

1  
2  
3 **ASSESSMENT OF NATURAL RADIOACTIVITY AND HAZARD FROM CONSUMPTION OF**  
4 **COMMUNITY WATER SUPPLIED BY BOREHOLES AROUND GOLDMINE AREA IN KUILSE**  
5 **REGION, BURKINA FASO.**  
6

7 **Abstract:**

8 The activity concentrations of Natural Radionuclides  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in groundwater samples from Kuilsé  
9 Region of Burkina Faso were measured using a Gamma Spectrometry with High Purity Germanium detector. Also,  
10 Radiological Hazard due to these Natural Radionuclides through water ingestion is investigated. The mean activity  
11 concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in water samples from boreholes were found to be  $1.53 \pm 0.21 \text{ Bq. L}^{-1}$ ,  $0.58$   
12  $\pm 0.06 \text{ Bq. L}^{-1}$  and  $4.76 \pm 0.66 \text{ Bq. L}^{-1}$  respectively. The average Annual Committed Effective Dose was  $0.16 \pm 0.02$   
13 mSv. The results obtained are below the recommended levels of  $10.0 \text{ Bq. L}^{-1}$  and  $1.0 \text{ Bq. L}^{-1}$  for  $^{238}\text{U}$  and  $^{232}\text{Th}$   
14 respectively for drinking water quality established by the WHO and 1 mSv per year dose limit recommended by the  
15 ICRP for public radiation exposure. These results indicate insignificant radiological hazard due to ingestion of  
16 NORMS in drinking water from boreholes by the communities in this areas danger of indiscriminate dumping of  
17 wastes as they affect human health.

18  
19  
20 .....  
21  
22  
23 **Key words: -**

24 ACTIVITY CONCENTRATION, EFFECTIVE DOSE, URANIUM, THORIUM, POTASSIUM, GROUNDWATER  
25

26 **Introduction: -**

27 The measurement of natural radioactivity level in the environment is necessary for the assessment of human  
28 exposure to radiation. Some natural radionuclides which are present in groundwater system with high amount, due  
29 to natural activity or caused by human activities can be taken into the body through ingestion. Mining is considered  
30 as one of the potential sources of exposure to NORM [11]. There are lots of mining companies operating in Burkina  
31 Faso. Nevertheless, related activities often expose groundwater to enhanced levels of radioactive contamination.  
32 Very little studies have been carried out regarding groundwater quality about NORM in Burkina Faso. Water is vital  
33 and, concurrently, one of the most important natural resources. About 70% of the Earth's surface is covered with  
34 water, which is estimated at a volume of approximately 1.4 billion km<sup>3</sup>. However, most of it is salty, and only  
35 around 2.5% of the global water resources (about 35 million km<sup>3</sup>) consists of freshwater [7]. Groundwater is the  
36 most important and highly used resource; however, its quality can be endangered. Because of the increasing interest  
37 in radioactivity and its applications, there is the need for an assessment of human exposure to radiation through  
38 groundwater ingestion.

39 The objective of this study was to assess the natural radioactivity level in groundwater around Taparko goldmine in  
40 Burkina Faso. This has been achieved by determining the concentration of certain radionuclides such as  $^{238}\text{U}$ ,  
41  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the groundwater system and the Annual Committed Effective Dose due to water ingestion.  
42

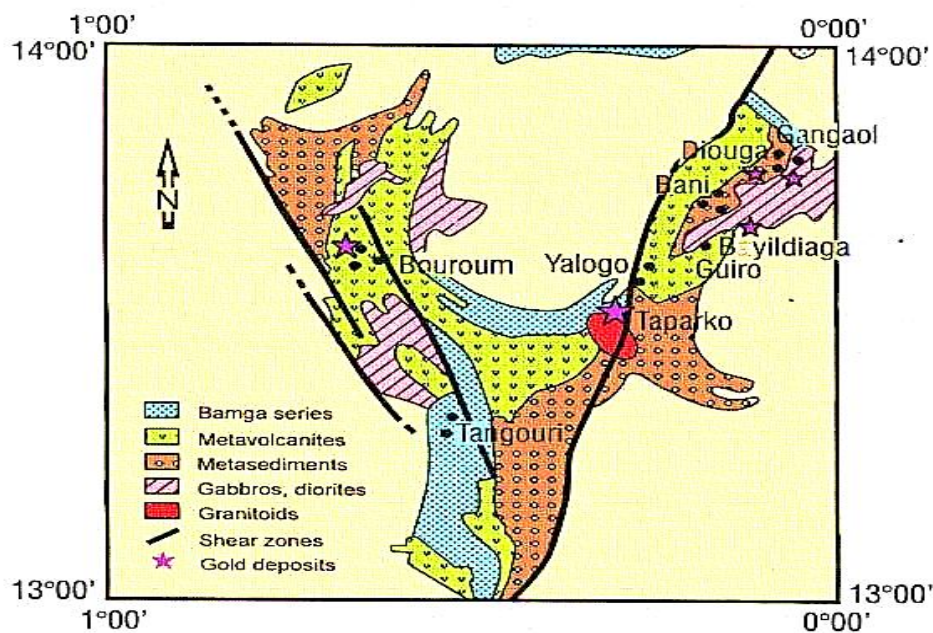
43 **Materials and Methods**

44 • **Study Area**

45 The investigated area is the village of Taparko around the mine site.

46 Taparko is located in the Namantenga province of Burkina Faso in Kuilsé Region, approximately 200 km from  
47 Ouagadougou, the Capital City of Burkina Faso, at a latitude of  $13^{\circ} 27'55.28''\text{N}$  and a longitude of  $0^{\circ} 19'27.99''\text{W}$ .  
48 The base of Namentenga belongs to two geological eras: Inferior precambrian formations (Anttebirimian)

49 represented by compound gneisses with biotites and amphiboles, and compound gneisses and granites; those of  
 50 mean Precambrian (Birimian) represented by the plutonic rocks and the volcanogenic rocks. The plutonic rocks  
 51 consist of granites with biotites. Figure 1 shows the geology of the study area.



52  
 53 **Figure 1:** Local Geology of Taparko area (Nordgold, 2013)  
 54

55 • **Sampling And Samples Preparation**

56 Water samples were collected from boreholes in Taparko village around the mining site. The sampling bottles (one  
 57 and half liter polyethylene container) were rinsed three (3) times with the water to be sampled, followed by filling  
 58 the bottle with water to the brim [11]. Each water sample was acidified with two (2) drops of concentrated 65%  
 59 HNO<sub>3</sub> just after the collection of the water samples. The sampled borehole water is used to fill one liter of a  
 60 Marinelli beaker and tightly sealed to cut off the background radiation. The water samples were then analysed for  
 61 <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K activity concentration using a Gamma Spectrometry system with High Purity Germanium  
 62 detector. Table 1 shows the samples location coordinates.

63 **Table 1 :** Samples location coordinates

Sample Code	above sea level (m)	Samples location coordinates	
WSTA-001	164	N 13° 31' 40.50"	W 00° 20' 37.41"
WSTA-002	263	N 13° 30' 19.46"	W 00° 19' 51.70"
WSTA-003	234	N 13° 29' 52.13"	W 00° 19' 45.22"
WSTA-004	238	N 13° 31' 29.87"	W 00° 20' 56.95"
WSTA-005	322	N 13° 29' 25.78"	W 00° 19' 22.89"
WSTA-006	330	N 13° 29' 36.54"	W 00° 19' 33.52"
WSTA-007	328	N 13° 29' 57.82"	W 00° 18' 59.46"

WSTA-008	326	N 13° 29' 39.19"	W 00° 19' 08.41"
WSTA-009	318	N 13° 29' 09.97"	W 00° 19' 01.26"
WSTA-010	322	N 13° 29' 11.97"	W 00° 19' 93.00"
WSTA-011	309	N 13° 28' 50.88"	W 00° 19' 36.22"
WSTA-012	313	N 13° 28' 55.94"	W 00° 19' 44.48"
WSTA-013	315	N 13° 29' 02.36"	W 00° 19' 47.84"
WSTA-014	299	N 13° 27' 44.52"	W 00° 19' 46.58"
WSTA-015	311	N 13° 27' 39.49"	W 00° 19' 33.15"
WSTA-016	307	N 13° 28' 16.63"	W 00° 19' 26.74"
WSTA-017	310	N 13° 28' 30.64"	W 00° 19' 36.67"

64

65

66 • ***Gamma Ray Spectrometry System***

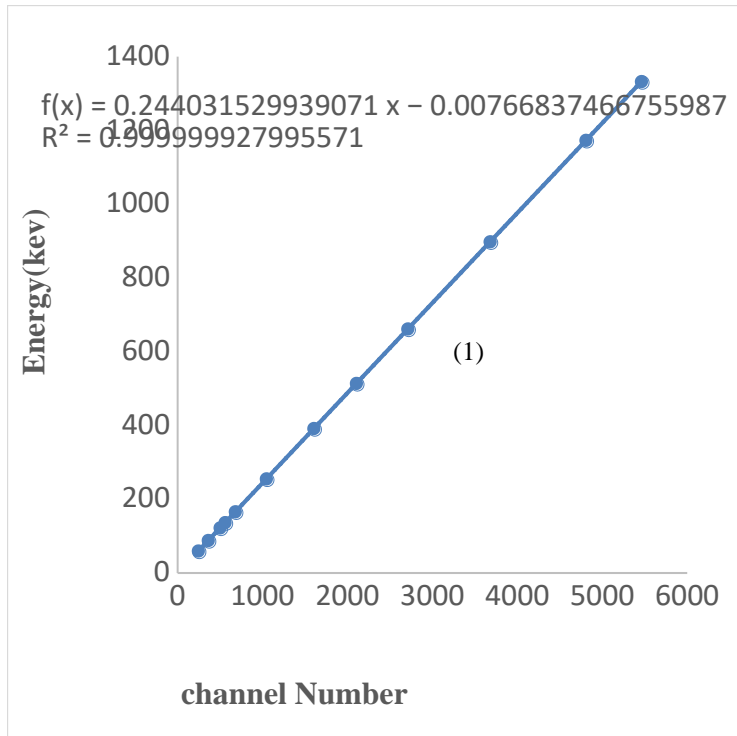
67 The actAvity concentrations of the natural radionuclides 238U, 232Th and 40K in groundwater samples were  
68 measured using a Gamma Spectrometry system with High Purity Germanium detector.

69 The gamma ray spectrometry system used for this study consists of a High Purity Germanium (HPGe) detector with  
70 the following characteristics (Canberra detector model GX4020, cryostat model 7500SL and preamplifier model  
71 2002CSL). It has a diameter of 60.5 mm, length of 61.5 mm. The resolution of the detector is 2.0 keV and relative  
72 efficiency of 40% for 1.33 MeV gamma energy of 60Co. The output from the detector is connected to a desk top  
73 computer provided with "Genie 2000" configuration software for spectrum acquisition and evaluation.

74 In order to do the measurement, energy calibration was done previously.

75 A relationship between the channel numbers corresponding to specific gamma-ray energies was determined before  
76 sample measurement. The establishment of this relationship is known as energy calibration and the idea is to  
77 identify the radionuclides in a sample. The linearity of energy response is an essential feature for any  $\gamma$ -ray detector  
78 and the direct proportionality between the quality of energy deposited in the detector by the incident radiation event  
79 and the height of the output pulse ensures that the system is working properly . Accurate calibration involves a  
80 standard source with gamma ray energies that are not widely different from those to be measured in the unknown  
81 spectrum.

82 The energy calibration was done by means of multi peaked and multi nuclide radioactive standard sources emitting  
83 gamma rays of precisely known energy and the peak position in channels with this energy is identified. In this study  
84 this was carried out by counting standard radionuclides (a mixture of 241Am, 109Cd, 139Ce, 57Co, 60Co, 137Cs,  
85 113Sn, 85Sr and 88Y) of known activities with well-defined energies in the energy range of 60 to ~2000 keV. The  
86 standard was counted on a detector for 10 hours or 36000 s. The energy calibration curve is given in figure 2



87

88 **Figure 2:** Energy Calibration Curve

89

90

91 • **Determination of Activity Concentration**

92

93 From the spectrum analysis, count rates for each detected photo peak and activity per unit volume (specific  
 94 activity) for each of the detected nuclides are calculated. The specific activity (in  $Bq.L^{-1}$ ),  $A_{sk}$ , of a nuclide  $k$ , and for  
 95 a peak at energy  $E$ , is given by:

96

$$A_{sk} = \frac{(NetArea)_{Ek}}{\epsilon_{Ek} \times P_{\gamma} \times T}$$

97

98 Where,  $A_{sk}$  is the activity concentration (Bq/L) of the radionuclide of interest,  $\epsilon_{Ek}$  is the detection efficiency at  
 99 energy  $E_k$ ,  $T$  is the counting live time,  $P_{\gamma}$  is the number of gamma-rays per disintegration of this radionuclide for a  
 100 transition at energy  $E$  of the measured sample of water [2]. If there is more than one peak in the energy analysis  
 101 range for a nuclide, then an attempt is made to average the activities for the peak. The result is then the weighted  
 102 radionuclide's average activity concentration. The activity concentrations of  $^{238}U$  and  $^{232}Th$  in samples collected  
 103 were determined using the measured  $\gamma$ -ray photo peaks, emitted by specific radionuclides in their decay series  
 104 whereas the activity concentrations of  $^{40}K$  is calculated from the measured  $\gamma$ -ray photo peaks directly. In other  
 105 words, the activity concentration of  $^{238}U$  was calculated from the average of 609.31 keV of  $^{214}Bi$  and 1764.5 keV  
 106 of  $^{214}Bi$ , in the decay series of  $^{232}Th$  gamma photons are emitted at energies of 239 keV ( $^{212}Pb$ ), 583 keV ( $^{208}Tl$ )  
 107 and 911 keV ( $^{228}Ac$ ) which are used to determine the activity concentrations of  $^{232}Th$  by gamma spectrometry,  
 108 and  $^{40}K$  was determined from 1460.0 keV.

109

110 □ **Calculation of Annual Committed Effective Dose**

111 The committed effective doses ( $E$ ) was estimated from the activity concentrations of each individual radionuclide by  
 112 applying the annual water consumption rate for adults of 730 L/year (2 L/day multiplied by 365 days) and the dose

113 conversion factors for  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  taken from the BSS and UNSCEAR report [4 ;11], using the relation  
 114 (2). The total annual effective dose D (Sv  $\text{y}^{-1}$ ) to an individual was established by summing contributions from all  
 115 radionuclides present in the water samples

$$116 \quad E_{ing} = \sum A_{sp} \times I_w \times C_f$$

117 Where,  $A_{sp}$  is the activity concentration of the radionuclides in the water sample in Bq/L,  $I_w$  is the annual intake of  
 118 water in liters per year, and  $C_f$  is the ingestion dose coefficient in Sv/Bq [11]. The risk incurred by the population is  
 119 estimated by assuming a linear dose-effect relationship with no threshold as per ICRP practice. For low doses ICRP  
 120 fatal cancer risk factor is 0.05  $\text{Sv}^{-1}$  [5].

121 **□ Risk Assessment**

122  
 123 The risk factor states that the probability of a person dying of cancer increases by 5% for a total dose of 1 Sv  
 124 received during his lifetime. The average annual committed effective dose D (Sv/y) for the measured water samples  
 125 in this study, was used to estimate cancer risk for an adult person using the following relationship:

$$126 \quad \text{Risk} = \text{Dose (Sv)} \times \text{risk factor (Sv}^{-1}\text{)} \quad (3)$$

127 Where, Dose (Sv) is equals to mean annual committed effective dose D (Sv/y) x life-time (years).

128 Risk factor (Sv $^{-1}$ ) = 0.05 [5] for low dose.

129 **Results and Discussions**

130  
 131 The mean activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in water samples from boreholes that provide drinking  
 132 water to the community around the goldmine site of Taparko are shown in Table 2. The mean values for  $^{238}\text{U}$ ,  
 133  $^{232}\text{Th}$  and  $^{40}\text{K}$  are  $1.53 \pm 0.21 \text{Bq.L}^{-1}$  in a range of 0.93 - 2.64  $\text{Bq.L}^{-1}$ ,  $0.58 \pm 0.06$  in a range of 0.45 - 0.79  $\text{Bq.L}^{-1}$   
 134 and  $4.76 \pm 0.66 \text{Bq.L}^{-1}$  in a range of 3.62 - 6.30  $\text{Bq.L}^{-1}$  respectively. The highest value obtained for Uranium was  
 135  $2.64 \text{Bq.L}^{-1}$  which is far to the limit of  $10 \text{Bq.L}^{-1}$ . For Thorium the maximum value was  $0.79 \text{Bq.L}^{-1}$ . The results  
 136 obtained are below the recommended levels of  $10.0 \text{Bq.L}^{-1}$  and  $1.0 \text{Bq.L}^{-1}$  for  $^{238}\text{U}$  and  $^{232}\text{Th}$  respectively for  
 137 drinking water established by the World Health Organization [13]. Table 2 shows the activity concentration of  
 138  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  from Taparko area water samples.

139 **Table 2:** activity concentration of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ .

Sample ID	Activity Concentration (Bq/L)		
	U	Th	K
WSTA-001	$1.80 \pm 0.09$	$0.60 \pm 0.04$	$3.85 \pm 0.58$
WSTA-002	$2.64 \pm 0.33$	$0.52 \pm 0.03$	$4.12 \pm 0.56$
WSTA-003	$1.92 \pm 0.11$	$0.50 \pm 0.04$	$3.62 \pm 0.54$
WSTA-004	$1.45 \pm 0.27$	$0.53 \pm 0.05$	$5.23 \pm 0.71$
WSTA-005	$1.11 \pm 0.13$	$0.60 \pm 0.08$	$3.85 \pm 0.62$
WSTA-006	$1.51 \pm 0.24$	$0.59 \pm 0.03$	$6.30 \pm 0.85$
WSTA-007	$0.97 \pm 0.03$	$0.60 \pm 0.08$	$4.80 \pm 0.69$
WSTA-008	$1.64 \pm 0.23$	$0.59 \pm 0.07$	$4.33 \pm 0.32$
WSTA-009	$1.53 \pm 0.19$	$0.62 \pm 0.06$	$3.95 \pm 0.59$
WSTA-010	$2.04 \pm 0.30$	$0.56 \pm 0.07$	$4.73 \pm 0.68$
WSTA-011	$0.93 \pm 0.28$	$0.62 \pm 0.06$	$4.29 \pm 0.67$

WSTA-012	1.13 ± 0.19	0.79 ± 0.09	4.92 ± 0.71
WSTA-013	1.61 ± 0.24	0.58 ± 0.07	5.16 ± 0.73
WSTA-014	1.08 ± 0.09	0.76 ± 0.08	5.45 ± 0.71
WSTA-015	1.60 ± 0.26	0.46 ± 0.06	5.30 ± 0.76
WSTA-016	1.32 ± 0.24	0.45 ± 0.04	5.50 ± 0.74
WSTA-017	1.76 ± 0.29	0.50 ± 0.06	5.68 ± 0.82
<hr/>			
Min	0.93 ± 0.28	0.45 ± 0.04	3.62 ± 0.54
Max	2.64 ± 0.33	0.79 ± 0.09	6.30 ± 0.85
Mean	1.53 ± 0.21	0.58 ± 0.06	4.76 ± 0.66

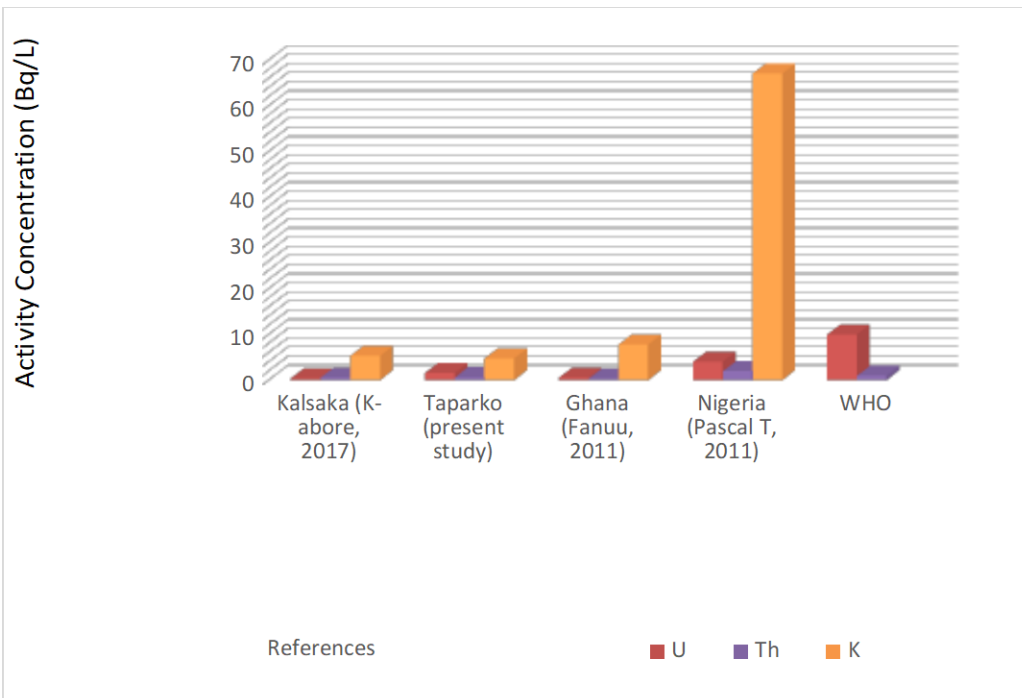
140

141 The results from table 2 show also that the activity concentration of potassium is higher than uranium and the  
 142 concentration of thorium is lower than uranium for all the samples.

143 A comparison of the activity concentrations of <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K for the present work with our previous work  
 144 and other works and WHO guidelines values is given by the figure 3 [16]. This shows that these is no significant  
 145 different between the results of this work and the others about <sup>238</sup>U and <sup>232</sup>Th activity concentration.

146

147 **Figure 3:** Comparison of activity concentration



148 Table 3 shows the ingestion dose coefficient of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ . Table 4 presents the annual committed  
 149 effective dose (ACED) from drinking water samples and the contribution of each radionuclide to the total ACED.  
 150 The mean contributions are  $0.049 \pm 0.006 \text{ mSv}\cdot\text{year}^{-1}$ ,  $0.092 \pm 0.009 \text{ mSv}\cdot\text{year}^{-1}$  and  $0.021 \pm 0.003 \text{ mSv}\cdot\text{year}^{-1}$  for  
 151  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  respectively. The total Annual Committed Effective Dose obtained was  $0.16 \pm 0.02 \text{ mSv}\cdot\text{year}^{-1}$ .  
 152 This study shows that the drinking water samples give an internal exposure which is in the range of worldwide  
 153 limit of exposure of  $0.12 \text{ mSv}\cdot\text{year}^{-1}$ ,  $0.1 \text{ mSv}\cdot\text{year}^{-1}$  and  $1.0 \text{ mSv}\cdot\text{year}^{-1}$  for UNSCEAR reported, and the WHO and  
 154 ICRP preference limit respectively. The United Nations Scientific Committee on Effects of Atomic Radiation  
 155 (UNSCEAR, 2000) has been reported that the worldwide average exposure to natural sources in foods and drinking  
 156 water (ingestion exposure) is  $0.29 \text{ mSv}\cdot\text{year}^{-1}$  (about  $0.17 \text{ mSv}\cdot\text{year}^{-1}$  from  $^{40}\text{K}$  and about  $0.12 \text{ mSv}\cdot\text{year}^{-1}$  from  $^{238}\text{U}$   
 157 and  $^{232}\text{Th}$ ) [19]  
 158

159 **Table 3:** Dose Coefficient of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$

Radionuclide	Dose Coefficient(Sv/Bq) [17]
$^{238}\text{U}$	$4.5 \times 10^{-8}$
$^{232}\text{Th}$	$2.3 \times 10^{-7}$
$^{40}\text{K}$	$6.2 \times 10^{-9}$

160  
161  
162  
163  
164  
165  
166

**Table 4:** (ACED) from drinking water samples

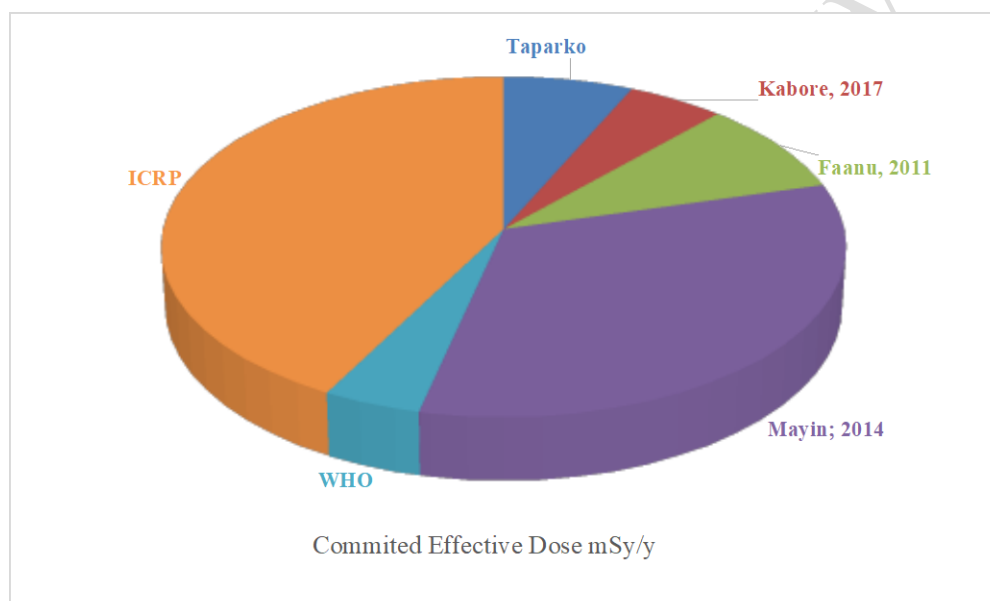
Sample ID	Dose contribution ( $\mu\text{Sv}/\text{y}$ )			Average
	U	Th	K	ACED (mSv/y)
WSTA-001	$57,82 \pm 2,8$	$96,94 \pm 7,4$	$17,43 \pm 2,6$	$0,17 \pm 0,01$
WSTA-002	$85,02 \pm 10,7$	$82,98 \pm 5,6$	$18,63 \pm 2,5$	$0,19 \pm 0,02$
WSTA-003	$63,92 \pm 3,5$	$81,58 \pm 7,2$	$16,36 \pm 2,4$	$0,16 \pm 0,01$
WSTA-004	$46,55 \pm 8,8$	$85,82 \pm 7,8$	$23,68 \pm 2,4$	$0,15 \pm 0,02$
WSTA-005	$35,53 \pm 4,2$	$82,10 \pm 12,8$	$18,66 \pm 3,8$	$0,13 \pm 0,02$
WSTA-006	$48,11 \pm 7,7$	$95,14 \pm 5,6$	$28,52 \pm 3,1$	$0,17 \pm 0,02$
WSTA-007	$31,24 \pm 0,9$	$97,07 \pm 12,8$	$21,73 \pm 2,8$	$0,15 \pm 0,02$
WSTA-008	$52,69 \pm 7,4$	$96,13 \pm 12,3$	$19,59 \pm 2,7$	$0,17 \pm 0,02$
WSTA-009	$49,18 \pm 6,1$	$99,3 \pm 9,04$	$17,89 \pm 3,8$	$0,17 \pm 0,02$
WSTA-010	$65,81 \pm 9,6$	$89,26 \pm 12,3$	$21,38 \pm 3,1$	$0,18 \pm 0,02$
WSTA-011	$29,88 \pm 8,9$	$99,25 \pm 9,04$	$19,43 \pm 3,9$	$0,15 \pm 0,01$
WSTA-012	$36,37 \pm 6,1$	$127,49 \pm 12,5$	$22,3 \pm 3,3$	$0,19 \pm 0,02$
WSTA-013	$52,02 \pm 7,7$	$92,98 \pm 12,3$	$23,36 \pm 3,6$	$0,17 \pm 0,02$

WSTA-001	34,84±2,8	122,75±12,8	24,65±3,3	0,18±0,02	167
WSTA-002	51,51±8,5	73,09±9,04	23,99±3,4	0,15±0,02	168
WSTA-003	42,52±7,7	72,19±9,03	22,95±3,3	0,14±0,02	169
WSTA-004	56,62±9,2	81,34±7,8	25,69±3,9	0,16±0,02	170
Min	29,88 ±8,9	72,19±9,03	16,36±2,4	0,13±0,02	171
Max	85,02±10,7	127,49±12,5	28,52±3,1	0,19±0,02	172
Mean	49,39 ±6,5	92,72 ±9,7	21,6 ±3,1	<b>0,16±0,02</b>	173

174

175

176



177

178

179

180

181

182

183

184

185

186 Figure 4 shows a comparison of the Annual Committed Effective Dose of this work with the results of other works  
187 and WHO and ICRP guideline values. It shows that the results are in the range of worldwide limit of ingestion  
188 exposure.

189

190 **Figure 4:** comparison of ACED of this work with the results of other works and WHO and ICRP guideline values

191 The Annual Committed Effective Dose due to ingestion of water by adults was estimated to be **0.16 mSv/year**.  
192 Using this value and a life-time of 58.96 years (Burkina Faso, 2015), the exposure was evaluated as **09.43 mSv** for  
193 this life time. The risk from this exposure is estimated to be  $4.5 \times 10^{-4}$  due to water consumption, using a risk factor  
194 of  $0.05 \text{ Sv}^{-1}$  [11]. This value is less than ten times the total risk ( $6.0 \times 10^{-3}$ ) from all natural radiation sources based  
195 on global average annual radiation dose of 2.4 mSv. Yr-1 to man [13]. The estimated values are far less than the  
196 ICRP cancer risk of  $2.5 \times 10^{-3}$  based on annual dose limit of 1 mSv for the general public, which gives annual death  
197 probability of  $10^{-5}$  [6].  
198

## 199 Conclusion

200  
201 The activity concentrations of Natural Radionuclides 238U, 232Th and 40K in groundwater samples were measured  
202 using Gamma Spectrometry with High Purity Germanium detector. The mean activity concentrations were 1.53  
203 Bq/L, 0.58 Bq/L and 4.76 Bq/L for 238U, 232Th and 40K respectively. The average annual committed effective  
204 dose estimated was 0.16 mSv/y. The risk from this exposure was  $4.5 \times 10^{-4}$  for a life-time of 58.96 years which is  
205 less than ten times the total risk ( $6.0 \times 10^{-3}$ ) from all natural radiation sources based on global average annual  
206 radiation dose of 2.4 mSv.yr-1 to man and less than the ICRP cancer risk of  $2.5 \times 10^{-3}$  based on annual dose limit  
207 of 1 mSv for the general public, which gives annual death probability of  $10^{-5}$ . The activity concentrations measured  
208 are far below the ICRP recommended level of 1000 Bq/L for which remedial action is needed. The average annual  
209 committed effective dose is also lower than the 1mSv per year dose limit recommended by the ICRP for public  
210 radiation exposure control. The results from this work indicate insignificant levels of the natural radionuclides,  
211 implying that the mining activities do not pose any significant radiological hazard due to NORMS to the  
212 communities who are drinking the water from boreholes in this area

213

## 214 References

215

- 216 1. O.S Ajayi, G. Adesida” Radioactivity in some sachet drinking water samples produced in Nigeria”. Iran. J.  
217 Radiat. Res., 2009, 7(3) 151-153.
- 218 2. E. O. Darko, A. Faanu, A. Razak, , G. Emi-Reynolds, , J. Yeboah, O. C. Opong,. and H. K E. Akaho, “Public  
219 exposure to hazards associated with natural radioactivity in open-pit mining in Ghana” Radiat. Prot. Dosim.  
220 2006, 138(1), 45 – 51.
- 221 3. A. Faanu, J. H. Ephraim, and E. O. Darko. “Assessment of public exposure to naturally occurring radioactive  
222 materials from mining and mineral processing activities of Tarkwa Goldmine in Ghana” Environmental  
223 Monitoring and Assessment, (2011), 180(1-4), 15–29.
- 224 4. IAEA. “International Basic Safety Standard for protection against ionizing radiation and for the Safety of  
225 Radiation Sources” Safety Series No115, International Atomic Energy Agency, Vienna, 1996.
- 226 5. IAEA, “Extent of environmental contamination by naturally occurring radioactive material (NORM) and  
227 technological options for mitigation”. IAEA technical reports series no. 419, 2003
- 228 6. ICRP. “Recommendation of the International Commission of Radiological Protection”. ICRP Publication 60.  
229 Pergamon Press, Oxford, 1990.
- 230 7. L. I. Nwankwo, “Determination of Natural Radioactivity in Groundwater in Tanke-Ilorin, Nigeria”, Journal of  
231 Applied Ecology, vol. 21(1), 2013
- 232 8. L. Osvath. “Basic hands-on gamma calibration for low activity environmental levels”, Radiometrics Laboratory  
233 Marine Environment Laboratories, Monaco, 2008

- 234 9. Y. Serfo-Armah, B.J.B. Nyako, D.K. Adotey, D. Adomako, and E.H.K. Akaho) “The impact of small-scale  
235 mining activities on the levels of mercury in the environment: The case of Prestea and its environs” Journal of  
236 Radioanalytical and Nuclear Chemistry, 2004, 262, 685-690.
- 237 10. M.Sey, “Characteristic of Mine Waste and Radiation Dose Reconstruction of a Historical Mine of Konongo-  
238 Odomase in the Ashanti Region”, Ghana. University of Ghana, Accra. 2014
- 239 11. UNSCEAR “United Nations Scientific Committee on the Effect of Atomic Radiation: Sources and effects of  
240 ionizing radiation”, United Nations, New York, 2000
- 241 12. UNSCEAR). “Report to general assembly with scientific annexes”, Volume I, United Nation New York, 2008.
- 242 13. WHO. “Guidelines for Drinking-Water Quality”, third ed. Geneva, Switzerland. 2004
- 243 14. WHO. “Guidelines for Drinking-Water Quality”, fourth ed. Geneva, Switzerland, 2011
- 244 15. Nordgold integrated Report, Burkina Faso 2013.
- 245 16. K. Kabore, I. Zongo, L. T. Bambara, M. Derra, O. Cisse, F. Zougmoref, A. I. Doe “Determination of Natural  
246 Radioactivity Level and Hazard Assessment of Groundwater Samples from Mining Area in the North Region of  
247 Burkina Faso”, American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS),  
248 2017, Volume 37, No 1, pp 187-199.
- 249
- 250

251

UNDER PEER REVIEW IN IJER