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RESEARCH ARTICLE

ASSESSMENT OF NATURAL RADIOACTIVITY AND HAZARD FROM CONSUMPTION OF COMMUNITY WATER SUPPLIED BY BOREHOLES AROUND GOLDMINE AREA IN KUILSE REGION, BURKINA FASO

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Abstract

The activity concentrations of Natural Radionuclides ^{238}U , ^{232}Th and ^{40}K in groundwater samples from Kuilsé Region of Burkina Faso 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 $1.53 \pm 0.21 \text{ Bq. L}^{-1}$, $0.58 \pm 0.06 \text{ Bq. L}^{-1}$ and $4.76 \pm 0.66 \text{ Bq. L}^{-1}$ respectively. The average Annual Committed Effective Dose was $0.16 \pm 0.02 \text{ mSv}$. 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.

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Introduction:-

The measurement of natural radioactivity level in the environment is necessary for the assessment of human exposure to radiation. Some natural radionuclides which are present in groundwater system with high amount, due to natural activity or caused by human activities can be taken into the body through ingestion. Mining is considered as one of the potential sources of exposure to NORM [11]. There are lots of mining companies operating in Burkina Faso. Nevertheless, related activities often expose groundwater to enhanced levels of radioactive contamination. Very little studies have been carried out regarding groundwater quality about NORM in Burkina Faso. Water is vital and, concurrently, one of the most important natural resources. About 70% of the Earth's surface is covered with water, which is estimated at a volume of approximately 1.4 billion km^3 . However, most of it is salty, and only around 2.5% of the global water resources (about 35 million km^3) consists of freshwater [7]. Groundwater is the

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most important and highly used resource; however, its quality can be endangered. Because of the increasing interest in radioactivity and its applications, there is the need for an assessment of human exposure to radiation through groundwater ingestion.

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

Materials and Methods:-

Study Area:-

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

Taparko is located in the Namantenga province of Burkina Faso in Kulsé Region, approximately 200 km from Ouagadougou, the Capital City of Burkina Faso, at a latitude of $13^{\circ} 27'55.28''\text{N}$ and a longitude of $0^{\circ} 19'27.99''\text{W}$. The base of Namantenga belongs to two geological eras: Inferior precambrian formations (Anttebirimian) represented by compound gneisses with biotites and amphiboles, and compound gneisses and granites; those of mean Precambrian (Birimian) represented by the plutonic rocks and the volcanogenic rocks. The plutonic rocks consist of granites with biotites. Figure 1 shows the geology of the study area.

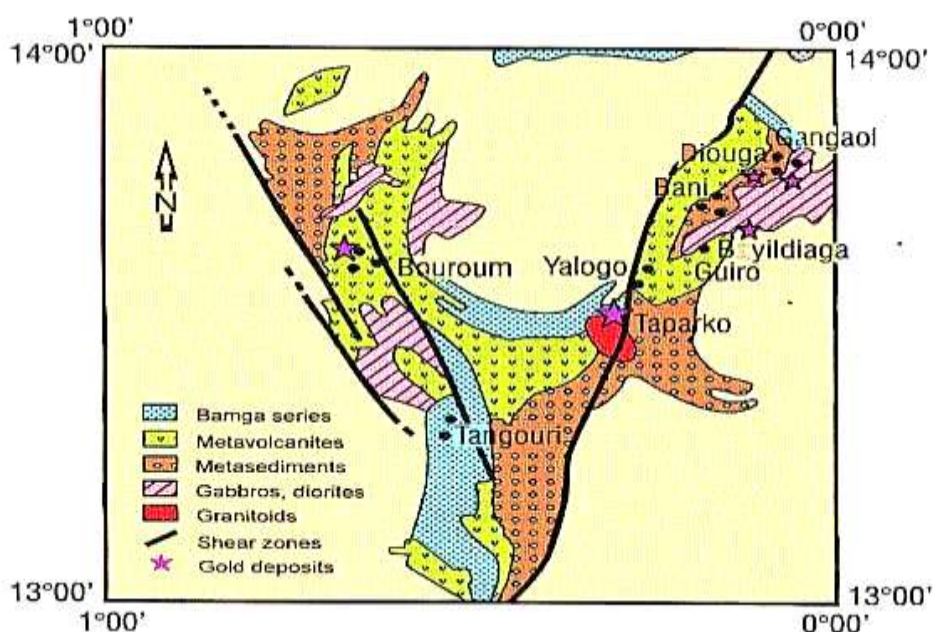


Figure 1: Local Geology of Taparko area (Nordgold, 2013)

Sampling And Samples Preparation:-

Water samples were collected from boreholes in Taparko village around the mining site. 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 [11]. 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
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"

Gamma Ray Spectrometry System:-

The actAvity concentrations of the natural radionuclides ^{238}U , ^{232}Th and ^{40}K 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 ^{60}Co . The output from the detector is connected to a desk top computer provided with "Genie 2000" configuration software for spectrum acquisition and evaluation.

In order to do the measurement, energy calibration was done previously:-

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 (Osvath et al., 2008). Accurate calibration involves 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. After counting, the spectrum consists of a series of energy-distributed peaks. These peaks represent the energy of the incident photons and allow identification of the radioisotope emitting gamma radiation. They extend across multiple channels and follow a Gaussian distribution of energy, with the full width at half maximum (FWHM) varying with energy. The peak area corresponds to the

number of counts per second and is proportional to the element's activity in Becquerels. The energy calibration curve is given in figure 2

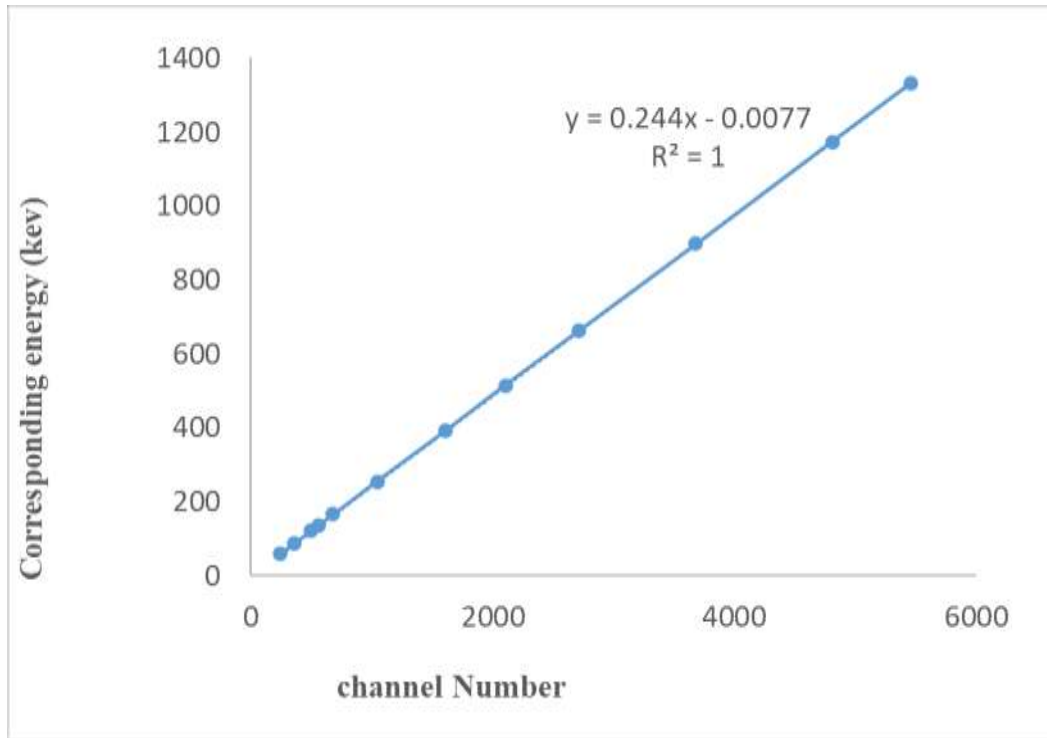


Figure 2: Energy Calibration Curve

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 $\text{Bq} \cdot \text{L}^{-1}$), A_{Sk} , of a nuclide k, and for a peak at energy E, is given by:

$$A_{Sk} = \frac{(\text{NetArea})_{Ek}}{\epsilon_{Ek} \times p_{\gamma} \times T} \quad (1)$$

Where, A_{Sk} is the activity concentration ($\text{Bq} \cdot \text{L}^{-1}$) of the radionuclide of interest, ϵ_{Ek} is the detection efficiency at energy E_k , T is the counting live time, p_{γ} is the number of gamma-rays per disintegration of this radionuclide for a transition at energy E of the measured sample of water [2]. 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 of 609.31 keV of ^{214}Bi and 1764.5 keV 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) and 911 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.

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 $730 \text{ L} \cdot \text{year}^{-1}$ ($2 \text{ L} \cdot \text{day}^{-1}$ multiplied by 365 days) and the dose conversion factors for ^{238}U , ^{232}Th and ^{40}K related to radiological ingestion, taken from the BSS and

UNSCEAR report [4 ;11], using the relation (2). 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

$$E_{ing} = \sum A_{sp} \times I_w \times C_f \quad (2)$$

Where, A_{sp} is the activity concentration of the radionuclides in the water sample in Bq.L^{-1} , I_w is the annual intake of water in liters per year, and C_f is the ingestion dose coefficient in Sv.Bq^{-1} [11]. 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} [5].

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^{-1}) for the measured water samples in this study, was used to estimate cancer risk for an adult person using the following relationship:

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

Where, Dose (Sv) is equals to mean annual committed effective dose D (Sv. y^{-1}) x life-time (years).

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

Results and Discussions:-

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 Taparko are shown in Table 2. The mean values for ^{238}U , ^{232}Th and ^{40}K are $1.53 \pm 0.21 \text{ Bq.L}^{-1}$ in a range of 0.93 - 2.64 Bq.L^{-1} , 0.58 ± 0.06 in a range of 0.45 - 0.79 Bq.L^{-1} and $4.76 \pm 0.66 \text{ Bq.L}^{-1}$ in a range of 3.62 - 6.30 Bq.L^{-1} respectively. The highest value obtained for Uranium was 2.64 Bq. L^{-1} which is far below the limit of 10 Bq. L^{-1} . For Thorium the maximum value was 0.79 Bq. L^{-1} . 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 [13]. Table 2 shows the activity concentration of ^{238}U , ^{232}Th and ^{40}K from Taparko area water samples.

Table 2: activity concentration of ^{238}U , ^{232}Th and ^{40}K .

Sample ID	Activity Concentration (Bq. L^{-1})		
	U	Th	K
WSTA-001	1.80 ± 0.09	0.60 ± 0.04	3.85 ± 0.58
WSTA-002	2.64 ± 0.33	0.52 ± 0.03	4.12 ± 0.56
WSTA-003	1.92 ± 0.11	0.50 ± 0.04	3.62 ± 0.54
WSTA-004	1.45 ± 0.27	0.53 ± 0.05	5.23 ± 0.71
WSTA-005	1.11 ± 0.13	0.60 ± 0.08	3.85 ± 0.62
WSTA-006	1.51 ± 0.24	0.59 ± 0.03	6.30 ± 0.85
WSTA-007	0.97 ± 0.03	0.60 ± 0.08	4.80 ± 0.69
WSTA-008	1.64 ± 0.23	0.59 ± 0.07	4.33 ± 0.32
WSTA-009	1.53 ± 0.19	0.62 ± 0.06	3.95 ± 0.59
WSTA-010	2.04 ± 0.30	0.56 ± 0.07	4.73 ± 0.68
WSTA-011	0.93 ± 0.28	0.62 ± 0.06	4.29 ± 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
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

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

Figure 3 shows comparison of the activity concentrations of uranium-238 (²³⁸U), thorium-232 (²³²Th), and potassium-40 (⁴⁰K) obtained in this study with our previous work, other studies, and WHO reference values [16].

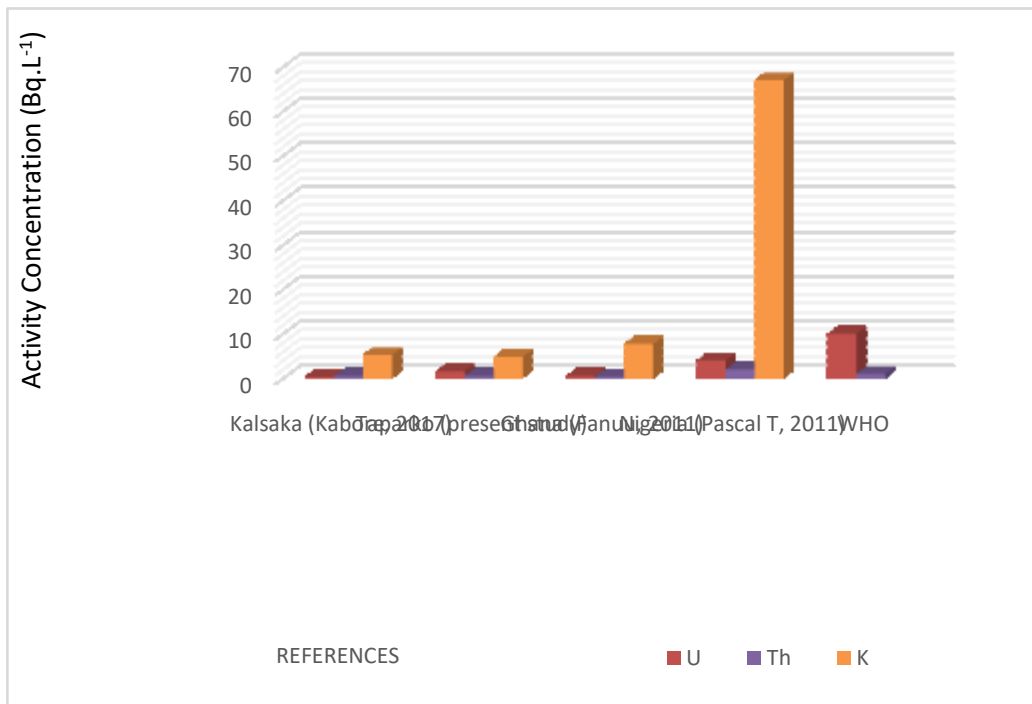


Figure 3: Comparison of activity concentration

We observed that the average concentration of ²³⁸U in the samples from the present study (Taparko site in the Kuilsé region) is three times higher than that of our previous study (Kalsaka site in the Yaadga region). This could be explained by the existence of uranium anomalies in the Kuilsé region, which some studies may confirm. The concentrations of ²³²Th are also slightly higher in the present study than in our previous work. However, the concentrations are less than one. Unlike uranium and thorium, potassium has a higher concentration in Kalsaka than in Taparko (present study). This can be explained by the fact that the environment is more acidic in the Yaadga region than in the Kuilsé region, as thorium is more soluble in groundwater and in more acidic environments. Also, when comparing our results to WHO standards, we observed that our values are lower than those recommended by the WHO for drinking water. They are approximately ten (10) times lower for uranium and two (2) times lower for potassium. The WHO recommended limit values are 10 Bq. L⁻¹ for uranium and 1 Bq. L⁻¹ for thorium.

Table 3 shows the ingestion dose coefficient of ^{238}U , ^{232}Th and ^{40}K . Table 4 presents the annual committed effective dose (ACED) from drinking water samples and the contribution of each radionuclide to the total ACED. The mean contributions are $0.049 \pm 0.006 \text{ mSv.y}^{-1}$, $0.092 \pm 0.009 \text{ mSv.y}^{-1}$ and $0.021 \pm 0.003 \text{ mSv.y}^{-1}$ for ^{238}U , ^{232}Th and ^{40}K respectively. The total Annual Committed Effective Dose obtained was $0.16 \pm 0.02 \text{ mSv.y}^{-1}$. 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.y^{-1} , 0.1 mSv.y^{-1} and 1.0 mSv.y^{-1} for UNSCEAR reported, and 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.y^{-1} (about 0.17 mSv.y^{-1} from ^{40}K and about 0.12 mSv.y^{-1} from ^{238}U and ^{232}Th) [19]

Table 3: Dose Coefficient of ^{238}U , ^{232}Th and ^{40}K

Radionuclide	Dose Coefficient(Sv.Bq^{-1}) [17]
^{238}U	4.5×10^{-8}
^{232}Th	2.3×10^{-7}
^{40}K	6.2×10^{-9}

Table 4: (ACED) from drinking water samples

Sample ID	Dose contribution ($\mu\text{Sv.y}^{-1}$)			Average ACED (mSv.y^{-1})
	U	Th	K	
WSTA-001	57.82 ±2.8	96.94±7.4	17.43±2.6	0.17±0.01
WSTA-002	85.02±10.7	82.98±5.6	18.63±2.5	0.19±0.02
WSTA-003	63.92±3.5	81.58±7.2	16.36±2.4	0.16±0.01
WSTA-004	46.55±8.8	85.82±7.8	23.68±2.4	0.15±0.02
WSTA-005	35.53±4.2	82.10±12.8	18.66±3.8	0.13±0.02
WSTA-006	48.11±7.7	95.14±5.6	28.52±3.1	0.17±0.02
WSTA-007	31.24±0.9	97.07±12.8	21.73±2.8	0.15±0.02
WSTA-008	52.69±7.4	96.13±12.3	19.59±2.7	0.17±0.02
WSTA-009	49.18±6.1	99.3±9.04	17.89±3.8	0.17±0.02
WSTA-010	65.81±9.6	89.26±12.3	21.38±3.1	0.18±0.02
WSTA-011	29.88±8.9	99.25±9.04	19.43±3.9	0.15±0.01
WSTA-012	36.37±6.1	127.49±12.5	22.3±3.3	0.19±0.02
WSTA-013	52.02±7.7	92.98±12.3	23.36±3.6	0.17±0.02
WSTA-014	34.84±2.8	122.75±12.8	24.65±3.3	0.18±0.02
WSTA-015	51.51±8.5	73.09±9.04	23.99±3.4	0.15±0.02
WSTA-016	42.52±7.7	72.19±9.03	22.95±3.3	0.14±0.02
WSTA-017	56.62±9.2	81.34±7.8	25.69±3.9	0.16±0.02
Min	29.88 ±8.9	72.19±9.03	16.36±2.4	0.13±0.02
Max	85.02±10.7	127.49±12.5	28.52±3.1	0.19±0.02
Mean	49.39 ±6.5	92.72 ±9.7	21.6 ±3.1	0.16±0.02

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

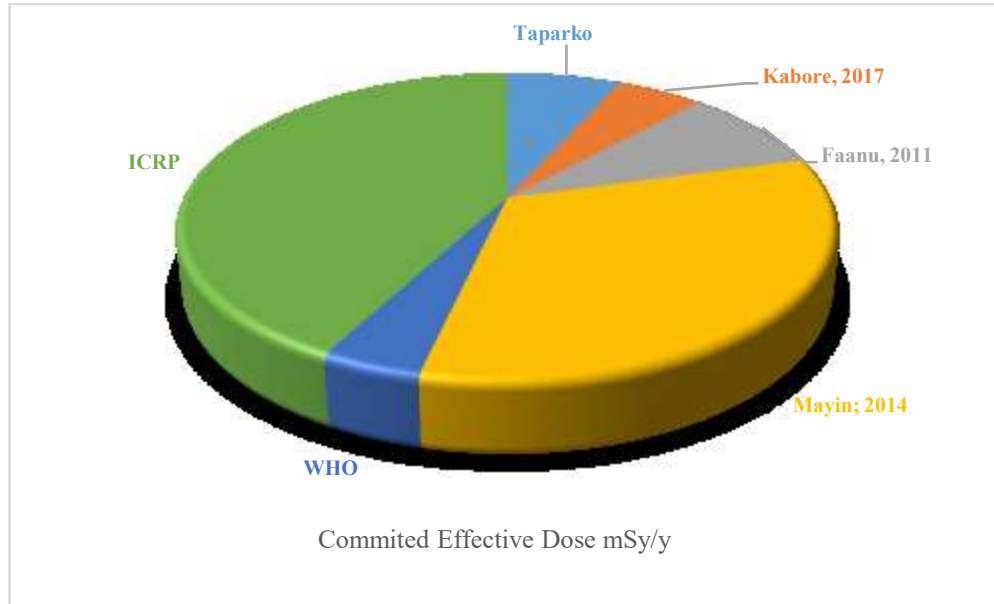


Figure 4: comparison of ACED of this work with the results of other works and WHO and ICRP guideline values

The Annual Committed Effective Dose due to ingestion of water by adults was estimated to be **0.16 mSv.y⁻¹**. Using this value and a life-time of 58.96 years (Burkina Faso, 2015), the exposure was evaluated as **09.43 mSv** for this life time. The risk from this exposure is estimated to be **4.5 × 10⁻⁴** due to water consumption, using a risk factor of 0.05 Sv⁻¹ [11]. This value is less than ten times the total risk (6.0 × 10⁻³) from all natural radiation sources based on global average annual radiation dose of 2.4 mSv. Y⁻¹ to man [13]. The estimated values are 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 [6].

Conclusion:-

This study was to assess the impact of natural radioactivity to public due to water ingestion in Kuilse region of Burkina Faso. The activity concentrations of Natural Radionuclides ²³⁸U, ²³²Th and ⁴⁰K in groundwater samples were measured using Gamma Spectrometry with High Purity Germanium detector. The activity concentrations measured are far below the ICRP recommended level of 1000 Bq. L⁻¹ for which remedial action is needed. The average annual committed effective dose is also lower than the 1 mSv 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 insignificant radiological hazard due to NORMS to the communities who are drinking the water from boreholes in this area.

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