International Journal of Science and Technology Volume 2 No. 11, November, 2013

Preliminary study on the levels of natural radionuclides in sediments of the Tono irrigation dam, Navrongo

Raymond Agalga[1], E O Darko[1], Cyril Schandorf [2]
[1]Radiation Protection Institute, Ghana Atomic Energy Commission, Kwabenya
[2]School of Nuclear and Allied Science, University of Ghana, Legon

ABSTRACT

The concentrations of natural radionuclide ^{238}U, ^{232}Th and ^{40}K in the sediments of the Tono irrigation dam have been evaluated using gamma spectrometry. The study was carried as part of efforts to acquire data needed by the Regulatory Body in Ghana to set NORM standards for the country. From the study, the concentrations of natural radionuclides ^{238}U, ^{232}Th and ^{40}K ranged from 5.19Bq/Kg to 8.66 Bq/Kg with an average of 7.31Bq/L for ^{238}U, 5.83 Bq/Kg to 8.16 Bq/Kg with an average of 6.91 Bq/Kg for ^{232}Th. and 218.73 Bq/Kg to 453.25 Bq/Kg with an average of 379.94 Bq/Kg for ^{40}K. The Radium Equivalent Activity(Ra_{eq}), Internal Hazard Index(H_{in}), External Hazard Index(H_{ex}) , Indoor Absorbed Dose Rate (D_{in}) and the corresponding Indoor Annual Effective Dose (ADE) were evaluated for the public to assess radiological hazard arising due to the use of the sediments as a building material. The results were observed to be lower than limits internationally reported and recommended for building materials.

Keywords: *Tono Irrigation dam, sediments, gamma spectroscopy, natural radionuclide, hazard index*

1. INTRODUCTION

Naturally occurring radioactive materials (NORMs) contain insignificant amounts of radionuclides in the environment. Geological materials when disturbed or altered from natural settings, present technologically enhanced concentrations of NORMs above the background radiation levels due to human activities this may result in a relative increase in radiation exposures and risks to the public and the environment. Radioactivity in the environment is mainly due to the presence of long-lived radionuclides; of the ^{238}U, ^{235}U and ^{232}Th series and ^{40}K. Their distribution in the earth crust depends on the type of rocks formation under the earth's crust (Mujahid and Hussain, 2010).

When rocks are disintegrated through natural processes, radionuclides are carried to soil by rain and flows (Taskin et al., 2009). Soil radionuclide activity concentration is one of the main determinants of the natural background radiation. The knowledge of the distribution of these radionuclides in soil, water, sediment, rock and building materials plays an important role in the protection, measurement, geoscientific research and guidelines for the use and management of these materials (Ravisankar et al, 2011).

Radioactivity present in surface continental waters is mainly due to the presence of radioactive elements in the earth crust. Human activities (mining, milling and processing of uranium ores and mineral sands, manufacture of fertilizers, burning of fossils fuels, metal refining, farming, etc.) have raised natural radioactivity concentrations in the environment. These Radioactive materials can reach surface continental waters by different pathways from each of the processes or activities. Rivers and Dam water can be contaminated by surface runoff of rainwater transporting leached radionuclides from cities, mine waste, soil weathering, agricultural areas (Pujol and Sanchez, 2000). In the long term, radioactivity in a water body can remain at significant levels as a result of secondary contamination processes. Due to gravitational settling and other depositional phenomena, the highest proportion of the radioactive materials is mainly found in the sediment compartment of the aquatic ecosystem. (Olatunde et al, 2011). Thus river sediment is considered as a durable and reliable register of the river pollution by radionuclides (Bikit et al, 2005). Knowledge of natural radioactivity present in aquatic sediments enables one to assess any possible radiological hazard to mankind by the uses of such materials especially in building and construction material (Ramasamy et al, 2011).

2. MATERIALS AND METHODS

2.1 Study Area

The Tono irrigation dam is a strategic asset to the Government of Ghana and the people of the nine communities that live around the catchment area. The Tono irrigation scheme is the largest in the country and has the largest agriculture dam in West Africa (David, 2008). It was constructed between 1975 to1985 on the Tono River. It covers a total catchment area of 3,600 ha and provides a developed area of 2,400 ha for growing irrigated crops. It is located at Tono in the Kassena Nankana District of the Upper East region and cuts across the Builsa District of the same region.

2.2 Sampling and Sample Preparation

Ten (10) sediment samples were taken from the Tono irrigation dam. The sediments were taken from points about ten (10) meters from the bank of the dam where sediments are believed not to be disturbed. The point of collection of each sample was given a unique code and noted with its GPS coordinate taken with a Garmin eTrex Venture HC handheld GPS device. The distance between the sampling points was about 1.5 Km. Samples were air dried in the laboratory for a week and oven dried at 110^oC to ensure the samples were properly dried. The samples were ground into powdered using a stone mill and sieved through a 0.45micron mesh, weighed and sealed into a 1Litre Marinelli beaker. The samples were kept for a period of 30 days to assume secular equilibrium between parent and daughter radionuclides.

2.3 Sample Analysis

Radiometric analyses of the samples were carried out using a High resolution gamma spectrometer consisting of high purity germanium detector and counting in the laboratories of the Ghana Research Reactor-I Centre of the National Nuclear Research Institute, Ghana Atomic Energy Commission. The high purity germanium detector crystal has a diameter of about 36 mm and thickness of about 10 mm. The crystal is housed in an aluminium canister with a 0.5 mm thick beryllium entrance window. A lead shield, built with 5 cm thick lead brick surrounds the detector to prevent it from external background radiation reaching the detector. The detector is coupled to a Canberra 1510 signal processing unit which contains the power supply, amplifier and analogue to digital converter. Digitized counts are collected in a Canberra S100 multi-channel analyzer. The detector is connected to an Uninterrupted Power Supply (UPS). The detector is cooled with liquid nitrogen at -196 ^0C (77K) provided in a 35 litre Dewar. The ambient temperature around the detector varied between 16^oC and 37^oC during the period of measurement.

Prior to the analysis of the samples, energy and efficiency calibrations were performed to enable identification and quantification of the radionuclides of interest. The detector system was calibrated using the multinuclide reference standard solution (NW 146) provide by the International Atomic Energy Commission (IAEA). The standard was counted in the 1.0 litre Marinelli beaker using a counting time of 36000 seconds. Table 1 shows the gamma lines used to determine the concentrations of ^{238}U, ^{232}Th and ^{40}K in the samples.

3. RESULTS AND DISCUSSIONS

3.1 Activity Concentration

The specific activity concentration ($BqKg^{-1}$) in Sediments was computed using the following relation from Awudu et al, (2010).

$$C_{sam} = \frac{N_{sam}}{P_E \times \varepsilon(E\gamma) \times M_{sam} \times T_c} \qquad (1)$$

Where, C_{sam} is the concentration of a specific radionuclide in a sample, M_{sam} is the mass of the sample (Kg), N_{sam} is the net counts for the sample in the peak range, P_E is the emission probability, T_c is the counting time, and ε (Eγ) is the photo peak efficiency.

The results of activity concentrations (in Bq Kg^{-1}) of ^{228}U, ^{232}Th and ^{40}K in the samples are shown in Table 2. It can be seen from the table that the concentration of ^{238}U, ^{232}Th and ^{40}K in the dam sediment ranged from 5.19 to 8.66 $Bqkg^{-1}$, 5.83 to 8.16 $Bqkg^{-1}$ and 218.73 to 453.25 $Bqkg^{-1}$ with an average of 7.31 $Bqkg^{-1}$, 6.91 $Bqkg^{-1}$, and 379.94 $Bqkg^{-1}$ respectively. In all sampled areas the activity concentration of potassium was higher than that of uranium and thorium, clearly shown in Figure 2. The natural concentrations of ^{238}U and ^{232}Th in the earth's crust are 2.9 and 9.6 ppm, which are equivalent to activity concentrations of 36 and 39 $Bqkg^{-1}$, respectively. This indicates that the concentration of ^{238}U and ^{232}Th from this work is less than the natural concentration in the earth's crust and the average concentration reported elsewhere as shown in Table 3. Uranium is often found in deficit with respect to thorium in the solid surface environment because uranium's 4+ oxidation state makes it soluble (Perianez and Aguirre, 1997). The results from this work show an average ^{232}Th/ ^{238}U of 1.02 meaning on the average, ^{238}U concentration is greater than ^{232}Th ^{in} sediments samples of Tono irrigation dam.

3.2 Radiological Detriments

To quantify the radiation detriment to members of the public as a result of the activity concentration in the sediments, the radium equivalent activity (Ra_{eq}), external hazard index (H_{ex}) and internal hazard index (H_{in}), indoor absorbed dose rate and the corresponding indoor annual effective dose were used as radiological indicators to estimate the radiological implications of the use of sediments from the Tono Irrigation dam as building materials. The results are shown in Table 4.

3.2.1 Indoor Absorbed Dose Rate.

The indoor absorbed dose rate (D_{in}) due to the external gamma radiation from the ^{238}U, ^{232}Th and ^{40}K radionuclides in the sediment when used as building material, were evaluated using the following formulae and assumptions provided in the EC report.

$$D_{in} = 0.92 \times C_U + 0.10 \times C_{TH} + 0.08 C_K \qquad (2)$$

Where D_{in} ($nGyhr^{-1}$) represents the total indoor air absorbed dose rate due to the specific activity concentrations C_K, C_U and C_{Th} ($Bqkg^{-1}$) for ^{40}K, ^{238}U and ^{232}Th, respectively and 0.92, 0.10 and 0.08 are coefficients corresponding to a standard room size of $4\,m \times 5\,m \times 2.8\,m$ with walls, floor and ceiling thickness and density of 20 cm and 2350 kg m^{-3} (concrete), respectively according to the EC report.

3.2.2 Indoor Annual Effective Dose.

The indoor annual effective dose (AED) due to the absorbed dose in air were calculated using the following equation

$$AED = D_{in} \times 8760 hryr^{-1} \times 0.8 \times 0.7 SvGy^{-1} \times 10^{-6} \quad (3)$$

Where D_{in} is the Indoor Absorbed Dose Rate, 0.8 is the indoor occupancy proposed by UNSCEAR, 2000 and 0.7 $Svyr^{-1}$ is the dose conversion factor respectively

The estimated D_{in} and AED values for the samples ranged from 24.59 to 45.04 $nGyh^{-1}$ and 0.12 to 0.22 mSv, respectively. From the data in the Table 4, the estimated mean value of D_{in}, 36.93 $nGyh^{-1}$ is lower than world average indoor absorbed gamma dose rate of 84nGyh-1. The mean estimated annual effective dose rate (0.18mSv) is less than the permissible limit.

3.2.4 Radium Equivalent Activity.

It is a weighted sum of activities of ^{238}U, ^{232}Th, and ^{40}K; and it is based on the assumption that 370Bqkg^{-1} of ^{238}U, 259 Bq.kg^{-1} of ^{232}Th, and 4810 Bq.kg^{-1} of ^{40}K produce the same gamma radiation dose rate (Matilullah et al., 2004; Fatima et al., 2008). To minimize radiation hazards, materials whose Ra_{eq} is greater than 370 Bq kg^{-1} should not be used for building or construction. The radium equivalent activity Ra_{eq} for each sample was calculated by using the following formula from Zaidi et al, (1999).

$$Ra_{eq} = C_U + 1.43 C_{Th} + 0.77 C_K \quad (4)$$

Where C_U, C_{Th} and C_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bqkg^{-1}, in the sediment samples respectively.

The result from table 4 shows that the estimated Ra_{eq} ranged from 32.25 BqKg^{-1} to 55.14 BqKg^{-1}. This means that sediments from Tono irrigation dam will pose insignificant radiological risk when used as building materials.

3.2.4 External and Internal Hazards Indices.

The External hazard index (H_{ex}) and Internal Hazard Index (H_{in}) values was calculated using the following equations from Beretka and Mathew, (1985). These are hazard indicators that predict the external and internal detriment of Natural Radiation from ^{238}U, ^{232}Th and ^{40}K.

$$H_{ex} = \frac{C_U}{370} + \frac{C_{TH}}{259} + \frac{C_K}{4810}$$

$$H_{in} = \frac{C_U}{185} + \frac{C_{TH}}{259} + \frac{C_K}{4810} \quad (5)$$

Where C_U, C_{Th} and C_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bqkg^{-1}, respectively.

For radiological detriment, the value of H_{ex} and H_{in} should be greater than or equals to 1. From table 4 it is clear that the estimated H_{ex} and H_{in} determined to be 0.14 and 0.12 respectively are less than 1. This means that sediments of Tono irrigation dam are for use as construction materials from the internal dose point of view.

4. CONCLUSION

The Tono irrigation scheme remains the single largest irrigation project in Ghana and thus very strategic to government's efforts of providing food security especially in the three northern regions of the country which experiences worsening erratic rainfall pattern over the years. The levels of Natural radionuclides ^{238}U, ^{232}Th, and ^{40}K concentration in sediments of the Dam have been determined from samples taken at various points on the dam. The mean activity concentration has been found to be of lower and consistent with results obtained in sediments elsewhere. The mean indoor absorbed dose rate associated with the calculated activity should the sediment be used as a building material has been found to be 36.93n$Gyhr^{-1}$ with an associated mean indoor annual effective dose of 0.18$Svyr^{-1}$. The values of the radiological assessment indices obtained were observed to be lower than limits internationally reported and recommended for building materials. However seasonal variation in water quantity in the dam can affect the radionuclide concentration in the dam.

ACKNOWLEDGEMENT

The authors are grateful to the Ministry of Environment Science Technology and Innovation (MESTI)for providing funds through the MASTEES Scholarship Scheme to fund the research and to the Radiation Protection Institute and GHARR-I facility for allowing us use their laboratories.

REFERENCES

[1]. Awudu A.R., Darko E.O., Schandorf C., Hayford E.K. Hayford, M.K. and Abekoe Ofori-Danson P.K., (2010) Determination of activity concentration levels of ^{238}U, ^{232}Th and ^{40}K in drinking water in a gold mine in Ghana. Operational Radiation Safety Health Physics Journal 99(2): page 149-153

[2]. Beck JW, Edwards RL, Ito E, Taylor FW, Recy J, Rougerie F,Joannot P, Henin C (1992) Sea-surface temperature from coral skeletal strontium/calcium ratios. Science 257(5070): page 644-647

[3]. Beretka J, Mathew PJ (1985). Natural radioactivity of Australian building materials, industrial wastes and by-products. Health Phys., 48(1): page 87-95.

[4]. David A. Y. (2008) Irrigation-led Strategy for Poverty Reduction in Northern Ghana: Large Scale Versus Small Scale Irrigation, Gauging the Evidence, Msc. thesis at the Institute of Social Studies, The Hague

[5]. EC, Office European Commission Report on Radiological protection principles concerning the natural radioactivity of building materials, Radiation protection 112, Directorate- General Environment, Nuclear Safety and Civil Protection, Luxembourg, (1999).

[6]. Bikit I., J. Slivka, Veskovi´c M., Varga E., Žiki´c-Todorovi´c, MrYa N. D., Forkapi´ S. (2006) Measurement of Danube sediment radioactivity in

Serbia and Montenegro using gamma ray spectrometry, Radiation Measurements 41(4):page 477–481

[7]. Kurnaz A, Keser R, Okumusoglu NT, Karahan G, Cevic U (2007) Determination of radioactivity levels and hazards of soil and sediment samples in Firtina Valley (Turkey). Applied Radiation Isotopes, 65(11): page 1281-1289.

[8]. Krmar M. , J. Slivka, E. Varga, I. Bikit, M. Vesković, (2009) Correlations of natural radionuclides in sediment from Danube. Journal of Geochemical Exploration. 100(1): page 20-24.

[9]. Mujahid and Hussain (2011) Measurement of Natural Radioactivity from soil samples of Sind, Pakistan, Radiation Protection Dosimetry 145(4): page 351–355

[10]. Olatunde Michael Oni, Idowu Peter Farai, Ayodeji Oladiran Awodugba (2011) Natural Radionuclide Concentrations and Radiological Impact Assessment of River Sediments of the Coastal Areas of Nigeria, Journal of Environmental Protection 2(4): page 418-423

[11]. Pujol L and Sanchez-C (2000) Natural and artificial radioactivity in surface waters of the Ebro river basin (Northeast Spain), Journal of Environmental Radioactivity 51(2): page 181-210

[12]. Ravisankar R., Chandrasekaran A., Eswaran P., Rajalakashmi A., Vijayagopal P., Meenakshisundaram V. (2011) Natural Radioactivity Measurement in River Bed samples in and around Manaloorpet Riverbed Area, Tamilnadu, India, International Journal of Science and Technology 1 (1): page 38 -42

[13]. Ramasamy V. , Suresh G. , Rajkumar P. , Murugesan S. , Mullainathan S. , Meenakshisundaram V. 2011, Reassessment and comparison of natural radioactivity levels in relation to granulometric contents of recently excavated major river sediments, Journal of Radioanalytical and Nuclear Chemistry. 292(1): page 381-393

[14]. Taskin, H., Karavus M., Ay P., Topuzoglu A., Hindiroglu S. and Karahan G., (2009) Radionuclide concentrations in soil and lifetime cancer risk due to the gamma radioactivity in Kirklareli, Turkey. Journal of Environmental Radioactivity. 100(1): page 49-53.

[15]. Tsai TL, Lin CC, Wang TW, Chu TC (2008) Radioactivity concentrations and dose assessment for soil samples around a nuclear power plant IV in Taiwan. Journal of Radiological Protection, 28(3): pages 347-360

[16]. UNSCEAR 2000 Sources and effects of ionizing radiation, United Nations Scientific Committee on the Effects of Atomic Radiation (New York, USA: United Nations Publication).

[17]. Zaidi, J.H., Arif, M., Ahmad, S., Fatima, I., Qureshi, I.H.(1999) Determination of natural radioactivity in building materials used in the Rawalpindi/Islamabad area by g-ray spectrometry and instrumental neutron activation analysis. Applied Radiation Isotope 51(5): page 559–564

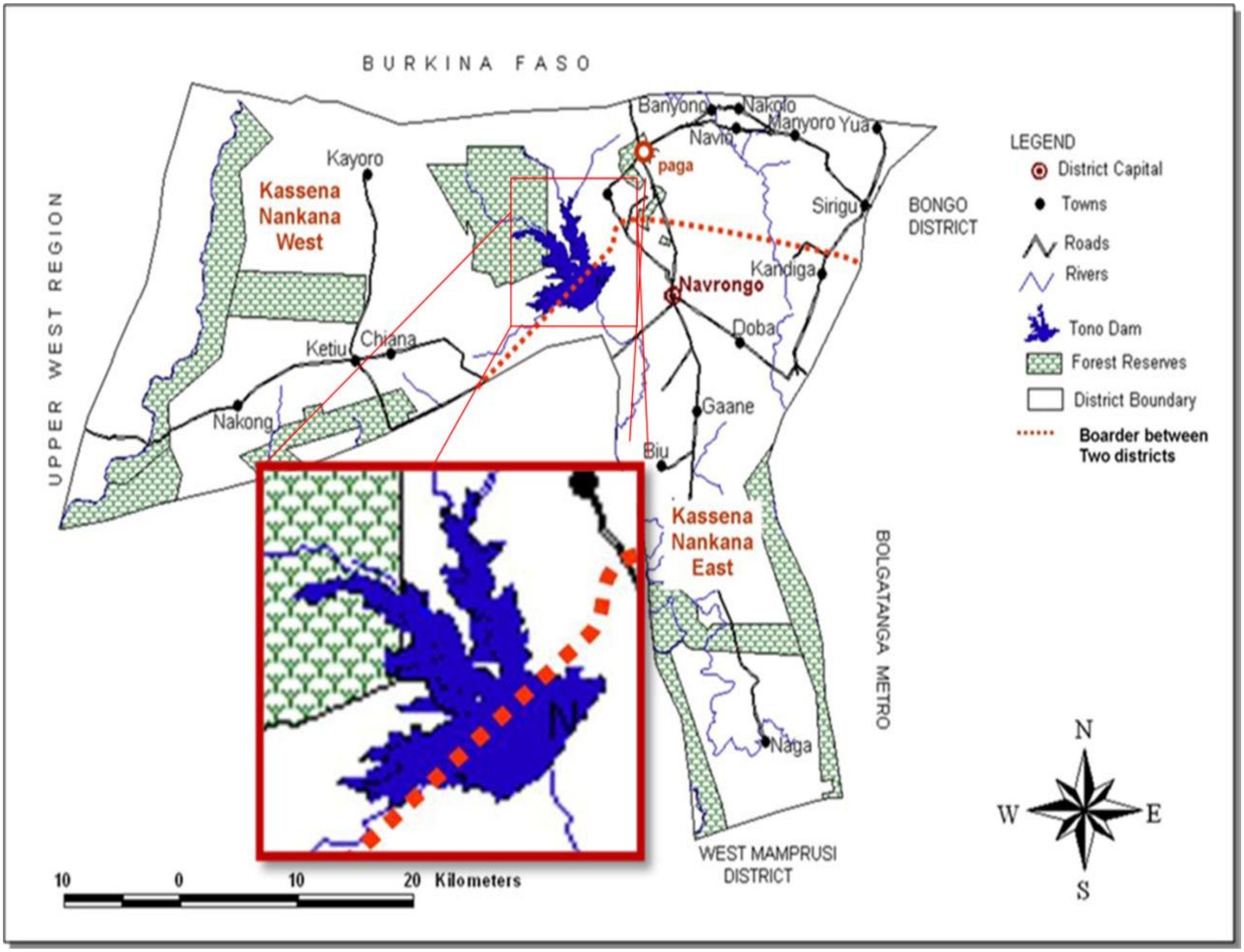

Figure 1: A map of Kassena Nankana District Showing the Study Area (inset)

Table 1: Spectroscopic parameters employed for quantification (Tsai et al., 2008).

Element	Emitter nuclide	Half-life of nuclide	Gamma-ray energy (keV)	Absolute Emission probability of Gamma decay (%)
^{238}U	^{214}Bi	19.90 min	609.31	46.30
	^{214}Pb	26.80 min	351.9	37.20
^{232}Th	^{212}Bi	60.55 min	727.17	11.80
	^{212}Pb	10.64 hours	238.63	44.60
	228Ac	6.25 hours	911.21	27.70
^{40}K	^{40}K	1.3×10^9 years	1460.8	10.67

Table 2: Activity concentration of Natural radionuclide associated with Sediments from the Ton Irrigation Dam

SAMPLE ID	Activity Concentration ($BqKg^{-1}$)		
	^{238}U	^{232}Th	^{40}K
TS3	7.07	5.83	218.73
TS5	7.29	5.95	415.38
TS7	5.97	6.01	352.25
TS8	5.19	6.49	375.76
TS10	8.34	8.16	436.60
TS14	5.83	6.52	362.75
TS15	7.21	7.39	360.63
TS16	6.34	7.69	382.55
TS17	8.66	8.10	453.25
TS19	6.54	7.76	383.50

Table 3: Reported values of Natural Radionuclide activity Concentrations (Bq kg^{-1}) in sediments elsewhere compared to results from this work

Country	Activity Concentration (Bq kg^{-1})			Description	Reference
	^{238}U	^{232}Th	^{40}K		
Worlds Average	40	40	370		UNSCEAR 2000
India	7.31	46.8	384.03	Sediments Ponnaiyar river.	Ramasamy et al 2009
Serbia	42	36	445	Sediment from Danube river	M. Krmar et al.(2009)
Turkey	39	38	573	Sediment samples in Firtina Valley	A. Kurnaz et al.(2007)
Ghana	7.31	6.91	379.94	Tono Irrigation Dam	This Work

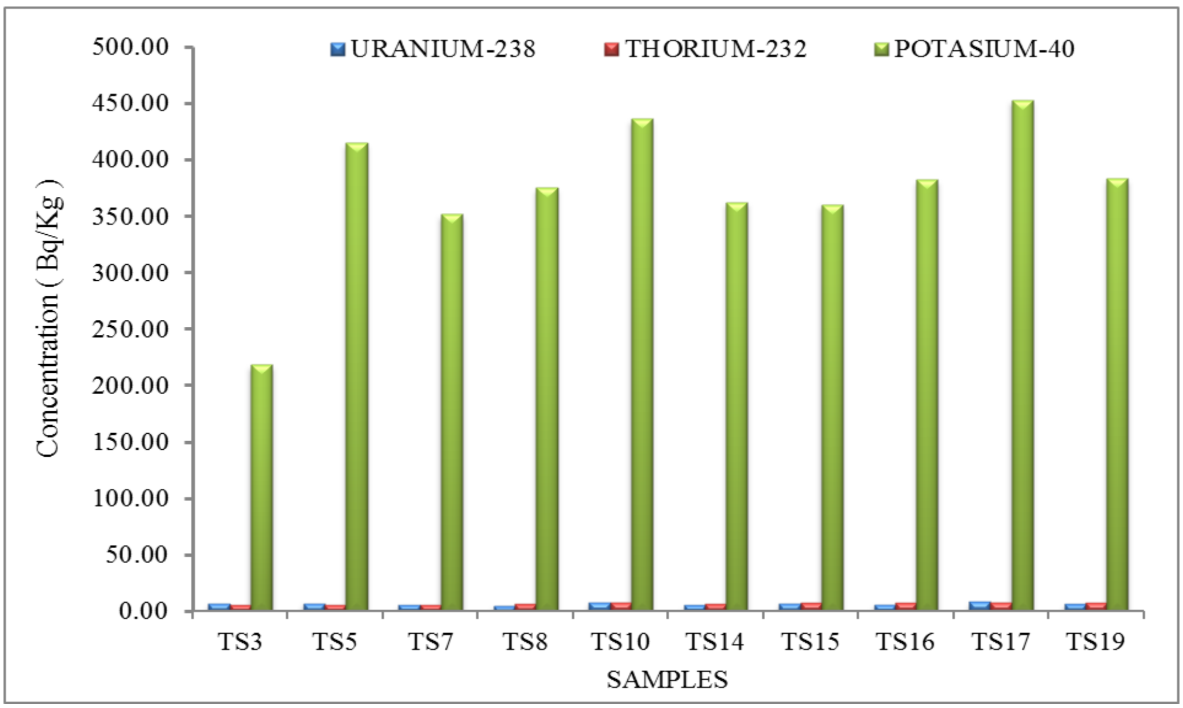

Figure 2: Average Concentration of Natural Radionuclide (^{238}U, ^{232}Th and ^{40}K) in sediment from the Tono irrigation dam

Table 4: Indoor Annual Effective dose, Indoor Absorb Dose, and radioactivity indices associated with Sediments from the Tono Irrigation Dam

SAMPLE ID	Indoor Absorb Dose Rate	Hazard Indices		Annual indoor Effective Dose
	D_{in} (nGyhr^{-1})	R_{eq}(BqKg^{-1})	H_{in}	H_{ex}	AED (mSv)
TS3	24.59	32.25	0.09	0.11	0.12
TS5	40.53	47.78	0.13	0.15	0.20
TS7	34.27	41.69	0.11	0.13	0.17
TS8	35.48	43.40	0.12	0.13	0.17
TS10	43.42	53.63	0.14	0.17	0.21
TS14	35.04	43.09	0.12	0.13	0.17
TS15	36.22	45.55	0.12	0.14	0.18
TS16	37.21	46.79	0.13	0.14	0.18
TS17	45.04	55.14	0.15	0.17	0.22
TS19	37.47	47.17	0.13	0.15	0.18