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THE ACTIVITY CONCENTRATIONS AND HAZARD INDICES IN SEDIMENT SAMPLES FROM THE AFRICAN COASTS

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Abstract

In this work we have been interested in a compilation of data covering the period from 2000 to present of radionuclide activity concentrations in estuary or marine sediments of the African continent. So, we included three radionuclides as the most representative of natural radioactivity (^{226}Ra, ^{232}Th and ^{40}K) in sediment samples taken from 20 coastal areas, by considering the Atlantic Ocean (Nigeria, Ghana, Morocco and Canary Islands), the Mediterranean Sea (Spain and Egypt) and the Red Sea (Egypt). Therefore, we have relied on scientific publications as well as on our own results.

Moreover, to characterize the potential radiation dose to humans resulting from exposure to sediment natural radioactivity, eight radiological hazard indices were estimated: Total Absorbed Dose Rate in air (D), Annual Effective Dose Equivalent (AEDE), Annual Gonadal Dose Equivalent (AGDE), Radium Equivalent Activity (Ra_{eq}), External Hazard Index (H_{ex}), Internal Hazard Index (H_{in}), Gamma Index ($I\gamma$) and Excess Lifetime Cancer Risk (ELCR).

The highest activity concentrations were found in sediment samples in Atlantic Ocean, especially in one site in Nigeria with a great exceed of the World Wide Average concentrations of ^{226}Ra, ^{232}Thand ^{40}K, which are 35, 30 and 400 Bq Kg^{-1} respectively.

Also, the calculation of the eight radiological hazard indices indicated significant radiological risks always in the same site in Nigeria in Atlantic Ocean.

1. Introduction

The sources of radioactivity in the marine environment are numerous and diversified. Radiation comes from anthropogenic and natural sources. Naturally occurring radioactive materials (NORMs) are acknowledged as the largest sources of exposure to human health [1]. Long-term exposures to radioactivity and inhalation of radionuclides have serious health effects such as chronic lung diseases, acute leucopoenia, anemia and necrosis of the mouth.

Radionuclides such as ^{226}Ra, ^{232}Th and ^{40}K are widely distributed in the marine environment as a result of two forms: those that come from the earth's crust (terrestrial radioactivity) and those which result from the interaction of atmospheric gases with cosmic rays (cosmogenic radioactivity)[2].Sediment contamination by these radionuclides is of particular interest from radiological point of view, as they can form the basis of radiological assessments for the human population [3].

Exposure to radium may result in teeth fracture, anemia and cataract and may even cause cancer of various types. Thorium exposure can cause lung, pancreas, hepatic, bone and kidney cancers and leukemia [4, 5]. And potassium plays a significant role as a mutagenic agent in evolution [6].

The main objectives of this work are to studythe evolution of the three natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K) and to identify their cause radiological effects in some African estuary or marine sediment from 2000 to present.

2. Materials and methods

2.1. Study Regions

In this work, we studied the activity concentrations of the three natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in estuary or marine sediments of the African continent. In fact, there is not much information in all coastal countries; so wemanaged to compile the maximum of database by considering the period from 2000 to present. For this, we have relied on the scientific publications as well as on our own results. Also, we considered it is useful to provide some results of analysis of sampling done during the 1990s, since their exploitation took place only in the 2000s. In total, we were able to gather 20 regions from 16 references covering 5 countries [3, 7-21].

The studies chosen have focused on beach sediments, estuarine sediments and surface sediments as shown in Table 1 and Figure 1. Sediment samples were oven-dried and analyzed using a Gamma Spectrometer. We were able to cover three directions, the Atlantic Ocean on the west (Morocco, Canary Islands, Ghana and Nigeria), the Mediterranean Sea coast of Egypt and Spain on the north and the Red Sea coast of Egypt on the east.

The selection of the three widely used natural radionuclides was made in order to assess after radiological risks to human health. In fact, these radionuclides represent the risk of external exposure due to gamma rays and internal emissions from radon and its descendants[1].

Table 1:Codes and names of compilation areas of ^{226}Ra, ^{232}Th and ^{40}K concentrations in some sediment samples from the African coasts.

Oceans&Seas	Country	Location	Code
Miditerane anSea	Spain	BayAlgeciras, 2006	1
	Egypt	Nile Delta Coastal profiles	2
		Shore sed., between Alexandria & Port Said	3
		Shore sed., Alexandria	4
RedSea	Egypt	Safaga	5
		Hurgada	6
		Ras Ghareb Coast	7
		Ras El Behar	8
		Hamraween	9
		Shore sed., between Shuqeir and Marsaalam,	10
		Quseir city	11
Atlantic Ocean	Negeria	2008	12
		River Igbokoda, Ondo State	13
		Bonny Estuary	14
	Ghana	Shore sed., coast of Accra	15
		Tema Harbour, Accra	16
	Morocco	Sebou Estuary, 2009	17
		Oualidia	18
		Sidi Moussa	19
	Spain	GranCanaria (CanaryIslands)	20

Figure 1: Localization of compilation areas of ^{226}Ra, ^{232}Th and ^{40}K concentrations in some sedimentsamples from the African coasts.

2.2. Radiological risk assessment

In order to better understand the effects of radiation due to natural radioactive elements and assess the radiological risk to human health of a population in a given region, some radiological parameters such as Total Absorbed Dose Rate in air (D), Radium Equivalent Activity (Ra_{eq}), External Hazard Index (H_{ex}), Internal Hazard Index (H_{in}), Annual Gonadal Dose Equivalent (AGDE), Annual Effective Dose Equivalent (AEDE), Gamma Index (Iγ), Excess Lifetime Cancer Risk (ELCR), were calculated by considering the activity concentrations $A_{(^{226}Ra)}$, $A_{(^{232}Th)}$ and $A_{(^{40}K)}$ (in Bq kg^{-1}) of the three natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K, respectively in the marine sediments samples in coastal African.

Bellow, we define the different parameters of radiological risk:

Total Absorbed Dose Rate in air D (nGy h^{-1}) expresses the rate of exposure to gamma radiation in air at 1 m above the ground. The D was calculated by Monte Carlo method using (1) [14]:

$$D\ (nGyh^{-1}) = 0.462\ A_{(^{226}Ra)} + 0.604\ A_{(^{232}Th)} + 0.0417\ A_{(^{40}K)}. \quad (1)$$

Annual Effective Dose Equivalent AEDE (mSV) is calculated by applying a dose conversion factor of 0.7 Sv Gy^{-1} and occupancy factor for outdoor to assess the dose rate to an individual from outdoor gamma radiation over a period of one year. AEDE was calculated using (2) [22].

$$AEDE = D \times T \times F. \quad (2)$$

D is the calculated dose rate in (nGy h^{-1}), T the outdoor occupancy time (0.2 * 24 h * 365.25 day), which means (1753 h y^{-1}) and F the conversion factor (0.7 10^{-6}Sv Gy^{-1}).

Annual Gonadal Dose Equivalent AGDE (µSV y^{-1}) estimates the potential radiation dose that the gonads may receive from ^{226}Ra, ^{232}Th and ^{40}K. AGDE was calculated using (3)[22].

$$AGDE = 3.09\ A_{(^{226}Ra)} + 4.18\ A_{(^{232}Th)} + 0.314\ A_{(^{40}K)}. \quad (3)$$

Radium Equivalent Activity Ra_{eq} (Bq kg^{-1}) is a weighted sum of activities of the above three radionuclides based on the assumption that (370 Bq Kg^{-1} of ^{226}Ra), (259 ^{259}Bq Kg^{-1} of ^{232}Th) and (4810 Bq Kg^{-1} of ^{40}K) produces the same gamma dose rate. The Ra_{eq} was calculated using (4 or 5) [14]:

$$Ra_{eq} = 370\ \{(1/370)\ A_{(^{226}Ra)} + (1/259)\ A_{(^{232}Th)} + (1/4810)\ A_{(^{40}K)}\}. \quad (4)$$

$$Ra_{eq} = A_{(^{226}Ra)} + 1.43\ A_{(^{232}Th)} + 0.077\ A_{(^{40}K)}. \quad (5)$$

External Hazard Index H_{ex} is a measure of the indoor radiation dose rate associated with external gamma radiation exposure from natural radionuclides and it is important when considering the suitability of sediments as building materials [23]. For human health safety, the value of H_{ex} must not exceed 1.0 [23]. Owing to their relatively higher sensitivity to ionizing radiation compared to other organs of the body, the gonads are considered to be at a high risk of radiation exposure and are therefore of great interest in radiological assessment [22, 24].

H_{ex} was calculated using (6) [23]:

$$H_{ex} = \{(A_{(^{226}Ra)} / 370) + (A_{(^{232}Th)} / 259) + (A_{(^{40}K)} / 4810)\} < 1. \quad (6)$$

Internal Hazard Index H_{in} is used to control the internal exposure to ^{222}Rn and its radioactive progeny [25]. The internal exposure to radon and its daughter products is quantified by the internal hazard index (H_{in}), which is given by the following equation (7) [26]:

$$H_{in} = \{(A_{(^{226}Ra)} / 185) + (A_{(^{232}Th)} / 259) + (A_{(^{40}K)} / 4810)\} < 1. \quad (7)$$

Gamma Index Iγ:
The emission of gamma radiation depends on the dose criterion and the quantity of the sediment. Iγ was calculated using equation (8) [27].

$$I\gamma = \{(A_{(^{226}Ra)} / 150) + (A_{(^{232}Th)} / 100) + (A_{(^{40}K)} / 1500)\} < 1. \quad (8)$$

The value of these indexes must be less than unity in order to keep the radiation hazard insignificant.

Excess Lifetime Cancer Risk (ELCR) deals with the probability of developing cancer over a lifetime at a given exposure level(9) [27].

$$ELCR = AEDE \times DL \times RF. \quad (9)$$

With: AEDE: Annual Effective Dose Equivalent, DL: Duration of Life estimated at 70 years and RF: Risk Factor = 0.05.

3. Results

3.1. Natural Radionuclide activity concentrations

Table2 lists the radionuclides activity concentrations for ^{226}Ra, $^{232}Th$and ^{40}K in sediments of 20 regions in the three African coasts: the Atlantic Ocean, the Mediterranean Sea and the Red Sea.

For a better visualization, we represent the mean values in figure2.

In Mediterranean Sea, the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K are in the range of 5–24 Bq kg^{-1}, 2.1–23.95 Bq kg^{-1}, and 46–280.93 Bq kg^{-1} with a mean value of 12.22, 10.79 and 140.23 Bq kg^{-1} respectively. ^{226}Ra and ^{232}Th have low activity concentrations with the same order of magnitude, whereas, ^{40}K has the highest activity concentration. Shore sediments in Alexandria [10]and between Alexandria and Port Said city [9]have the lowest activity concentrations. These mean values are generally lower than the world wide average concentrations of ^{226}Ra, $^{232}Th$and ^{40}K, which are 35, 30 and 400 Bq Kg^{-1} respectively [1].

In Red Sea, always ^{226}Ra and ^{232}Th have similar values, except for the Hamraween region [13]; the activity concentrations of ^{226}Ra and ^{232}Th are in the range of 20.4–437.11 Bq kg^{-1} and 5.74–81.51 Bq kg^{-1} with the mean value 36.2 and 21.5 Bq Kg^{-1} respectively. However, the mean values of ^{40}K (409.8 Bq Kg^{-1}) shows an increase exceeding the world wide average concentration of ^{40}K (400 Bq Kg^{-1}) [1] at three regions; Safaga[11], Hurgada[11] and Shore sed., 1997 [14].

While *in Atlantic Ocean*: the values of ^{226}Ra differ from those of ^{232}Th five times. In an alarming way, the three radionuclides exceed the world wide average concentrations [1]in Bonny Estuary in Nigeria [18]. In addition, a less exceeding of the world wide average concentrations of ^{226}Ra, $^{232}Th$and ^{40}K [1]is also observed in Sdi Moussa in Morocco (Our Laboratory, 2016). The mean values of ^{226}Ra, ^{232}Th, and ^{40}K are 52.59, 104.56 and 675.57 Bq Kg^{-1} respectively.

Table 2:Minimum, maximum and average values of ^{226}Ra, ^{232}Th and ^{40}K concentrations in studied samples.

Oceans & Seas	Country	Location	Parameters	^{226}Ra (Bq Kg^{-1})	^{232}Th (Bq Kg^{-1})	^{40}K (Bq Kg^{-1})
Miditeranean Sea	Spain	Bay Algeciras, 2006[7]	Average	12.1	15	188
			Min	4.2	6.2	24
			Max	22.9	31.2	535
	Egypt	Nile Delta Coastal profiles[8]	Average	23.79	23.95	280.93
			Min	10.42	9.21	160.55
			Max	40.3	53.1	399.04
		Shore sed., between Alexandria & Port Said[9]	Average	8	2.1	46
			Min	3	0.6	10
			Max	13.8	7.8	138.8
		Shore sed., Alexandria [10]	Average	5	2.1	46
			Min	3	0.6	1
			Max	10.8	7.8	86.1
RedSea	Egypt	Safaga[11]	Average	25.3	21.4	618
			Min	10	9	421
			Max	64	37.4	969
		Hurgada[11]	Average	20.6	22.4	548
			Min	16.1	18.1	423
			Max	24.7	27.3	655
		Ras GharebCoast[12]	Average	28	23.9	381.4
			Min	6	8	86
			Max	52	45	1640
		Ras El Behar[13]	Average	15.2	16.2	330.7
			Min	7.34	5.59	103.56
			Max	24.21	28.95	455.28
		Hamraween[13]	Average	114.2	14.8	235.9
			Min	20.4	5.74	101.6
			Max	437.11	81.51	349.06
		Shore sed., 1997[14]	Average	24.6	31.4	427.5
			Min	5.2	2.3	97.6
			Max	105.6	221.9	1011.3
		Quseir city[15]	Average	25.8	20.1	327
			Min	1.28	3.9	14.8
			Max	57.8	47.2	2665.4
Atlantic Ocean	Negeria	2008[16]	Average	17.42	68.42	527.86
			Min	7.64	30.33	142.57
			Max	52.71	243.25	937.21
		River Igbokoda, Ondo State[17]	Average	11.15	10.73	63.89
			Min	6.6	5.7	17
			Max	19.4	23.6	99.8
		Bonny Estuary[18]	Average	281.67	577.67	3626
			Min	175	415	300
			Max	484	840	9800
	Ghana	Shore sed., coast of Accra[19]	Average	22.04	108.6	29.78
			Min	0.62	0.17	8.6
			Max	140.8	732	43.97
		Tema Harbour, Accra[3]	Average	14	30	320
			Min	10	19	250
			Max	20	70	570
	Morocco	Sebou Estuary, 2009[20]	Average	17.7	18.5	318.7
			Min	16	16	209
			Max	19	20	385
		Oualidia(Our Laboratory, 2016)	Average	28.84	41.11	264.68
			Min	16.02	24.6	116.39
			Max	47.42	76.4	380.01
		Sidi Moussa(Our Laboratory, 2016)	Average	62.86	64.72	449.24
			Min	18.08	23.39	318.18
			Max	126.01	126.12	526.31
	Spain	GranCanaria[21] (Canary Islands)	Average	17.6	21.3	480
			Min	8.1	7.4	130
			Max	26.7	41.9	1055

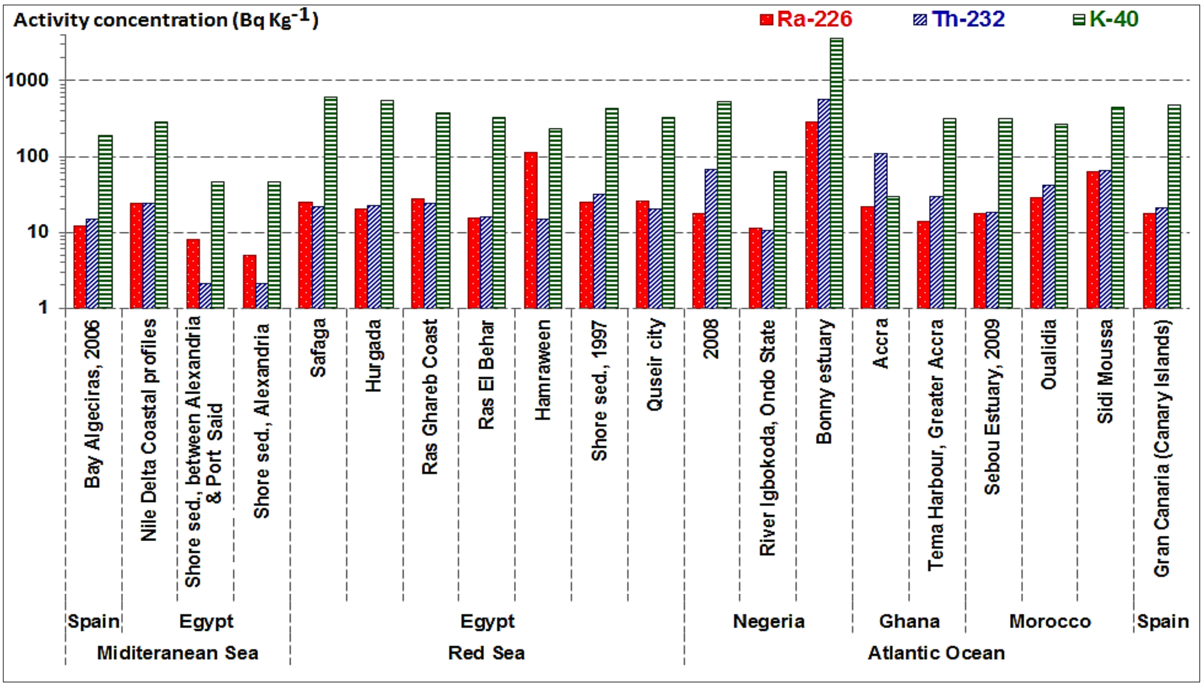

Figure 2: Mean activity Concentrations of the Radioelements (in Bq kg^{-1}) Found in Studied Samples.

3.2. Assessment of radiological hazard effects on human health

As shown in Table3 and figure3, the results obtained for Absorbed Dose Rate (D) in air due to natural radionuclides ^{226}Ra, ^{232}Th and ^{40}Kin the three directions, the Mediterranean Sea, the Red Sea and the Atlantic Ocean, are lower than 59 nGy h^{-1} (the world reference value)[1]. D knows a slight increase in Red Sea in Hamraween(71.54 nGy h^{-1})[13]and in Atlantic Ocean in Negeria 2008 (71.39nGy h^{-1}) [16], Accra (77.02 nGy h^{-1})[19] and Sidi Moussa (86.87 nGy h^{-1})(Our Laboratory, 2016). But in Bonny Estuary in Atlantic Ocean, Dexceeds the reference value more than 10 times (630.25nGy h^{-1}) [18], which can have serious consequences on human health. For the measured values *Annual Effective Dose Equivalent (AEDE)*, the range due to natural radionuclides is from 0.01 to 0.77 mSv. These values are considered normal and they are lower than the background radiation 2.4 mSv[1].The *Annual Gonadal Dose Equivalent (AGDE)*exceeds the permissible values of 300 µSvy^{-1} in 10 areas particularly in the Red Sea and the Atlantic Ocean. The calculated value in Bonny Estuary in Atlantic Ocean is far above 300 µSv y^{-1} of almost 15 times (4423.59 µSv y^{-1}).

As always, Bonny Estuary in Atlantic Ocean knows a significant overshoot of the reference standard for *Radium Equivalent Activity (Ra_{eq})*estimated at 370Bq Kg^{-1}, for the other regions, there is a respect of this recommended value for the safe use of materials in the construction of buildings[5, 28].Also, the same remark is observed for the *External Hazard Index (H_{ex})*, *Internal Hazard Index (H_{in})* and *Gamma Index ($I\gamma$)* that are far greater than the world permissible value of unity 3.75, 4.51 and 10.07 respectively in Bonny Estuary [18]. And almost equal to unity in Red Sea in Hamraween[13]and in Atlantic Ocean in Negeria(2008)[16], Accra [19]and Sidi Moussa (Our Laboratory, 2016). Similarly, for the *Excess Lifetime Cancer Risk (ELCR)*,there is a slight overshoot of the world average value of 0.25[1]in Hamraween[13], Nigeria (2008) [16],Accra[19]and Sidi Moussa(Our Laboratory, 2016).And as usual, Bonny Estuary knows the highest excess of this value2.71[18].

Table 3:Calculated D, AEDE, AGDE, Ra_{eq}, H_{ex}, H_{in}, Iγ and ELCR in the studied samples.

Oceans & Seas	Country	Location	D nGy h^{-1}	AEDE mSV	AGDE μSV y^{-1}	Ra_{eq} Bq Kg^{-1}	H_{ex}	H_{in}	Iγ	ELCR
MiditeranenSea	Spain	BayAlgeciras, 2006[7]	22.49	0.03	159.12	48.03	0.13	0.16	0.36	0.10
	Egypt	Nile Delta Coastal profiles[8]	37.17	0.05	261.83	79.67	0.22	0.28	0.59	0.16
		Shore sed., between Alexandria & Port Said[9]	29.09	0.04	201.28	68.50	0.19	0.19	0.48	0.13
		Shore sed., Alexandria, [10]	5.50	0.01	38.67	11.55	0.03	0.05	0.09	0.02
RedSea	Egypt	Safaga[11]	50.39	0.06	361.68	103.49	0.28	0.35	0.80	0.22
		Hurgada[11]	45.90	0.06	329.36	94.83	0.26	0.31	0.73	0.20
		Ras Ghareb[12]Coast	43.28	0.05	306.18	91.55	0.25	0.32	0.68	0.19
		Ras El Behar[13]	30.60	0.04	218.52	63.83	0.17	0.21	0.48	0.13
		Hamraween[13]	71.54	0.09	488.82	153.53	0.42	0.72	1.07	0.31
		Shore sed., 1997[14]	48.16	0.06	341.50	102.42	0.28	0.34	0.76	0.21
		Quseir city[15]	37.70	0.05	266.42	79.72	0.22	0.29	0.59	0.16
Atlantic Ocean	Negeria	2008[16]	71.39	0.09	505.57	155.91	0.42	0.47	1.15	0.31
		River Igbokoda, Ondo State[17]	14.30	0.02	99.37	31.41	0.09	0.12	0.22	0.06
		Bonny Estuary[18]	630.25	0.77	4423.59	1386.94	3.75	4.51	10.07	2.71
	Ghana	Accra[19]	77.02	0.09	531.40	179.63	0.49	0.55	1.25	0.33
		Tema Harbour, Greater Accra[3]	37.93	0.05	269.14	81.54	0.22	0.26	0.61	0.16
	Morocco	Oualidia(Our Laboratory, 2016)	49.19	0.06	344.07	108.01	0.29	0.37	0.78	0.21
		Sidi Moussa(Our Laboratory, 2016)	86.87	0.11	605.83	190.00	0.51	0.68	1.37	0.37
		Sebou Estuary, 2009[20]	32.64	0.04	232.10	68.70	0.19	0.23	0.52	0.14
	Spain	GranCanaria (CanaryIslands) [21]	41.01	0.05	294.14	85.02	0.23	0.28	0.65	0.18
The world reference values [1]			59	2.7	300	370	1	1	1	0.25

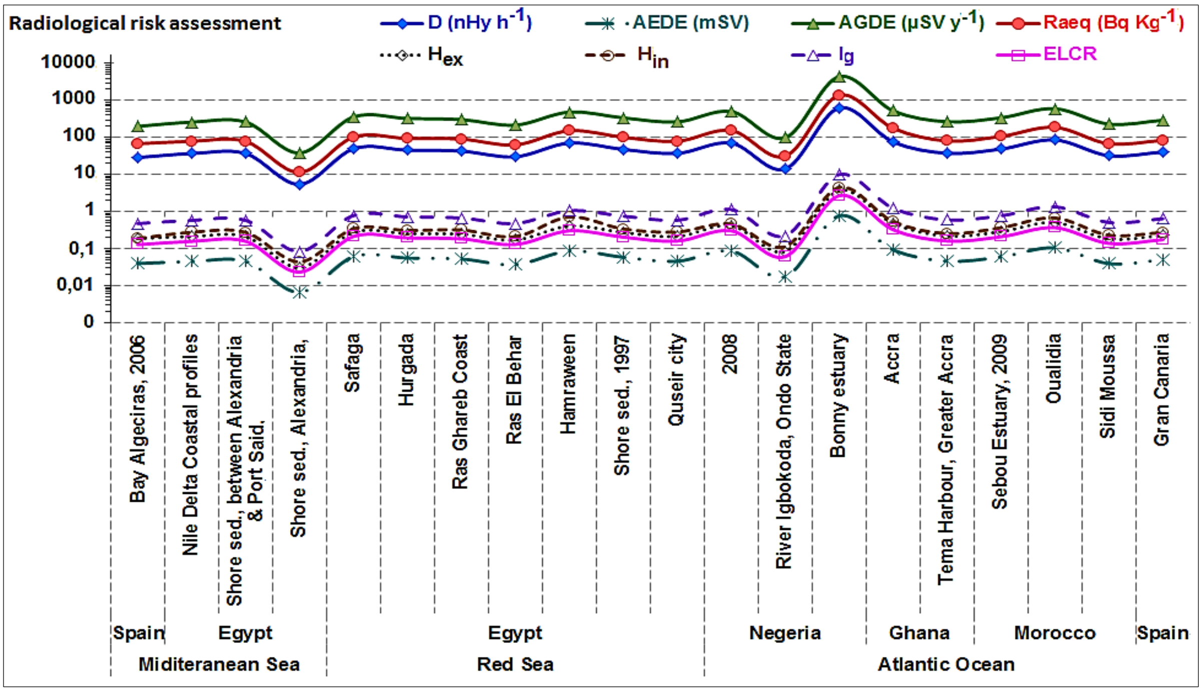

Figure 3:Profiles of radiological parameters calculated in the studied samples.

4. Discussion

From the results obtained, we can say that the activity concentrations in the Mediterranean Sea are lower than those of Red Sea and both of them are lower than those of Atlantic Ocean. Also, ^{40}K dominates over the other isotopes because it is the most abundant in continental rocks and it is elevated in many light minerals [27]. Also, activity of radionuclides measured in the sediments of the Bonny Estuary, Nigeria were higher than reported elsewhere and higher than reported global averages [1].

In addition, concerning radiological hazardindices, Bonny Estuary in the Atlantic Ocean has serious consequences on human health. Especially for AGDE, that implies that the gonadal values may pose serious threat to the bone marrow and the bone surface cells of the workers in the area under study [27];H_{ex}, H_{in} and $I\gamma$ which indicates that the value poses a high risk to respiratory diseases such as asthma, cancer including external diseases such as skin cancer, erythema, cataracts… [27]; and the ELCR that shows that the risk of developing cancer- by the workers and the people living near this environment in general- is very high [27].

In fact, the importance of the radionuclide activities measured and some radiological hazard indices calculated in the sediments of the Bonny Estuary can be explained by the oil production and rapid urbanization activities near the sampling site[18].

5. Conclusion

We can conclude that among the 20 regions studied in this work, the results obtained show that the mean activity concentration for ^{226}Ra, ^{232}Th and ^{40}K in sediment samples are 17.6, 15.7 and 216.9 Bq kg^{-1} respectively in Mediterranean Sea, 36.2, 21.5 and 409.8 Bq Kg^{-1} respectively in Red Sea and 52.59, 104.56 and 657.57 Bq Kg^{-1} respectively in Atlantic Ocean. These values in Atlantic Ocean and for ^{226}Ra and ^{40}K in Red Sea exceed the world reference values of 35, 30 and 400 Bq kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K respectively.

Concerning the radiological risk assessment, we found that four areas present a low risk, since there is a slight excess of the world permissible values, one area with serious health hazard (Bonny Estuary, Nigeria). While the remaining 15 areas considered to be safe.
The information obtained in this study can be used as reference data for future investigations on natural radioactivity.

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Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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