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*International Journal of
Nuclear and Radiation Science and Technology
(IJNuRaSaT)
Vol. 1-No.1 (2016) pp. 7-11
<http://ulakbim.dergipark.gov.tr/ijnurasat>*



Research Article

Evaluation of Natural Radioactivity and Assessment of Radiation Hazard Indices in Some Sediment Samples from Streams of East Algeria[#]

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(Received date: 30 October 2015, Accepted date: 15 February 2016)

[#] Presented in "2nd International Conference on Computational and Experimental Science and Engineering (ICCESEN-2015)"

Keywords

Dam sediment samples
Radionuclides
Gamma spectrometry
Radiation hazards

Abstract: The specific activities natural radionuclides have been measured in sediment samples collected from Beni Haroun Dam using gamma spectrometry. The mean activity concentrations of ^{238}U , ^{235}U and ^{232}Th as well as primordial ^{40}K were found 52.54, 2.37, 19.60 and 183.92 Bq/kg, respectively. The study also examined radiation hazard indices, the mean values obtained are 66.5 Bq/kg, 0.18, 0.25, 0.48 for Radium equivalent activity (R_{eq}), External Hazard index (H_{ex}), internal hazard index (H_{in}) and Representative level index (I_{r}), respectively. In addition, Absorbed dose rate (D) and annual effective dose (AED) were found equal to 30.76nGy h^{-1} and $37.75\mu\text{Sv y}^{-1}$, respectively. The results obtained in the current work are compared with analogue measurements from other locations.

1. Introduction

Natural radioactivity is widespread in the earth's crust and it exists in various geological formations in soil and rock, sediments, plants and water [1]. Gamma radiation from radionuclides, such as ^{40}K and the ^{238}U and ^{232}Th series and their decay products, represent the main external source of irradiation to the human body addition to beta decays and therefore contribute significantly to gamma radiation exposure [2]. The natural radionuclides concentration in sediments originates from soils and rocks would affect the natural radioactivity level of rivers and lake. To assess the natural radioactivity, several studies have been previously carried out in sediment samples of rivers and lake in some part of the world [3-10]. In the present work, concentrations of natural radionuclides in Beni haroun dam sediment samples

were determined using γ -ray spectroscopy and the radiological hazard indices were evaluated.

2 Materials and Methods

2.1 Description of study area

Beni Haroun dam, constructed in August 2003, is located in Algeria North-Eastern part, at about 15 km of the Mila city (Figure 1). This dam is a rectilinear gravity concrete dam of initial capacity equal to 963 Mm^3 and 120 m of deep which used for covering the needs on water of both allocation and irrigation of the neighboring provinces including the Constantine main city.

The Beni Haroun dam is located in downstream of the confluence of Rhumel and Oued Endja to 40 km north of Constantine.

2.2 Sample collection and measurement

Four samples were collected from Beni Haroun dam in spring 2013. Figure 1 shows the sampling locations.



Figure 1: Study area.

Approximately 1 kg of weight per sample was obtained at a depth 5 cm from the top surface layer. Each sample was then dried about 48h at 110°C temperature in an oven until weight become constant. About 30 to 35g of each dried sample has been packed in the cylindrical plastic container (d=53mm, h=16 mm) having the same geometry as detector and stored for four weeks before counting for to ensure the secular equilibrium between thorium and radium and their decay products [5]. The sediment samples are analyzed at low activity laboratory (LBA) [11], using two germanium detectors made of high purity quality. Both detectors are surrounded by 2 cm of lead exempt of natural radioactivity (archeological lead), and by 15 cm of purified lead. The two detectors and the lead plate are placed at the center of a two meter high cube. Each face of this cube is made with a liquid sparkle detector. The detectors have a relative efficiency of 20% and the energy resolution is 0.82 at 122 keV (^{57}Co) and 1.85 keV at 1332 keV (^{60}Co) gamma line [11]. The resultant spectral data was analysed using Interwinner (ITECH-instruments) software. Each sample was measured about 40h and was analyzed after subtraction of the background spectrum. The activity concentrations were calculated as follows:

Table 1: Prominent gamma energy used for estimation of radionuclides activity

Parent radionuclides	Gamma emitting nuclide	Gamma energy(keV)	Branching intensity of gamma decay (%)
^{238}U	^{234}Th	63.3	3.74
^{226}Ra	^{214}Pb	351.91	35.56
	^{214}Bi	609.31	40.48
^{238}U	-	143.77	10.50
	-	185.72	55.29
^{232}Th	^{212}Pb	238.6	43.55
	^{228}Ac	911	25.38

	^{208}Tl	583.1	27.52
^{40}K		1460.82	10.55

The activity concentrations for the natural radionuclides in the measured samples were evaluated using the following relation:

$$A_s = \frac{N_E}{\varepsilon_E p t m} \quad (1)$$

N_E and ε_E are the net peak area and the detection efficiency at energy E, respectively; p is the branching ratio of radionuclide of interest; t is the counting time (s); m is the weight of the measured sample in kg.

3 Radiation Hazard Indices Calculation

The known radiation health hazard indices analysis to arrive at a better and safer conclusion on the health status of a radiated or irradiated person and environment. To assess the radiation hazards associated with the sediment samples, six quantities have been defined [5, 8].

3.1 Radium equivalent activity index (Ra_{eq})

To represent the activity levels of ^{226}Ra , ^{232}Th and ^{40}K by a single quantity, which takes into account the radiation hazards associated with them, a common radiological Index has been introduced [8]. This Index is called Radium equivalent (Ra_{eq}) activity and is mathematically defined by [3]:

$$Ra_{eq} = 0.077A_k + 1.43A_{Th} + A_{Ra} \quad (2)$$

Where A_k , A_{Th} and A_{Ra} are the concentrations of ^{40}K , ^{232}Th and ^{226}Ra respectively. In the above relation, it has been assumed that 10 Bq/kg of ^{226}Ra , 7 Bq/kg of ^{232}Th and 130 Bq/kg of ^{40}K produce equal gamma dose. The maximum value of Ra_{eq} must be less than 370 Bq/kg for safe use [5, 8].

3.2 Representative level index (I_γ)

Another radiation hazard index used for the estimation of gamma radiation associated with the natural radionuclides in the soil called the representative level index I_γ , defined according to [3]:

$$I_\gamma = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (3)$$

The safety value for this index is ≤ 1

3.3 External and internal hazard indices

(H_{in}, H_{ex})

Other significant factors are dependent on the evaluation of the activity concentrations of ^{226}Ra . The first factor is named Internal Hazard Index (H_{in}) which represents radiation hazard to respiratory organs due to ^{222}Rn and ^{220}Rn and their progenies. The prime objective of these indices is to limit the radiation exposure attributable to natural radionuclides in the samples to the permissible dose equivalent limit 1 mSv y^{-1} [9]. The internal hazard index (H_{in}) is given by the equation:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (4)$$

The second factor is named External Hazard Index (H_{ex}) reflecting the external exposure. It is given by the following formula [3] :

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (5)$$

The values of the indices (H_{in} , H_{ex}) must be less than unity for the radiation hazard to be negligible [8]. A value of H_{in} and H_{ex} equal to 1 corresponds to a radium equivalent activity 370 Bq/kg [3].

3.4 Absorbed dose rate (D)

The absorbed dose rates in outdoor (D) due to gamma radiations in air at 1m above the ground surface for the uniform distribution of the naturally occurring radionuclides (^{226}Ra , ^{232}Th and ^{40}K) were calculated based on guidelines provided by [3]

$$D(n\text{Gy.h}^{-1}) = 0.462A_{Ra} + 0.621A_{Th} + 0.041A_K \quad (6)$$

The conversion factors used to compute absorbed γ -dose rate (D) in air per unit activity concentration in Bq/kg (dry-weight) corresponds to 0.462 nGy h^{-1} for ^{226}Ra (of U-series), 0.621 nGy h^{-1} for ^{232}Th and $0.0417 \text{ nGy h}^{-1}$ for ^{40}K [3].

The acceptable value for external absorbed dose rate must be less than 59 nGy h^{-1} [3].

3.5 Annual Effective Dose (AED)

The annual effective dose equivalent received outdoor by a member is calculated from the absorbed dose rate by applying dose conversion

factor of 0.7SvGy^{-1} and outdoor occupancy factor (0.2) proposed by [3] :

$$AED(\mu\text{Svy}^{-1}) = D(n\text{Gy.h}^{-1}) \times 8760\text{h} \times 0.7\text{SvGy}^{-1} \times 10^{-3} \times 0.2$$

$$AED(\mu\text{Svy}^{-1}) = D(n\text{Gy.h}^{-1}) \times 1.23 \quad (7)$$

The worldwide annual effective dose from the natural sources of radiation in areas of normal background is estimated to be $70 \mu\text{Svy}^{-1}$ by [3].

4 Results and Discussion

From gamma spectrometric analysis; the natural radionuclides were determined (^{238}U , ^{235}U , ^{232}Th , ^{40}K) in sediment samples. Table 2 present the activity concentrations measured in sediment samples from Beni Haroun dam. Most of the identified radionuclides presented in Table 2 belong to the ^{238}U , ^{232}Th decay chains. In addition to these ^{40}K was detected in all samples. However, no artificial radionuclide was detected at any of the site and the activity concentrations of radionuclides varied from site to site.

The result shows that the values of the activity concentration for ^{238}U are found in the range of 12.90 ± 2.45 to $136.75 \pm 64.53 \text{ Bq/kg}$ with the mean value $52.55 \pm 16.57 \text{ Bq/kg}$. The ^{232}Th concentration is varied in the range of 7.87 ± 0.52 to $47.56 \pm 7.75 \text{ Bq/kg}$ with the mean value $19.60 \pm 1.99 \text{ Bq/kg}$. ^{40}K concentrations are found to vary from 62.58 ± 7.77 to $324.50 \pm 107.50 \text{ Bq/kg}$ with the mean value of $183.93 \pm 27.37 \text{ Bq/kg}$. However, the ^{235}U activity concentration is much smaller than the other radionuclides. It's found in the range of 0.60 ± 0.11 to $6.12 \pm 2.17 \text{ Bq/kg}$ with the mean value of $2.37 \pm 0.91 \text{ Bq/kg}$.

The measured activity concentration values in the current world are compared with the results values reported worldwide as shown in the Table 3. The variations by location in the presented data arise from the fact that natural radionuclides are not distributed evenly in the earth's crust and the intensive uses of the fertilizers near the dam. The results showed that the measured activity concentration of ^{238}U in this work is higher than data presented from Sudan, Egypt and Nigeria (Igboho). ^{232}Th concentration in the present study is greater than Sudan and Igboho (Nigeria) but it's less than Egypt. We also noted that activity concentration of ^{40}K is lower than data presented in the all countries as shown in Table 3. The obtained results are compared to the worldwide average concentration of these radionuclides in the sediment

reported by [3] which 33, 35, 400 Bq/kg for ^{238}U , ^{232}Th and ^{40}K respectively, as shows in Table 3.

The Activity concentrations of radionuclides were used to assess the radiological indexes using the equation mentioned in the text. The values of R_{eq} are less than the accepted safety limits value as well as the values of the representative level index I_γ , H_{ex} and H_{in} which are below the limit of unity as shown in Table 4. The values of absorbed dose (D) ranged from 12.33 ± 0.67 to $61.36 \pm 6.53 \text{ nGyh}^{-1}$ with the mean value $30.76 \pm 2.54 \text{ nGyh}^{-1}$ which is lower than the world average value of 59 nGyh^{-1} given by

[3]. The annual effective dose equivalent (AED) mean value is $37.75 \pm 2.91 \mu\text{Svy}^{-1}$, this value is lower than $70 \mu\text{Svy}^{-1}$ recommended by[3].

Table 2: Activity concentrations of natural radionuclides in samples

Origin	Radionuclides	$A_I(\text{Bq/Kg})$	$A_{II}(\text{Bq/Kg})$	$A_{III}(\text{Bq/Kg})$	$A_{IV}(\text{Bq/Kg})$
^{238}U Series	^{214}Bi	31.22 ± 9.76	8.33 ± 1.17	16.09 ± 4.47	18.55 ± 1.46
	^{214}Pb	36.87 ± 8.67	8.97 ± 0.76	15.50 ± 1.80	21.48 ± 1.47
	^{226}Ra	41.43 ± 8.30	10.42 ± 0.87	20.55 ± 1.90	24.96 ± 4.24
	^{234}Th	-	12.90 ± 2.45	45.74 ± 18.71	21.31 ± 4.05
^{232}Th Series	^{208}Tl	46.34 ± 13.94	8.52 ± 1.10	12.48 ± 2.59	22.47 ± 1.91
	^{212}Bi	-	7.86 ± 3.44	-	19.38 ± 3.43
	^{212}Pb	49.20 ± 12.23	7.88 ± 0.77	10.23 ± 1.35	20.37 ± 1.59
	^{228}Ac	47.18 ± 14.03	7.22 ± 0.80	17.45 ± 3.46	19.58 ± 1.34
^{235}U Series	^{235}U	6.12 ± 2.17	0.60 ± 0.11	1.78 ± 1.19	0.98 ± 0.19
Primordial	^{40}K	324.5 ± 107.5	62.58 ± 7.77	78.71 ± 1.88	269.9 ± 18.01

Table 3: The comparison of measurement results of activity concentrations of ^{238}U , ^{232}Th and ^{40}K from various countries.

Location	Number of samples	$^{238}\text{U}(\text{Bq/Kg})$		$^{232}\text{Th}(\text{Bq/Kg})$		$^{40}\text{K}(\text{Bq/Kg})$		Reference
		Range	Mean	Range	Mean	Range	Mean	
Sudan	18	6-78	20.11	8-43	19.10	92-688	280.29	[12]
Igboho, Nigeria	10	6-9	3.2 ± 10.3	0.16-2.85	8.6 ± 2.9	187-695	581.9 ± 24.1	[7]
Egypt	30	13-42	29.15	10-47	45.08	74-139	115.72	[13]
Beni Haroun Algeria	4	13-137	52.55 ± 16.57	2-48	22.41 ± 1.99	63-325	183.93 ± 27.37	Present study
World's average	-	-	33	-	30	-	400	[3]

Table 4: Radiation hazard index of sediment samples

Samples	I	II	III	IV	safety limits value (UNSCEAR, 2000)
$R_{eq}(\text{Bqkg}^{-1})$	134.43 ± 16.13	26.79 ± 1.43	29.47 ± 14.76	75.33 ± 13.98	370
H_{ex}	0.36 ± 0.043	0.07 ± 0.01	0.08 ± 0.01	0.20 ± 0.01	1
H_{in}	0.48 ± 0.06	0.10 ± 0.01	0.14 ± 0.01	0.27 ± 0.01	1
I_γ	0.97 ± 0.01	0.19 ± 0.01	0.21 ± 0.02	0.55 ± 0.01	1
$D(\text{nGyh}^{-1})$	61.36 ± 6.53	12.33 ± 0.67	13.88 ± 1.49	35.17 ± 1.45	59
$AED(\mu\text{Svy}^{-1})$	75.67 ± 8.05	15.13 ± 0.01	17.04 ± 1.82	43.16 ± 1.78	70

5 Conclusion

The natural radioactivity levels of ^{238}U , ^{235}U , ^{232}Th and ^{40}K have been measured in sediment samples collected from Beni Haroun dam using gamma ray spectrometry. The obtained results showed that the radionuclides ^{238}U , ^{232}Th decay chains and ^{40}K are contained in all samples. The ^{235}U radionuclide is present in small quantities across all samples. The mean activity concentrations ^{232}Th and ^{40}K in this

work are found lower than the world average identified by [3] but the mean value of ^{238}U in investigated work is higher than the world average due to uses of the fertilizers near the study area. The artificial radionuclide was not found in the current study. The values of the radiation hazard parameters from this work are not significant compared to the world average

Acknowledgement

Authors thanks to ICCESN-2015 for the organization and the supports providing during this conference.

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