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# Determination of Natural Radioactivity Level and Hazard Assessment of Groundwater Samples from Mining Area in the North Region of Burkina Faso

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**Abstract**

The activity concentrations of Natural Radionuclides $^{238}$U. $^{232}$Th and $^{40}$K in groundwater samples were measured using a Gamma Spectrometry with High Purity Germanium detector. Also. Radiological Hazard due to these Natural Radionuclides through water ingestion is investigated. The mean activity concentrations of $^{238}$U, $^{232}$Th and $^{40}$K in water samples from boreholes were found to be 0.36 ± 0.07 Bq.L$^{-1}$. 0.50 ±0.09 Bq.L$^{-1}$ and 5.32 ± 0.76 Bq.L$^{-1}$ respectively. The average Annual Committed Effective Dose was 0.16 ± 0.02 mSv. The results obtained are below the recommended levels of 10.0 Bq.L$^{-1}$ and 1.0 Bq.L$^{-1}$ for $^{238}$U and $^{232}$Th respectively for drinking water quality established by the WHO and 1 mSv per year dose limit recommended by the ICRP for public radiation exposure. These results indicate insignificant radiological hazard due to ingestion of NORMS in drinking water from boreholes by the communities in this area.

***Keywords:*** Activity concentration; Effective Dose; Uranium; Thorium; Potassium; Groundwater.

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## 1. Introduction

Radionuclides are present everywhere in the natural environment [1]. The main natural contributors to external exposure from gamma-radiation are the uranium and thorium series together with potassium 40 ($^{40}$K) and may be present in small quantities on the surface of the earth [1.2]. Long-lived radioactive elements such as uranium, thorium and potassium and their decay products. such as radium and radon are examples of Naturally Occurring Radioactive Materials (NORMs). These elements have always been present in the earth's crust and atmosphere since the beginning of creation.

The $^{238}$U and its daughters rather than $^{226}$Ra and its daughter products are responsible for the major fraction of the internal dose receive by humans from naturally occurring radionuclides. Even though the concentrations of these radionuclides are widely distributed in nature, they have been found to depend on the local geological conditions and as a result vary from place to place [3.4]. Throughout the history of life on earth, organisms have been continuously exposed to radiation mainly from cosmic rays in the atmosphere, and from naturally occurring radionuclides which are ubiquitously distributed in all living and non-living components of the biosphere . A wide range of activity concentrations in a wide variety of materials is reported [5].

Mining has been identified as one of the potential sources of exposures to NORM [6].

Within the last ten years there are many mining companies operating in Burkina Faso and some are even implanting. However like in the other developing countries, in Burkina Faso mining activities have not been duly controlled and as a result no radiological regulatory controls are really applied. Therefore, there is general lack of awareness and knowledge of the radiological hazards and exposure levels by legislators, regulators and operators.

The objective of the study was to assess the level of NORM in the North region of Burkina Faso surrounding the mining site of Kalsaka. This consists of measuring the activity concentrations of $^{238}$U, $^{232}$Th and $^{40}$K in groundwater samples from Kalsaka area around the mining site assessing the Radiological Hazard and risk associated with exposure to the members of the community living in this area.

## 2. Materials and Methods

### *2.1. Studied Area characteristics*

The studied area is the North region of Burkina Faso in the mining area of Kalsaka. Kalsaka is located in the North region of Burkina Faso approximately 150km from Ouagadougou, the Capital City of Burkina Faso at a latitude of 13° 10'51''N and a longitude of 1° 58'46''W.

### Climate and Vegetation

The climate of the northeast region is essentially dry continental Sudano-SahelianIn the South and Sahelian in the North. It is characterized by two seasons: a dry season from October to May with a cold period from

November to February characterized by north-east (harmattan) and southwest winds;

A rainy season from June to September with an average rainfall that varies between 500 and 800 mm. This duration varies from year to year. Thermal amplitudes are also very variable: Maximum temperatures reach 45°C (in April) and minimum temperatures is 15°C (in January). Evapotranspiration rises to 2600 mm in the North and 1900 mm in the South. Only the months of July, August and September may present an excess of precipitation on evapotranspiration and thus contribute to the supply of underground aquifers. As far as vegetation is concerned the northern region of Burkina Faso is located in the savannah of Burkina Faso. The main plant formations are: tiger bush in islands scattered to the north; Typically sahelian vegetation at the Center; Thorny trees and shrubs concentrates dominate in the plains: it is the shrub steppe. A savanna more southerly and along the backwaters. The extent and density of which reduced by anthropogenic degradation [7].

**Geology**

The crystalline rocks constitute almost the entire subsoil of the northern region except in the northwest where the base disappears under the sedimentary formations of the infracambrian [7].Figure1 shows the geology of the study area.

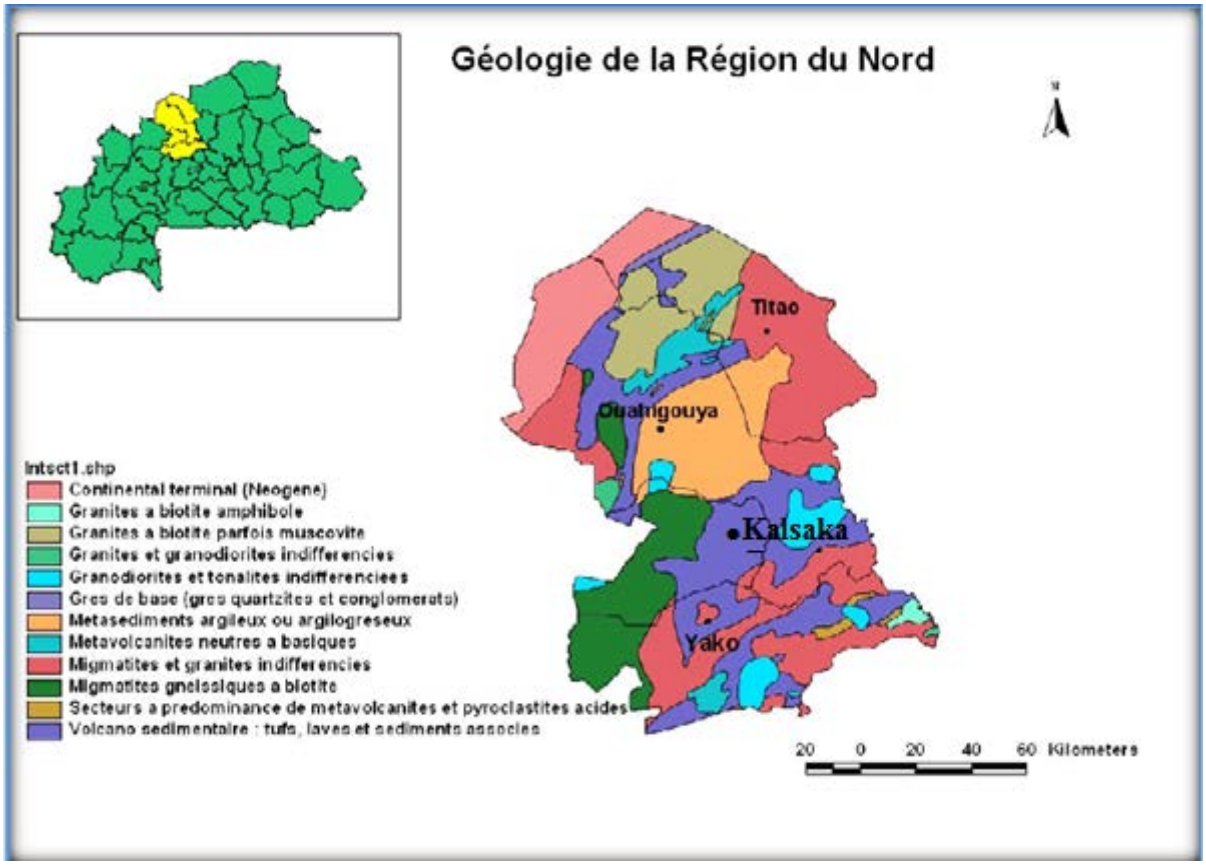



**Figure1:** Geological map of the studied area [7]

***2.2. Sampling and samples preparation***

Twenty (20) water samples were collected from boreholes which supply drinking water to the population in the North region of Burkina Faso surrounding the mining site of Kalsaka in Burkina Faso. The sampling bottles (one and half liter polyethylene container) were rinsed three (3) times with the water to be sampled, followed by filling the bottle with water to the brim [8]. Each water sample was acidified with two (2) drops of concentrated 65% $HNO_3$ just after the collection of the water samples. The sampled borehole water is used to fill one liter of a Marinelli beaker and tightly sealed to cut off the background radiation. The water samples were then analysed for $^{238}U$, $^{232}Th$ and $^{40}K$ activity concentration using a Gamma Spectrometry system with High Purity Germanium detector. Table 1 shows the samples location coordinates.

**Table 1:** Samples location coordinates

| Sample Code | above sea level (m) | Samples location coordinates | |
|---|---|---|---|
| WSKA-001 | 331 | N 13° 09' 52.5" | W 01° 59' 13.3" |
| WSKA-002 | 330 | N 13° 09' 52.2" | W 01° 59' 10.7" |
| WSKA-003 | 323 | N 13° 09' 40.4" | W 01° 59' 01.2" |
| WSKA-004 | 319 | N 13° 09' 16.8" | W 01° 59' 06.7" |
| WSKA-005 | 324 | N 13° 09' 02.6" | W 01° 59' 03.7" |
| WSKA-006 | 322 | N 13° 08' 55.3" | W 01° 58' 43.0" |
| WSKA-007 | 330 | N 13° 08' 57.7" | W 01° 58' 38.4" |
| WSKA-008 | 328 | N 13° 09' 35.5" | W 01° 59' 01.0" |
| WSKA-009 | 326 | N 13° 09' 26.0" | W 01° 59' 31.0" |
| WSKA-010 | 318 | N 13° 09' 33.7" | W 01° 59' 45.2" |
| WSKA-011 | 322 | N 13° 09' 56.3" | W 01° 59' 58.2" |
| WSKA-012 | 309 | N 13° 09' 47.7" | W 02° 00' 10.1" |
| WSKA-013 | 313 | N 13° 10' 04.6" | W 01° 59' 45.3" |
| WSKA-014 | 315 | N 13° 10' 14.0" | W 01° 59' 35.4" |
| WSKA-015 | 299 | N 13° 10' 31.8" | W 01° 59' 13.4" |
| WSKA-016 | 336 | N 13° 10' 50.3" | W 01° 59' 10.8" |
| WSKA-017 | 359 | N 13° 09' 59.2" | W 01° 58' 57.1" |
| WSKA-018 | 343 | N 13° 10' 00.2" | W 01° 59' 05.6" |
| WSKA-019 | 346 | N 13° 10' 14.1" | W 01° 58' 13.5" |
| WSKA-020 | 310 | N 13° 08' 74.1" | W 01° 58' 46.5" |

**Gamma Ray Spectrometry System**

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

spectrometry system used for this study consists of a High Purity Germanium (HPGe) detector with the following characteristics (Canberra detector model GX4020. cryostat model 7500SL and preamplifier model 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 efficiency of 40% for 1.33 MeV gamma energy of 60Co. The output from the detector is connected to a desk top computer provided with "Genie 2000"configuration software for spectrum acquisition and evaluation. Figure2 shows a block diagram of a particular gamma spectroscopic system. In order to do the measurement, energy calibration was done previously.

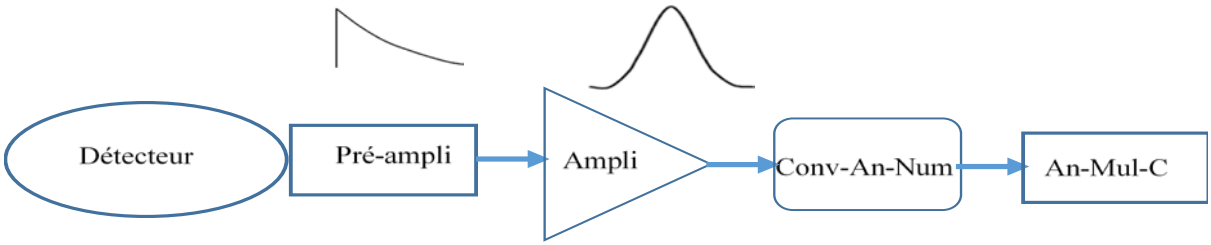



**Figure 2:** block diagram of a particular gamma spectroscopic system.

A relationship between the channel numbers corresponding to specific gamma-ray energies was determined before sample measurement. The establishment of this relationship is known as energy calibration and the idea is to identify the radionuclides in a sample. The linearity of energy response is an essential feature for any γ-ray detector and the direct proportionality between the quality of energy deposited in the detector by the incident radiation event and the height of the output pulse ensures that the system is working properly [9]. Accurate calibration involve a standard source with gamma ray energies that are not widely different from those to be measured in the unknown spectrum. The energy calibration was done by means of multi peaked and multi nuclide radioactive standard sources emitting gamma rays of precisely known energy and the peak position in channels with this energy is identified. In this study this was carried out by counting standard radionuclides (a mixture of $^{241}$Am, $^{109}$Cd, $^{139}$Ce, $^{57}$Co, $^{60}$Co, $^{137}$Cs, $^{113}$Sn, $^{85}$Sr and $^{88}$Y) of known activities with well-defined energies in the energy range of 60 to ~2000 keV. The standard was counted on a detector for 10 hours or 36000 s. Figure 2 shows a spectrum of sample after ten (10) hours of counting and the energy calibration curve is given in figure 3

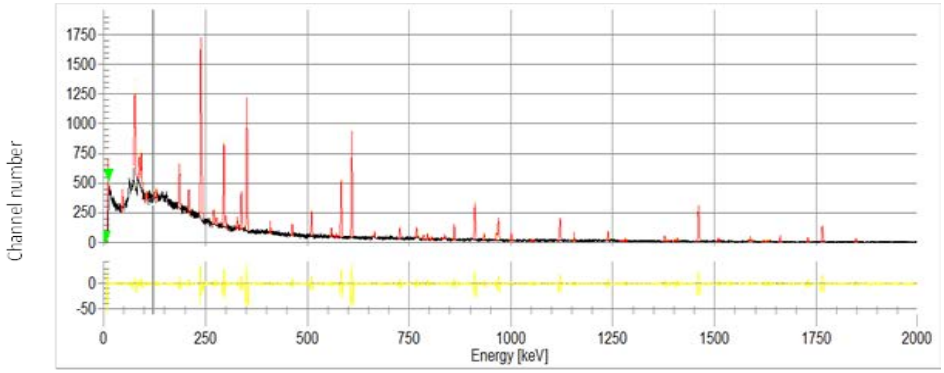



**Figure 2:** spectrum of sample with multi- peaks after counting

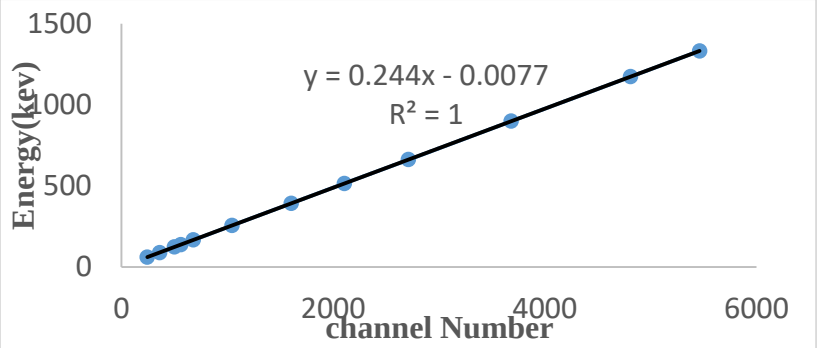



**Figure 3:** Energy Calibration Curve

**Determination of Activity Concentration**

From the spectrum analysis, count rates for each detected photo peak and activity per unit volume (specific activity) for each of the detected nuclides are calculated. The specific activity (in $Bq.L^{-1}$) $A_{Sk}$ of a nuclide k, and for a peak at energy E is given by equation (1) [10]:

$$A_{Sk} = \frac{(N_A . exp(\lambda_p . t_d))}{\varepsilon(E) \times p_\gamma \times T_c \times m} \quad (1)$$

Where, $N_A$ is the net counts of the radionuclide in the samples, td is the delay time between sampling and counting, $p_\gamma$ is the gamma ray emission probability (gamma ray yield), ε(E) is the absolute counting efficiency of the detector system, Tc is the sample counting time, m is the mass of the sample (kg) (m=1kg, because one liter of water is used for each sample), $\exp(\lambda_p t_d)$ is the decay correction factor for delay between time of sampling and counting, and λp is the decay constant of the parent radionuclide[11.12]. If there is more than one peak in the energy analysis range for a nuclide, then an attempt is made to average the activities for the peak. The result is then the weighted radionuclide's average activity concentration. The activity concentrations of $^{238}U$ and $^{232}Th$ in samples collected were determined using the measured γ-ray photo peaks emitted by specific radionuclides in their decay series whereas the activity concentrations of $^{40}K$ is calculated from the measured γ-ray photo peaks directly. In other words, the activity concentration of $^{238}U$ was calculated from the average energies of 609.31 keV and 1764.5 keV of $^{214}Bi$ and 295.25keV, 351.92 keV of $^{214}Pb$. In the decay series of $^{232}Th$, gamma photons are emitted at energies of 238.63 keV ($^{212}Pb$), 583.19 keV ($^{208}Tl$) and 911.21 keV ($^{228}Ac$) which are used to determine the activity concentrations of $^{232}Th$ by gamma spectrometry and $^{40}K$ was determined from 1460.0 keV. The activity concentrations of $^{214}Bi$ and $^{214}Pb$ in secular equilibrium with their parents were assumed to represent $^{238}U$ activity concentration; and the activity concentrations of $^{208}Tl$ and $^{228}Ac$ in secular equilibrium with their parents were also assumed to represent $^{232}Th$ activity concentration [13].

**Uncertainty estimation**

The uncertainties associated with the determination of activity concentrations of each radionuclide were estimated from expression used in the calculation of the specific activity concentration, viz equation (1). The overall uncertainty in the determination of the activity concentration was obtained using equation (2)

$$\Delta A_{sk} = A_{sk} \cdot \left[ \left( \frac{\Delta(N_A)}{N_A} \right)^2 + \left( \frac{\Delta\varepsilon(E)}{\varepsilon(E)} \right)^2 + \left( \frac{\Delta(P_\gamma)}{P_\gamma} \right)^2 \right]^{1/2} \quad (2)$$

Where

$\Delta(N_A)$ is determined from the uncertainty in the integration of the peak area of full energy event,

$\Delta\varepsilon(E)$ is the uncertainty in the efficiency calibration of the counting system,

$\Delta(P_\gamma)$ is the uncertainty of the gamma ray emission probability,

**Calculation of Annual Committed Effective Dose**

The committed effective doses (E)was estimated from the activity concentrations of each individual radionuclide by applying the annual water consumption rate for adults of 730 L/year (2 L/day multiplied by 365 days) and the dose conversion factors for 238U. 232Th and 40K taken from the BSS and UNSCEAR report [14.15] using the relation (3). The total annual effective dose D ($Sv.y^{-1}$) to an individual was established by summing contributions from all radionuclides present in the water samples

$$E_{ing} = \sum A_{sp} \times I_W \times C_f \quad (3)$$

Where. Asp is the activity concentration of the radionuclides in the water sample in Bq/L. Iw is the annual intake of water in liters per year. and Cf is the ingestion dose coefficient in Sv/Bq [15]. The risk incurred by the population is estimated by assuming a linear dose-effect relationship with no threshold as per ICRP practice. For low doses ICRP fatal cancer risk factor is 0.05 Sv-1 [16].

**Risk assessment**

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

Risk =Dose(Sv) ×risk factor (Sv-1 ) (4)

Where Dose (Sv) is equals to mean annual committed effective dose D (Sv/y) x life-time (years). Risk factor ($Sv^{-1}$) = 0.05 for low dose [16].

**3. Results**

The mean activity concentrations of $^{238}U$. $^{232}Th$ and $^{40}K$ in water samples from boreholes that provide drinking

water to the community around the goldmine site of Kalsaka were calculated using the methods cited before. The mean values for $^{238}U$, $^{232}Th$ and $^{40}K$ concentrations are 0.36 ± 0.07 Bq.L$^{-1}$ in a range of 0.19 - 0.71 Bq.L$^{-1}$, 0.50 ±0.09 Bq.L-1 in a range of 0.18 - 0.72 Bq.L$^{-1}$ and 5.32 ± 0.76 Bq.L$^{-1}$ in a range of 3.93 - 6.26 Bq.L-1 respectively. The highest value obtained for Uranium was 0.71 Bq.L$^{-1}$. For Thorium the maximum value was 0.72 Bq.L$^{-1}$ and it was 6.26 Bq.L$^{-1}$ for Potassium. The activity concentrations of $^{238}U$. $^{232}Th$ and $^{40}K$ from the water sample are shown in Table 2.

**Table 2:** Activity concentration of $^{238}U$. $^{232}Th$ and $^{40}K$

| Sample ID | Activity Concentration (Bq.L-1) | | |
|---|---|---|---|
| | U | Th | K |
| WSKA-001 | 0.30 ± 0.06 | 0.59 ± 0.06 | 4.46 ± 0.74 |
| WSKA-002 | 0.41 ± 0.05 | 0.39 ± 0.03 | 6.18 ± 0.85 |
| WSKA-003 | 0.31 ± 0.07 | 0.51 ± 0.04 | 5.52 ± 0.76 |
| WSKA-004 | 0.27 ± 0.06 | 0.52 ± 0.07 | 5.30 ± 0.76 |
| WSKA-005 | 0.61 ± 0.14 | 0.59 ± 0.13 | 3.93 ± 0.57 |
| WSKA-006 | 0.32 ± 0.07 | 0.52 ± 0.17 | 5.10 ± 0.73 |
| WSKA-007 | 0.24 ± 0.05 | 0.51 ± 0.19 | 4.35 ± 0.69 |
| WSKA-008 | 0.27 ± 0.06 | 0.41 ± 0.08 | 5.42 ± 0.78 |
| WSKA-009 | 0.41 ± 0.07 | 0.66 ± 0.08 | 5.38 ± 0.74 |
| WSKA-010 | 0.23 ± 0.05 | 0.58 ± 0.20 | 5.31 ± 0.76 |
| WSKA-011 | 0.39 ± 0.08 | 0.54 ± 0.09 | 5.63 ± 0.81 |
| WSKA-012 | 0.37 ± 0.10 | 0.39 ± 0.06 | 4.87 ± 0.70 |
| WSKA-013 | 0.40 ± 0.08 | 0.27 ± 0.01 | 5.57 ± 0.80 |
| WSKA-014 | 0.19 ± 0.06 | 0.52 ± 0.20 | 5.21 ± 0.70 |
| WSKA-015 | 0.71 ± 0.18 | 0.18 ± 0.03 | 6.03 ± 0.82 |
| WSKA-016 | 0.36 ± 0.06 | 0.27 ± 0.04 | 5.38 ± 0.79 |
| WSKA-017 | 0.34 ± 0.07 | 0.49 ± 0.09 | 6.01 ± 0.86 |
| WSKA-018 | 0.28 ± 0.06 | 0.71 ± 0.23 | 5.26 ± 0.75 |
| WSKA-019 | 0.25 ± 0.03 | 0.67 ± 0.20 | 5.34 ± 0.76 |
| WSKA-020 | 0.48 ± 0.07 | 0.72 ± 0.11 | 6.26 ± 0.86 |
| Min | 0.19 ± 0.06 | 0.18 ±0.03 | 3.93±0.57 |
| Max | 0.71 ± 0.18 | 0.72 ± 0.11 | 6.26±0.86 |
| **Mean** | **0.36 ± 0.07** | **0.50 ± 0.09** | **5.32 ± 0.76** |

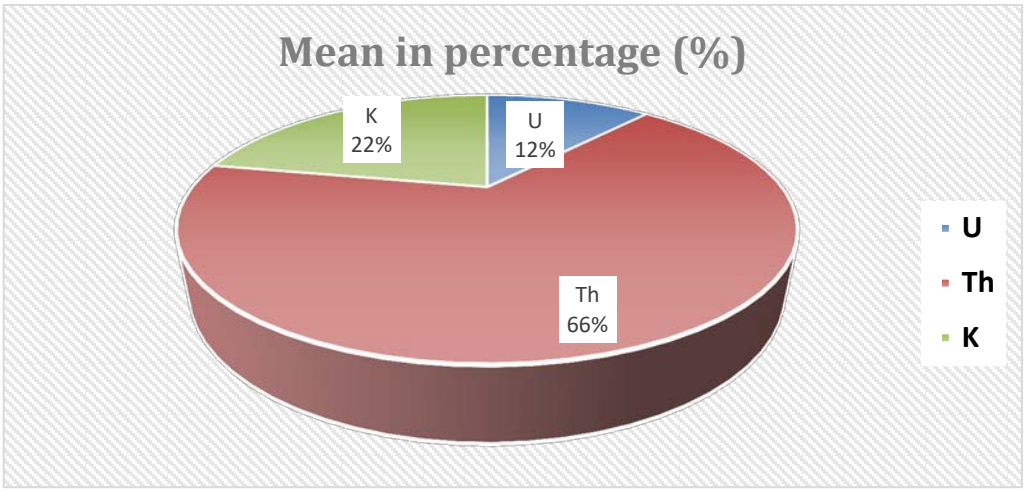
The annual committed effective dose (ACED) from drinking water samples was evaluated after calculating the contribution of each radionuclide for each sample. The mean contributions are 0.012 mSv.year-1. 0.080 mSv.year-1 and 0.024 mSv .year-1 for $^{238}$U. $^{232}$Th and $^{40}$K respectively. The total Annual Committed Effective Dose obtained was 0.12 mSv.year-1. Table 3 shows the ingestion dose coefficient of $^{238}$U, $^{232}$Th and $^{40}$K, Table 4 is the contribution of each radionuclide for each sample whereas figure 4 illustrates the contribution of each radionuclide to the total Annual Committed Effective Dose.

**Table 3:** Dose Coefficient of $^{238}$U, $^{232}$Th and $^{40}$K [17]

| Radionuclide | Dose Coefficient(SV/Bq) |
|---|---|
| 238U | 4.5x10-8 |
| 232Th | 2.3x10-7 |
| 40K | 6.2x10-9 |

**Table4:** Dose contribution of $^{238}$U. $^{232}$Th and $^{40}$K from water samples

| Sample ID | Dose contribution (µSv/y) | | | |
|---|---|---|---|---|
| | U | Th | K | Effective Dose(mSv/y) |
| WSKA-001 | 9.79 | 94.7 | 20.18 | 0.12467 |
| WSKA-002 | 13.11 | 63.37 | 27.96 | 0.10444 |
| WSKA-003 | 9.83 | 81.58 | 24.97 | 0.11638 |
| WSKA-004 | 8.76 | 82.75 | 24.02 | 0.11553 |
| WSKA-005 | 19.6 | 95.14 | 17.77 | 0.13251 |
| WSKA-006 | 10.29 | 83.87 | 23.1 | 0.11726 |
| WSKA-007 | 7.7 | 82.29 | 19.68 | 0.10967 |
| WSKA-008 | 8.83 | 66.02 | 24.55 | 0.0994 |
| WSKA-009 | 13.28 | 106.64 | 24.36 | 0.14428 |
| WSKA-010 | 7.43 | 94.35 | 25.03 | 0.12681 |
| WSKA-011 | 12.75 | 87.04 | 25.46 | 0.12525 |
| WSKA-012 | 11.87 | 62.78 | 22.4 | 0.09705 |
| WSKA-013 | 12.75 | 43.12 | 25.2 | 0.08107 |
| WSKA-014 | 5.96 | 84.13 | 23.56 | 0.11365 |
| WSKA-015 | 22.96 | 28.34 | 27.28 | 0.07858 |
| WSKA-016 | 11.72 | 42.96 | 24.37 | 0.07905 |
| WSKA-017 | 11.97 | 64.01 | 27.03 | 0.10301 |
| WSKA-018 | 8.84 | 114.12 | 23.8 | 0.14676 |
| WSKA-019 | 7.72 | 107.72 | 24.16 | 0.1396 |
| WSKA-020 | 15.3 | 114.92 | 28.35 | 0.15857 |
| Min | 5.96 | 28.34 | 17.77 | 0.07858 |
| Max | 22.96 | 114.92 | 28.35 | 0.15857 |




| | | | | |
|---|---|---|---|---|
| Mean | 11.523 | 79.9925 | 24.1615 | 0.115677 |

**Figure 3:** Dose Contribution of 238U, 232Th and 40K to the total Annual Committed Effective Dose. Seguenega

The Annual Committed Effective Dose due to ingestion of water by adults was estimated to be 0.12 mSv/year. Using this value and a life-time of 58.96 years (Burkina Faso, 2015), the exposure was evaluated to be 07.07 mSv for this life time. The risk from this exposure is estimated to be $3.5 \times 10^{-4}$ due to water consumption, using a risk factor of 0.05 Sv-1 [16.18]. This value is less than eighteen times the total risk (6.0 × 10-3) from all natural radiation sources based on global average annual radiation dose of 2.4 mSv. Yr-1 to man [18].

## 4. Discussion

Figure 4 shows a comparison of the activity concentrations of $^{238}U$, $^{232}Th$ and $^{40}K$ for the present work with other works and WHO guidelines values whereas figure 5

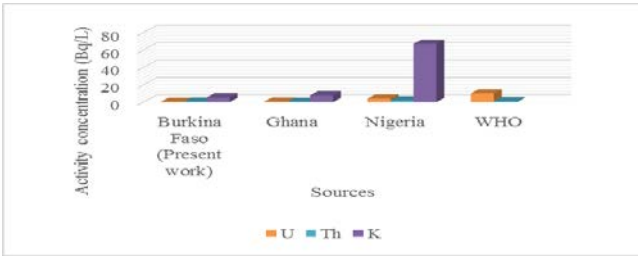



**Figure 4:** Comparison of the activity concentrations of 238U, 232Th and 40K with other works and WHO guidelines values

The mean values for $^{238}U$. $^{232}Th$ and $^{40}K$ concentrations are 0.36 ± 0.07 Bq.L$^{-1}$, 0.50 ±0.09 Bq.L$^{-1}$ and 5.32 ± 0.76 Bq.L$^{-1}$ respectively. The highest value obtained for Uranium was 0.71 Bq.L$^{-1}$. For Thorium the maximum value was 0.72 Bq.L$^{-1}$ and it was 6.26 Bq.L$^{-1}$ for Potassium. The mean values obtained in the present work are all mostly less than the values obtained in other countries. Also these values are approximately ten (10) times less and two (2) times less than the values recommended for $^{238}U$ and $^{232}Th$ respectively. The results obtained are below the recommended levels of 10.0 Bq.L$^{-1}$ and 1.0 Bq.L$^{-1}$ for $^{238}U$ and $^{232}Th$ respectively for drinking water established by the World Health Organization [18].

Figure 5 gives a comparison of the Annual Committed Effective Dose of this work with the results of other works and WHO and ICRP guideline values.

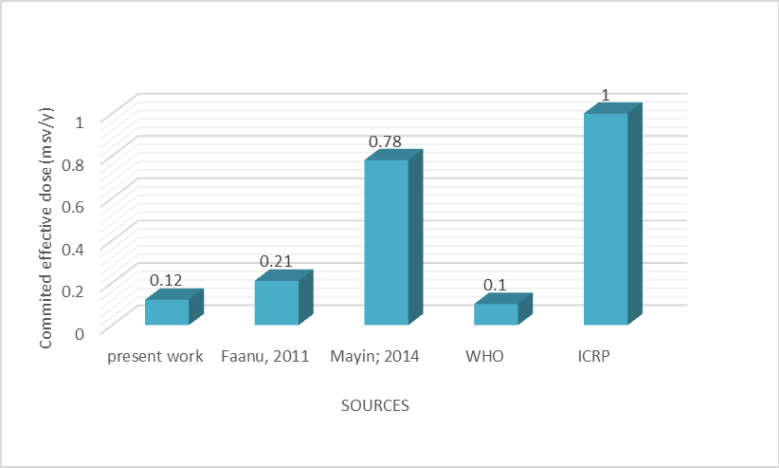



**Figure 5:** comparison of ACED of this work with the results of other works and WHO and ICRP guideline values

This study shows that the drinking water samples give an internal exposure which is in the range of worldwide limit of exposure of 0.12 mSv.year-$^{1}$, 0.1 mSv.year-1 and 1.0 mSv.year$^{-1}$ for UNSCEAR reported, the WHO and ICRP preference limit respectively. The United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR. 2000) has been reported that the worldwide average exposure to natural sources in foods and drinking water (ingestion exposure) is 0.29 mSv.year$^{-1}$ (about 0.17 mSv.year$^{-1}$ from 40K and about 0.12 mSv.year-1 from $^{238}U$ and $^{232}Th$) [11].

The risk from this exposure is estimated to be 3.5 × 10$^{-4}$ due to water consumption, using a risk factor of 0.05 Sv-1 [16.18].

This value is less than eighteen times the total risk (6.0 × 10-3) from all natural radiation sources based on global average annual radiation dose of 2.4 mSv. Yr$^{-1}$ to man [13].

The estimated values are also far less than the ICRP cancer risk of 2.5 × 10$^{-3}$ based on annual dose limit of 1 mSv for the general public, which gives annual death probability of 10-5 [19].

## 5. Conclusions

The activity concentrations of Natural Radionuclides 238U, 232Th and 40K in groundwater samples were measured using Gamma Spectrometry with High Purity Germanium detector. The mean activity concentrations of 238U, 232Th and 40K in water samples from boreholes were found to be 0.36 ± 0.07 Bq.L-1. 0.50 ±0.09 Bq.L-1 and 5.32 ± 0.76 Bq.L-1 respectively. The average annual committed effective dose estimated was 0.12 mSv/y. The risk from this exposure was 3.5 × 10-4 for a life-time of 58.96 years which is less than eighteen times the total risk (6.0 × 10-3) from all natural radiation sources based on global average annual radiation dose of 2.4 mSv.yr-1 to man and also far less than the ICRP cancer risk of 2. 5 × 10-3 based on annual dose limit of 1 mSv for the general public, which gives annual death probability of 10-5. The activity concentrations measured are far below the ICRP recommended level of 1000 Bq/L for which remedial action is needed. The average annual committed effective dose is also lower than the 1mSv per year dose limit recommended by the ICRP for public radiation exposure control. The results from this work indicate insignificant levels of the natural radionuclides, implying that the mining activities do not pose any significant radiological hazard due to NORMS to the communities who are drinking the water from boreholes in this area.

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