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Baseline assessment of naturally occurring radionuclides in borehole water of Asikam-gold mining community in Ghana

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ABSTRACT

The main source of drinking water and domestic usage for the population of Asikam in the Fanteakwa South Municipality is from hand-dug wells and mechanized boreholes. This study assessed naturally occurring radionuclides Radium-226(Ra-226), Thorium-232(Th-232) and Patassium-40(K-40) in the water from these sources. A random sample of 20 sampling points made up of 7 manually dug wells and 13 mechanically drilled boreholes were taken from Asikam Communities. The radioactive contents of the selected water sources were characterized and analysed using gamma spectrometry system with High Pure Germanium Detector. This assessment was carried out to determine the level of natural radioactivity that the processing of gold ore at the Asikam illegal mining site in Ghana exposes the public to. The mean activity concentrations of Ra-226, Th-232, and K-40 were obtained as 0.30 Bq/L, 0.49 Bq/L, and 2.44 Bq/L in the water samples respectively. The results from this study were found to be lower than the Guidance levels recommended by the World Health Organization (WHO, 2011; IAEA,2014) of 1 Bq/l for Ra-226 and Th-232. The estimated average committed annual effective dose for water samples was 0.17 mSv/yr which is lower than the 1 mSv/yr recommended limits for public exposure by the WHO. The cancer fatality risk and hereditary consequences from exposure to naturally occurring radionuclides which may result from the Asikam community's mining and mineral processing operations were evaluated and found to be insignificant. The findings of this study demonstrate radioactivity levels are within the range of natural background radiation levels as reported in the literature, and they compare favorably with findings from comparable studies conducted nationally and internationally. This study provides important baseline information for future research in the study area.

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Introduction

In nature, radionuclides are abundant and can be found in groundwater, soil, and rocks. For the purpose of the public's radiation exposure, it is crucial to understand the distribution of radionuclide levels in the environment [1]. Because it is less vulnerable to contamination than surface waters, in Africa, groundwater is often regarded as a reliable source of water. Most of Africa now uses groundwater for drinking and residential reasons due to surface water contamination and a lack of access to tap water. These groundwater supplies do, however, have poor quality, which exposes the general people to both chemical and biological hazards [2,3]. Drinking water may contain radionuclides from anthropogenic (i.e., man-made) or natural sources. Natural causes, such as desorption from the soil and wash off by rainwater, or technological processes involving naturally occurring radioactive materials can cause natural radionuclides, such as 40K, 3H, 14C, and those originating from the thorium and uranium decay series, in particular Radium-226, Radium-228, Uranium-234, Uranium-238, and lead-210, to be found in water (e.g. the mining and processing of mineral sands or phosphate fertilizer production and use) [4–10]. Africa has one of the fastest growing populations in the world, accounting for over 13% of the world's population. Approximately one-third of Africa entire population does not have access to a sufficient source of water [11,12]. The two main pathways by which Naturally Occurring Radionuclides enter the body are through ingestion and inhalation. The rise of internal exposure of organs and tissues in the human body is caused by the decay of ingested and inhaled radionuclides. The average worldwide exposure to natural sources in drinking water and foods is 0.29 mSv/y with 0.17 mSv/y from K-40 and about 0.12 mSv/y from Uranium and Thorium. The general populace is ignorant of the dangers that could arise from consuming water that has been exposed to natural radioactivity. When drinking water has high radioactive levels, one may experience random health problems like cancer [13]. Due to the requirement for enough water to satiate the continually increasing needs through conservation and control, it has become necessary to identify the various sources of radioactive contamination that are transported into boreholes by runoff or through actions of illegal miners. Natural radioactivity in borehole water and the potential health risks associated with consuming it are recognized as global issues in recent years [14–16]. There is evidence that drinking water radionuclides may cause cancer if consumed over an extended period of time [17–19]. Although these radionuclides are extensively spread in nature, it has been discovered that their concentrations change depending on the local geological conditions [20]. The levels depend on the kind of rock that the soil is made of Granite and other igneous rocks have higher radioactivity levels, while sedimentary rocks have lower levels. However, there are major outliers, since some shale and phosphate rocks have quite large quantities of radionuclides. Higher concentrations could result from human activities like mining and processing minerals [5,21,22]. Material that has dissolved mobility in groundwater can be important both during operations and after closure. Where shallow groundwater interacts with the environment above the surface, groundwater dispersal has its greatest environmental impact. Because it is soluble in fluids with a pH neutral, radium-226 is the radiologically most important radionuclide and both uranium-238 and uranium-234 are significant. Several industrial processes have been discovered to be possible sources of increased naturally occurring radionuclides, including the extraction of oil and gas, the production of electricity from coal and peat, the phosphate business, the zircon/zirconium industry, the manufacture of titanium dioxide pigments, and the mining and processing of metals like copper, gold, and aluminum. Boreholes used in newly developed communities in Asikam of Ghana serve as sources of drinking and domestic purposes for the inhabitants. However Illegal mining activities have increased for the past years in those communities which have become a national issue now (myjoyonline.com 20 May 2020). This mining activity, however, may contribute to an increase in NORM that will leak into the environment. However, workers as well as the public may be exposed to occupational radiation; there is therefore the need to investigate the current activity concentration of NORM in the borehole water in those communities. The current activity concentration of natural radionuclides may pose risk to the communities of Asikam and the public because of the increase in illegal mining activities.

The main aim of this study was to determine the baseline activity concentration of Naturally Occurring Radioactive Materials (NORM) levels in the boreholes water of the selected communities in Asikam – Ghana. The study focused on the determination of the radioactivity concentrations of NORM in groundwater system (boreholes) in mining communities in the select study area by gamma spectrometry and to estimate the radiological impacts on residents in communities and make proposals for safety measures if necessary. This study was necessary as no previous research had been done to evaluate the activity concentration levels of the natural radionuclides Ra-226, Th-232, and K-40 and as a result, there is a lack of knowledge on radiation doses and dangers related to these radionuclides from consumption of borehole water in the Asikam mining communities.

Methods

Description of the study area

Asikam is a settlement in the Fanteakwa South District of the Eastern Region of Ghana, located Northeast of Kibi and southwest of Akyem Adukrom. Chains of mountains, wooded valleys, and waterfalls can be found in Asikam. The Community is located between latitudes 6° 11′ 38" North and longitudes 0° 32′ 18" West, situated nearby to Nteso and Dobidi. The town is known for a lot of illegal artisanal small-scale mining popularly known as "galamsey" activities and these activities have led to the contamination of river Birim. The ore is obtained by open-pit mining methods from the Communities such as Asikam and its environs. Fig. 1 is the map showing the study area as well as the sampling points. Fig. 2 shows the

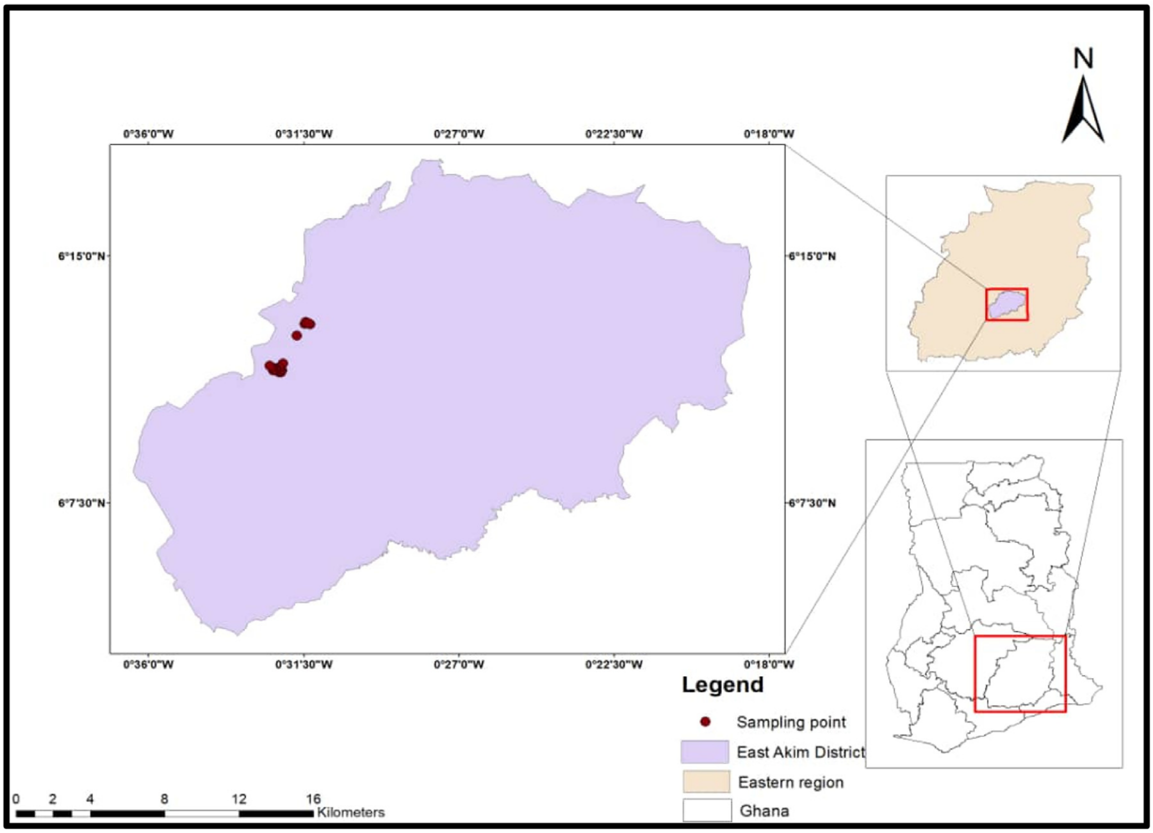

Fig. 1. Map showing Asikam as well as the sampling points.

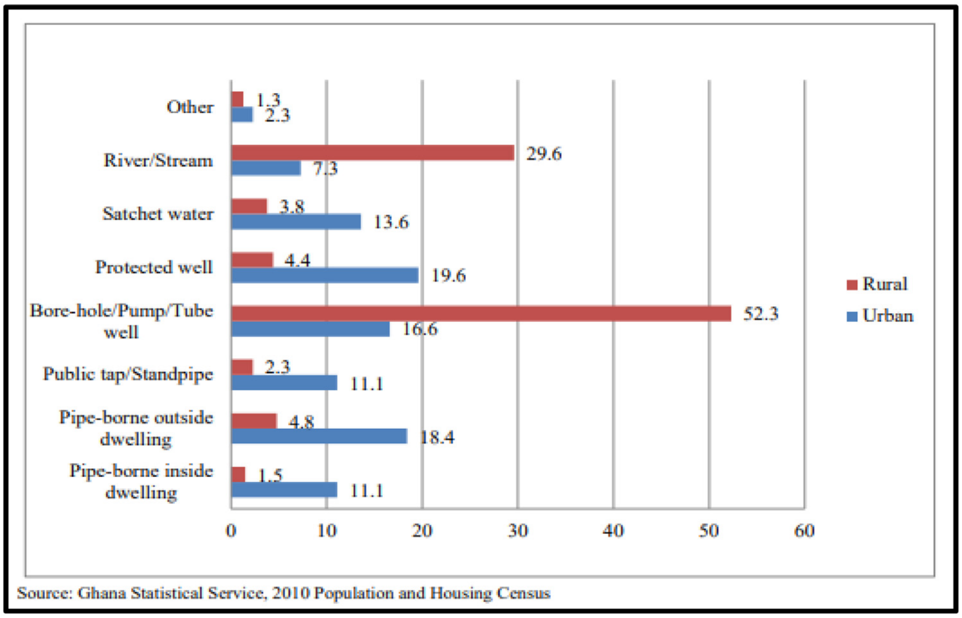

Fig. 2. Main source of drinking water for households by locality-Asikam.

various sources of drinking water for households in the district. According to the 2010 Population and Housing Census (PHC), almost sixty percent (60.0%) of households in the district either use borehole/pump/tube well (30.4%), river/stream (15.9%) or protected well (13.7%) as the main source of drinking, while about a quarter depends either on Public tap/Standpipe, pipe-borne outside or inside the dwelling. The least proportion of households uses unprotected springs (0.1%) as the main source of drinking water. At the locality level, however, protected well (19.6%), pipe-borne outside dwellings (18.4%) and bore-hole/pump/tube well (16.6%) are the three main sources of drinking water for urban localities whereas, about eighty percent of rural households depend either on borehole/pump/tube well (52.3%) or river/stream (29.6%).

Sample collection and preparation

The Global Positioning System (GPS) readings were used to record the sampling positions. Polyethylene sampling gallons were cleaned, dried and rinsed with the water to be sampled. Twenty (20) different water samples comprising 13 boreholes and 7 wells were collected in all. The physical parameters were recorded on-site before being carried to Ghana Atomic Energy Commission (GAEC) facilities in Kwabenya-Accra for Gamma Spectrometry (with high pure germanium detector) analysis. These included boreholes and wells that were randomly selected from Asikam, and its surroundings and stored in thermally insulated containers (ice chests) for transportation to the labs. The Marinelli beaker was rinsed with 1ml Conc. HNO_3 to prevent radionuclides from adhering to the walls of the container. The samples were homogenized and transferred into a 1L Marinelli beaker sealed with masking tape to prevent leakage. However, to attain equilibrium with their long-lived parent radionuclides, which is critical, [19], all the samples were stored for one month so that the short-lived daughters of U-238 and Th-232 decay. A high-purity germanium detector was used to count each sample for 36,000 seconds over the course of 10 hours for Radionuclides (Ra-226, Th-232, and K-40) in the water samples at the Radiation Protection Institute (RPI) laboratory of GAEC.

Instrumentation and calibration for gamma Spectrometry Measurements

The gamma rays in the water samples were analyzed using non-destructive direct gamma spectrometry and a High Purity Germanium detector (HPGe). In the gamma spectrometry system, the HPGe detector is coupled to a computer-based multi-channel analyzer (MCA). The detector's relative efficiency with a 2.0 keV energy resolution is 40% at the 1332 keV gamma ray energy of ^{60}Co. Radionuclides were quantitatively analyzed using the Genie 2000 gamma acquisition and analysis tool. The distinctive gamma-ray energies of individual radionuclides were used to characterize them. The detector is protected from background radiation by a 100 mm passive shielding of lead that is lined with 3 mm thick copper, cadmium, and plexiglass [4]. Liquid nitrogen was used to cool the detector at -196 0C. (77 k). Empty Marinelli beakers were meticulously cleaned and counted for 36000 s in the same geometry as the samples to determine the background distribution in the area surrounding the detector (quality control). The background spectra were used to adjust the measured isotopes' net peak area of gamma rays and the minimum detectable activities of Ra-226 (0.14 BqL^{-1}), Th-232 (0.16 BqL^{-1}) and ^{40}K (0.35 BqL^{-1}).

Energy and efficiency calibrations were performed by measuring standard radionuclides of known activities with well-defined energies from 60 keV to 2000 keV. The efficiency calibration of water samples was performed using standard radionuclides (multi-gamma certified cocktail standard (^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{60}Co and ^{88}Y,), which were uniformly distributed in solid water with volumes and densities of 1000cm3 and 0.98 gcm-3, respectively (source number: 9031-OL-146/14 and manufactured by Czech Metrology Institute). The activity concentrations of ^{226}Ra were determined using the γ-ray emissions and the respective γ-yield of ^{214}Pb at 351.9 keV (35.8%) and ^{214}Bi at 609.3 keV (44.8%). The ^{232}Th activity concentrations were determined through the gamma emissions of ^{228}Ac at 911 keV (26.6%), ^{212}Pb at 238.6 keV (43.3%) and ^{208}Tl at 583 keV (30.1%) and 2614.7 keV (35.3%) taking into consideration a branching ratio of 33.7% from ^{212}Bi towards ^{208}Tl. The ^{40}K activity concentration was determined directly from its emission line at 1460.8 keV (10.7%).

Calculation of activity concentrations and committed effective dose from spectral data

Activity concentrations of Ra-226, Th-232 and K-40 was determined at different energies.

The analytical equation, as shown

$$A_{sp} = \frac{N_{sam}}{P_E \cdot \varepsilon \cdot T_c \cdot L} \tag{1}$$

The activity concentration was calculated in Bql^{-1} for the water samples.

Where ε is counting efficiency, P_E is gamma yield, T_c is sample counting time and L is Volume of the water [23]. The committed effective dose was calculated using

$$E_T = (A_{w*} DCF_w) * I_w \tag{2}$$

Where I_w is water consumption rate which is 730 Ly^{-1}, A_w is the activity concentration of radionuclides in water (Bql^{-1}) *and* DCF_w is the dose conversion factor (Sv Bq^{-1}).

[24].

Table 1
Physical and Radionuclides parameters in Asikam.

	Physical characteristics					Radionuclides (Bq/L)		
ID	pH	Temp (°C)	TDS (mg/L)	E.Cond. (µS/cm)	SAL (ppm)	Ra-226	Th-232	K-40
Asik1	6.25	27.7	154	218	105	0.36±0.08	0.38±0.06	0.70±0.09
Asik2	5.03	28.3	140	196.9	95.7	0.67±0.15	0.48±0.10	0.63±0.11
Asik3	5.58	29.6	190	267	128	0.54±0.13	0.54±0.09	6.20±0.12
Asik4	5.49	28.8	86.8	122.1	61.9	0.69±0.16	0.30±0.19	0.83±0.07
Asik5	5.55	29.2	74.8	105.1	54.7	0.70±0.16	0.31±0.08	0.36±0.07
Asik6	5.04	30.2	126	177.9	86.8	0.04±0.01	0.21±0.08	0.33±0.05
Asik7	6.17	34.9	238	336	161	0.41±0.09	0.23±0.09	1.28±0.05
Asik8	5.97	31.1	152	216	105	0.35±0.08	0.27±0.02	6.67±0.6
Asik9	5.66	29.3	128	178.8	87.4	0.16±0.03	0.09±0.05	3.72±0.02
Asik10	5.48	31.0	186	262	126	0.05±0.01	0.17±0.07	3.38±0.03
Asik11	5.98	30.04	351	502	241	0.55±0.01	0.33±0.05	0.43±0.07
Asik12	5.19	30.5	341	485	233	0.71±0.16	0.25±0.04	0.63±0.05
Asik13	5.61	30.4	173	244	118	0.64±0.14	0.54±0.13	1.88±0.12
Asik14	5.50	31.0	366	518	246	1.07±0.24	0.25±0.07	0.77±0.05
Asik15	6.54	28.4	146	208	99.8	0.30±0.07	0.25±0.08	5.58±0.17
Asik16	4.79	30.6	45.7	64	37.8	0.29±0.06	0.27±0.06	6.64±0.06
Aduk1	5.07	30.1	109	153.7	75.9	0.71±0.06	0.25±0.04	1.44±0.03
Aduk2	5.88	33.9	131	184.1	90.9	0.61±0.14	0.50±0.11	0.48±0.11
Aduk3	5.39	28.5	180	253	122	0.39±0.09	0.38±0.07	1.96±0.08
Aduk4	5.31	29.7	208	293	141	0.51±0.11	0.47±0.03	1.34±0.10
Mean						**0.49**	**0.30**	**2.44**
WHO Guideline levels	6.50-8.50					1.00	1.00	N/A

Additionally, the ICRP cancer risk assessment approach was used to quantify the stochastic impact, (cancer and hereditary risks associated with low doses without the threshold dose). The ICRP's 2007 [25] recommendations propose nominal lifetime risk coefficients of fatal cancer of 4.1×10^{-2} Sv^{-1} for occupationally exposed workers and 5.5×10^{-2} Sv^{-1} for members of the general population. According to ICRP recommendations for the stochastic impact following exposure at low dose rates, the detriment-adjusted nominal risk coefficient is predicted to be 0.2×10^{-2} Sv^{-1} for the entire population and 0.1×10^{-2} Sv^{-1} for adult workers. The risk to the public in the vicinity that may be impacted by illegal mining activities and workers in those areas was then estimated using the 2007 recommended risk coefficients in the ICRP report [25] and an assumed 70-year lifetime of continuous exposure of the population to low-level radiation

$$Cancer\ Risk = E(Sv) \times CF\ \left(Sv^{-1}\right) \tag{3}$$

Where E is total annual effective dose, and (CF) is Cancer Risk Factor

$$Hereditary\ Effects = E(Sv) \times HF\ \left(Sv^{-1}\right) \tag{4}$$

Where E is total annual effective dose, and (HF) is Hereditary effect factor

Results and discussion

Physical and radionuclides characteristics

In general, the physical parameter data (Tables 1 and Fig. 3) revealed that Asikam thus Asik7, Asik11, Asik12 and Asik14 recorded relatively high electrical conductivity and TDS values compared to other sampling points. Salinity rises with conductivity and total dissolved solids, according to [26]. Clearly, this necessitates a review of the potential contributing geology and human actions. The electrical conductivity (EC), a measurement of an aqueous solution's capacity to carry electric current, was found to vary between 64 and 518 µS/cm in the water samples. The WHO recommends a value of 700 µS/cm for drinking water. No water sources gathered from the mining community had a value that was higher than recommended, as shown by a comparison between the study's findings and the WHO value. However, because these water sources are intended for consumption, any value above 700 S/cm may constitute a medical danger. The EC correlates with total dissolved solids (TDS), making it a helpful indication of mineralization in water bodies. All water samples had their TDS measured, and the findings ranged from 45.7 to 366.0 mg/L. TDS in drinking water should be between 600 and 1000 mg/L, according to WHO recommendations (WHO, 2004) and 500mg/L max according to Ghana Standards Authority (GSA). All of the study's findings fall short of the value suggested by the WHO and GSA. Rainwater leaches soluble and semi-soluble materials from the mining site; the leachate may affect aquifers beneath the ground. Acidic water with a pH of less than 6.5 is more likely to be contaminated with pollutants, making it unsafe to drink. It can also corrode (dissolve) metal pipes. The pH of groundwater normally ranges from roughly 6.0 to 8.5 in the absence of coal or iron sulfide minerals, depending on

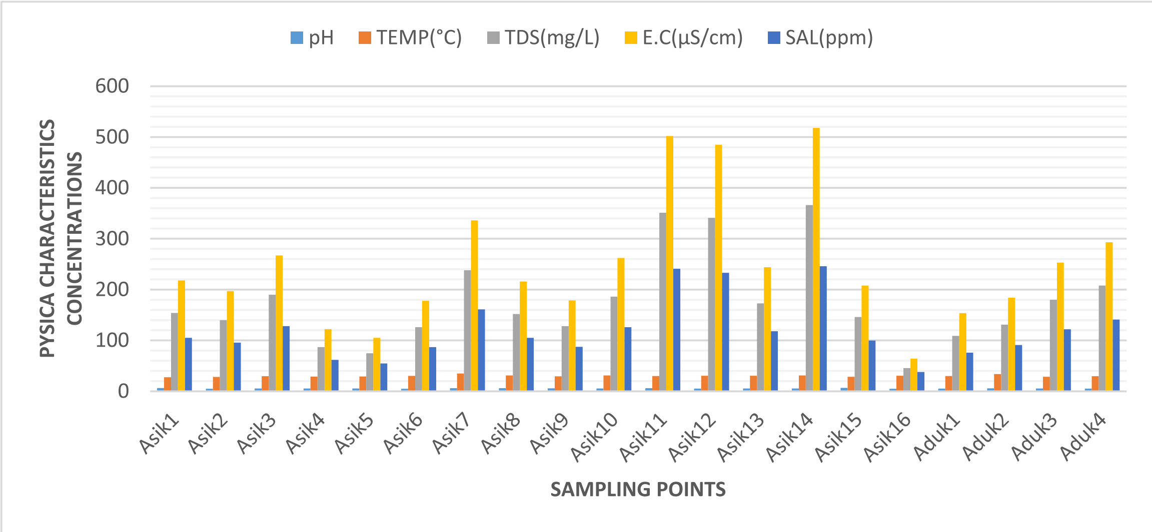

Fig. 3. Comparison of the physical characteristics Asikam groundwater.

Table 2
Pearson Correlation Matrix between Physical water quality parameters (pH, Temp, TDS, EC, Sal) and radionuclides content (R-226, Th-232 and K-40) for water samples.

	PH	TEMP	TDS	E.Cond	SAL	Ra_226	TH-232	K-K0
PH	1							
TEMP	0.121203	1						
TDS	0.185631	0.2217	1					
E.Cond	0.188229	0.219717	0.999936	1				
SAL	0.179355	0.223724	0.999592	0.999763	1			
Ra_226	-0.11102	0.035222	0.37143	0.370659	0.374328	1		
TH-232	-0.00302	-0.07594	-0.036029	-0.032764	-0.028143	0.052486	1	
K-K0	0.110782	-0.0496	-0.28873	-0.28824	-0.28888	-0.4124	-0.40692	1

the kind of soil and rock affected (WHO, 2004). Recorded pH levels in this finding range from 5.03-6.54 with an average of 5.57. All the water samples taken had pH levels that were somewhat acidic (less than 7.0). In the sampling areas, there are no appreciable temperature changes. Radionuclide concentrations often don't change significantly with the physical characteristics. The underlying rock formations of the region include the U-238-series Th-232-series, and K-40- as part of their matrix. The mean concentration of these radionuclides varies in all the locations (as presented in Table 1) in the following order: K-40>226Ra>232Th, in Bq/l.

The concentrations were measured in the following ranges: K-40(0.33–6.67)>Ra-226(0.04-1.07)>Th-232(0.09-0.54). However, K-40 is typically not considered while creating standards [27] as is unamenable to control. Therefore, Th-232 and Ra-226 are the radionuclides in the municipality's household water that is of greatest concern. Thorium isotopes were found in all measurements, although because of their high insolubility, their role in the radioactivity of the water is minimal [26]. However, Ra-226 and Ra-228, the daughters of U-238 and Th-232, are water soluble and transportable. Radium-226 exposure at high dosages has been linked to anemia, cataracts in the eyes, fractured teeth, and poor bone growth. Radium-226 has the potential to harm the respiratory system. This is because Po-218, a descendant of radon-222, can harm the respiratory system as well as other bodily tissues and organs when consumed [28]. Ra-226/Ra-228 = 1 Bq/l, Th-232 = 1 Bq/l, and U-238 = 10 Bq/l are the World Health Organization's ([29] recommended guidance levels for these radionuclides in drinking water, respectively. Most of the data from this study (Asikam) recorded low values, which ranged from (0.09-6.67Bq/l), as shown (Table 1) compared to the WHO guidance levels (WHO, 2011).

Pearson Correlation matrix using Microsoft Excel was employed to evaluate the relationship amongst the physicochemical parameters and the natural radionuclides concentration in waters (Table 2).

Generally, a positive correlation was seen among most of the physicochemical parameters and Th-232 and Ra-226. This shows that as the activity concentrations of Th-232 and Ra-226 increases, the parameters increase. A weak positive correlation was observed between Ra-226 and TDS, E. Cond., and Salinity which implies that, the activity concentration of Ra-226

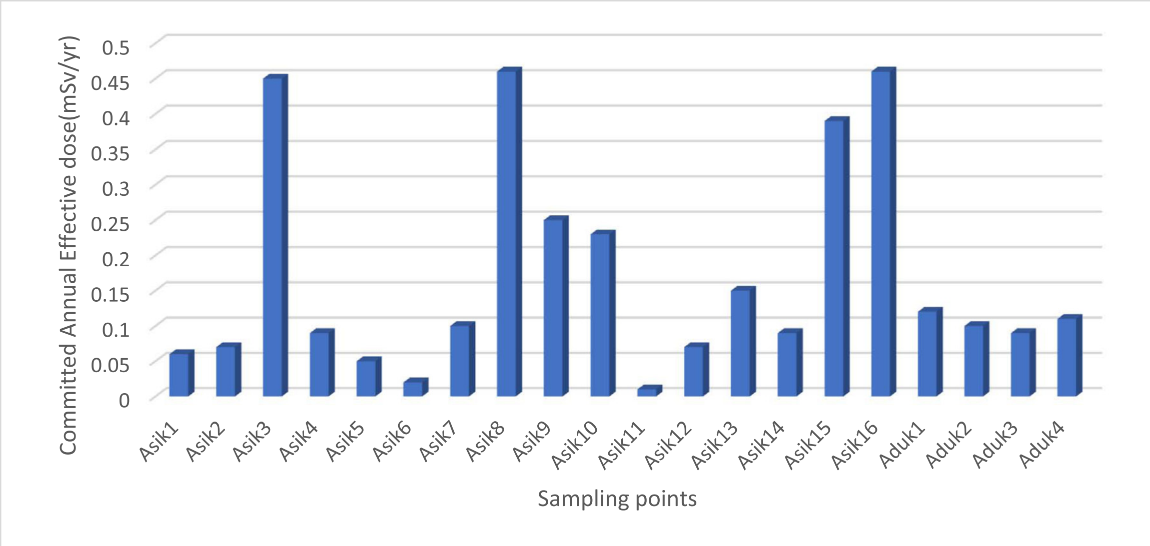

Fig. 4. Graph showing the Annual Effective Dose at various sample locations, Asikam.

is not attributed to the parameters. K-40 on the other hand showed a weak negative correlation with all physical parameters. Correlation is statistically insignificant at $p > 0.05$ and significant at $P \leq 0.05$ level (2-tailed) Pearson correlation. The outcome of the analysis shows a statistically significant correlation between the Physical water quality parameters (pH, TDS, EC, Sal) and Th-232 whiles Ra-226 recorded a significant correlation with Temp.

Committed annual effective dose

Due to the great insolubility of Th-232 and the fact that K-40 is not included in the standards, thorium has a limited impact on the radioactivity of water. The use of water in the study areas might undoubtedly have a radiological influence, and Ra-266, which has recorded relatively substantial quantities, is likely to be the source of any such impact. It is obvious that any radiological effects that may result from the use of water in these areas will probably come from Ra-266, which has reported relatively high amounts compared to Th-232.

Fig. 4 depicts the mean yearly dosage from water intake for people living in the Asikam communities. The estimated total doses that each Asikam inhabitant is expected to receive from drinking water from boreholes and wells are shown in Fig. 4. The average committed annual effective dose for the entire community was found to be 0.17 mSv/yr, which is lower than WHO, 2011 recommended limits of 1 mSv/yr. This result shows that the water quality of Asikam boreholes were within the WHO guidance levels. The study area has undergone mining for a very long time and as a result leaching of the radionuclide is possible. Leaching of the radionuclides into the water is more likely when these geological materials are in contact with the rocks.

The cancer fatality risk and hereditary consequences from exposure to naturally occurring radionuclides which may result from the Asikam community's mining and mineral processing operations were evaluated and found to be insignificant.

Conclusion

This study's objective was to evaluate the risks associated with radiation exposure from natural sources for study participants due to Asikam's mining and mineral processing operations. Internal exposure from drinking water containing natural radionuclides Ra-226, Th-232, and K-40 was the main exposure pathway taken into consideration for the study. The location is known for being a heavy mineral mining area, and there have been operations there for a few years now, which served as the study's impetus. No previous research had been done to evaluate the activity concentration levels of the Natural radioactivity Ra-226, Th-232, and K-40 before this study. As a result, no studies have ever been done to determine the radiation doses and dangers related to these radionuclides. These elements may be radioactive or chemically dangerous at high concentrations. Data on radiation doses and dangers, as well as activity concentrations of 226Ra, 232Th, and 40K in the various water samples, have been determined and established in this study using direct gamma spectrometry analysis. Mean levels of activity for K-40, Ra-226 and Th-232 in the water samples were 2.44, 0.49, and 0.30Bq/L, respectively. The findings of this study held up well to compare with findings from other studies both nationally and internationally. The findings show insignificant concentrations of natural radionuclides, suggesting that the local communities are not of immediate risk from radiological hazards associated with the mining activities. The risks to the public from exposure to naturally occurring radionuclides because of the mining and mineral processing operations of the Asikam community were examined and found to be negligible using the ICRP risk assessment technique for fatal cancer risk and hereditary effects. The results indicate there is no significant radiological health hazards associated in drinking Boreholes and wells in Asikam. This work provides useful data to help create a public awareness about the natural radioactivity levels in drinking and domestic water in the Asikam community.

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Declaration of Competing Interest

There is no conflict of interest.

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