both *S. glaucus* and *R. pictus* (Figure 4a). Also, the relationship is negative between clay content and thorium uptake by the two species (Figure 4b). As for *C. maritima* the negative relation between the two soil properties and radionuclides uptake is not strong.

DISCUSSION

The study of radionuclides uptake by plants in the present investigation revealed a strong negative relationship between uranium and thorium uptake by *S. glaucus* and *R. pictus* and the soil content of clay and organic matter. These results are in agreement with the previous studies (Fresquez *et al.*, 1998), which proved that radionuclide uptake by plants is higher in soil that contain more sand and less organic matter, such as those employed in the present study, as compared to soils which contain high amounts of clay, silt and organic matter, which act as binding agents. Moreover, previous study on the transfer of radioactive cesium in wheat grains demonstrated significant negative correlation between the radionuclides transfer and certain soil properties, such as: PH, clay, and cation exchange capacity (Skarlou 1996). The solubility of uranium in soil is dependent on several factors such as: pH, redox potential, temperature, soil texture, organic and inorganic compounds, moisture and microbial activity (Gavrilescu *et al.*, 2009). Soluble forms can migrate with soil water, be uptaken by plants or aquatic organisms or volatilized. The study of Savinkov *et al.* (2007) on the uptake of radiostrontium by plants from different soil types revealed a significant negative relationship between radiostrontium uptake and humus content in the soil. The results support the findings of Staunton *et al.* (2002) who reported that

organic matter content was suggested to affect the retention and migration of the fallout radionuclides in the environment.

The effect of soil texture on movement of several radionuclides, appear to be similar to the divalent Ca and Mg ions. Divalent cations are adsorbed by soil clay particles through ion exchange mechanisms, so relative rates of adsorption generally increase as soil clay content increases. Since movement in soils is inversely related to adsorption, downward movement of radionuclides would be lower in fine textured (high clay) soils (Mortvedt, 1994). In addition, Staunton *et al.* (2002) reported that clay minerals are known to adsorb radiocaesium very strongly. Clay components were found to decrease the available radiocaesium fraction (El-Reefy 2006). The uptake of radionuclides by plants is not only dependant on the soil characteristics but also on the plant species and the type of radionuclide. Species dependency in radionuclide uptake is well-documented by many authors (McGee *et al.*, 1993; Demirel *et al.*, 1994; Rauret and Firsakova, 1996).

Transfer factor (TF) is usually used in determining the ability of plant species to absorb radionuclide from soil or other substrates. This value is defined as the ratio of the concentration of a given radionuclide in aboveground plant organs to that in the soil (Mortvedt, 1994). Plant-soil transfer factor has been used in predicting the transport of radionuclides and other elements of interest through the food chain as well as in biogeochemical cycling of radionuclides. It is recognized that values of TF are dependent upon substrate concentration as well as other effects such as chemical forms of radionuclides, concentration of competing ions, and the plant species. Transfer factor values vary significantly among some plant species and soil types (Mortvedt, 1994). In the present study, the transfer factor for uranium in the three species did not show clear trend with its concentration in the soil. This finding is supported by the findings of Bunzl *et al.* (2000) who found a lack of relation between the concentrations of radiocaesium in plants and those in the soil. In addition, Martínez-Aguirre and García-León (1996) reported that transfer factor for plutonium decreases when its concentration in the soil increases but that not so clear for uranium. Obviously, these dependences are specific for the radionuclide types as noticed in the present study.

The use of transfer factor assumes a linear relationship between the concentrations of a certain element in the plant with that in the soil (Blanco Rodriguez 2002). Numerous studies have suggested that TF for radionuclides that mimic essential plant nutrients (e.g., Sr, Cs, and U) follow a non linear curve model and are high at low soil concentrations whereas non essential elements or elements that are not physiologically regulated by plants (e.g., Pu and Am) typically follow a linear curve model (Sheppard and Sheppard, 1985). The preliminary nature of our results demonstrates that uranium follows a non-linear curve model, with a behavior typical of essential elements as stated by Sheppard and Sheppard (Sheppard and Sheppard, 1985) who reported that uranium behaves as essential element at low concentration in the soil. On contrary, in the present study, more linearity was observed between the TF for thorium and its concentration in the soil, indicating that thorium may act as a non-essential element. However, it is difficult to statistically support particular models in most systems because of the wide variability in TF values (Mortvedt, 1994). The multifactorial character of the transfer makes it difficult to establish simple relationship between soil-plant attributes and transfer (Rosa *et al.*, 1997).

Various methods for remediation of soils contaminated with radioactive elements are known but only few of them have been applied under field conditions (Gavrilescu *et al.*, 2009). The objective of any remedial action is to reduce the risks to human health, environment and property to acceptable levels by removing or reducing the source of

contamination or by blocking exposure pathways. Bioremediation provides a technique for cleaning up pollution by enhancing the same biodegradation processes that occur in nature. Depending on the site and its contaminants, bioremediation may be safer and less expensive than alternative solutions such as incineration or landfilling of the contaminated materials (Gavrilescu *et al.*, 2009). Phytoremediation, the use of vegetation for in situ treatment of contaminants from soil and solutions is a promising technique that can deal with pollutants (Singha *et al.*, 2009). If the environment is contaminated by accidentally released radionuclides, phytoremediation may be an effective method for eliminating radionuclides from the contaminated soil (Chiu *et al.*, 2005).

The present study involved that the transfer of uranium and thorium from soil to plant was mostly higher in *S. glaucus* than that in both *C. maritima* and *R. pictus*. This may explain that *S. glaucus* may be the most suitable species for phytoremediation of the soil contaminated with uranium and thorium. Phytoremediation has long been recognized as a cost effective method for the decontamination of soil and water resources (Peng *et al.*, 2009). Further, a variety of pollutant attenuation mechanisms possessed by plants makes their use in remediating contaminated land and water more feasible than physical and chemical remediation. Plants act as solar-driven pumping and filtering systems as they take up contaminants through their roots and transport them through various plant tissues where they can be metabolized, sequestered, or volatilized (Peng *et al.*, 2009). The ability of plants to tack up radionuclides from soil is controlled by several factors as revealed from the current study such as soil characteristics, plant species and the type of radionuclide. Fertility of the contaminated soil is a major concern in phytoremediation as suggested by Chiu *et al.* (2005) where phytoremediation can be optimized by applying soil amendments to release the fixed-form of radionuclides (Zhu and Shaw, 2000).

CONCLUSION

The study of radionuclides uptake by different plant species suggested the ability of some species to absorb significant amounts of radionuclides that they can be used as phytoremediators of contaminated soils taking into account the soil properties. A 50% increased organic matter and clay content of soil decreases plant uptake of uranium and thorium by more than 50%. The soil-to-plant transfer factor of radionuclides ranges from 0.05 to 0.15% of soil radionuclides content.

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