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RADIOLOGICAL IMPLICATIONS OF ARTISANAL MINING ACTIVITIES IN BINDIN MARU LOCAL GOVERNMENT AREA, ZAMFARA STATE OF NIGERIA

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ABSTRACT

Contamination by radioactive substances of the environment due to Human-induced activities have been associated with significant human health challenges. twenty surface soil samples collected at random from Bindin artisanal gold mining site in Maru were assessed for their radiological contents using gamma spectrometric technique which employs NaI(Tl) detector. Radiological hazard parameters were also computed from the measured activity concentrations in order to assess the level of exposure of the miners and the public to ionizing radiation. Specific activities of ^{226}Ra, ^{232}Th and ^{40}K ranged from 11.937±1.1368 to 71.301±5.5722Bq.kg^{-1},3.357±0.2967to24.530±2.6918Bq.kg^{1} and 172.226±2.1510 to 533.011 ± 6.4362 Bq.kg^{-1} respectively, with mean values of 35.035±2.5809, 12.614±1.3169 and 346.446±3.91854 Bq.kg^{-1} in sequence. The mean values for ^{226}Ra was below the UNSCEAR stipulated global averages by some decimal point which is negligible. Computed average absorbed dose rate at 1 m above ground was 38.35nGy.h^{-1} with corresponding mean annual effective dose of 0.04704 mSv.y^{-1} external hazard index 0.21542 with corresponding internal hazard index 0.31011 and average gamma index of 0.59067. The data indicates moderate to elevated radiological risks in certain artisanal mining areas of Maru LGA. While most samples fall within international safety limits, localized exceedances warrant urgent attention to prevent long-term health and environmental consequences. Integrating these implications into national mining and environmental protection.

Keyboard: Radiological implication, Artisanal mining, health, hazard, environment.

1.0 INTRODUCTION

Artisanal mining is widespread across rural Nigeria, particularly in gold-bearing regions like Zamfara State. These activities often proceed without regulatory oversight, exposing workers and the surrounding environment to naturally occurring radioactive materials (NORM). The main radionuclides of concern—^{40}K, ^{232}Th, and ^{226}Ra—originate from geological formations and may accumulate through mining operations, tailings disposal, and soil disturbance.

Mining enhances human contact with radionuclides, which may enter the body through inhalation of dust, ingestion of contaminated food or water, or external exposure. Prior studies across Africa and globally highlight elevated radiological levels in unregulated mining environments. In Bindin village, artisanal gold extraction has been active for years, yet baseline radiological information is scarce. This research therefore quantifies radionuclide concentrations, evaluates environmental radiation exposure, and assesses potential health implications for miners and residents.

1.1 Aim and Objectives of the Study

This study aimed at quantifying the radiation dose to miners and the environment from artisanal mining activities around Bindin village in Maru LGA of Zamfara state through gamma spectrometry.

The objectives are to:

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i. Determine the specific activity concentration of naturally occurring radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in soil around Bindin Maru LGA

ii. Compute radiological parameters and assess the radiological health risk related to mining in the area.

3.0 MATERIALS AND METHODS

3.1 Study Area

Bindin artisanal goldmine lies within Maru LGA of Zamfara State, Nigeria (6.589193°E, 11.719014°N). The region is characterized by Guinea Savanna vegetation, granitic geology, and significant artisanal mining activity.

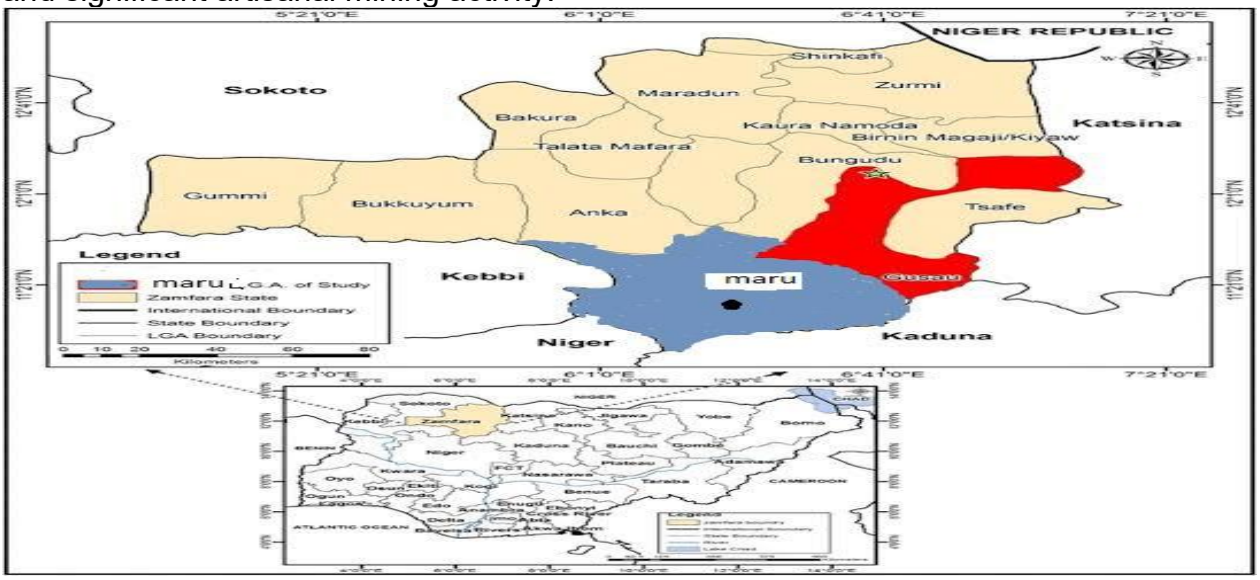


Figure 3.1: Location map of Maru in Zamfara State, Nigeria (www.researchgate.net/figure/Map-of-zamfara/)

3.2 Sample Collection and Preparation

Twenty surface soil samples (1 kg each) were randomly collected around mining pits and tailing sites, labeled AU01–AU20. Samples were air-dried, sieved to ensure homogeneity, and sealed in radon-impermeable containers for measurement at CERT, Zaria.

3.3 Gamma Spectrometric Analysis

A NaI(Tl) gamma-ray spectrometer connected to a PMT was used. The detector assembly was shielded using lead, cadmium, and copper to minimize background radiation. Energy calibration was performed using standard point sources. Each sample was counted for 29,000 s.

Activity concentration was computed using:

$$Activity(Ra,Th,K) = \frac{N_p}{\varepsilon t \gamma_d} \quad 3.1$$

Where N_p is the net peak area of a peak, ϵ is the detection efficiency, t is the counting live-time γ is the gamma ray yield per disintegration of specific nuclide for a transition of energy (Paramesh et al., 2003).

3.4 Radiological Hazard Indices

All radiological equations remain unchanged:

- **Raeq:**

$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_{K}$ 3.2

Where, C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively. In the above relation, it has been assumed that 10 Bqkg^{-1} of ^{226}Ra, 7 Bqkg^{-1} of ^{232}Th and 130 Bqkg^{-1} of ^{40}K

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produce equal gamma dose (Berekta and Mathew, 1985; Kolo *et al.*, 2019 and UNSCEAR, 2000). The maximum value of Ra_{eq} in soil must be less than 370 $Bqkg^{-1}$.

- **Gamma index:**

$$I\gamma = \frac{C_{Ra}}{150} + \frac{C_{Th}}{100} + \frac{C_k}{1500}. \quad (3.3)$$

The safety value for this index is ≤1.

- **Absorbed dose rate:**

$$D(\eta Gyh^{-1}) = 0.462C_{Ra} + 0.621C_{Th} + 0.0417C_k \quad (3.4)$$

- **Annual effective dose:**

$$AEDE = D\ (\eta Gyh^{-1}) \times 8760\ hyr^{-1} \times 0.7\ Sv/Gy \times (103mSv/10^9)\ \eta Gy \times 0.2 \quad (3.6)$$

External and Internal hazard indices:

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (3.7)$$

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (3.8)$$

The values of the indices (H_{ex}, H_{in}) must be less than unity for the radiation hazard to be negligible (Diab et al., 2008).

Sample	^{226}Ra (Bq/kg)	^{232}Th(Bq/kg)	^{40}K(Bq/kg)
1	31.546 ± 1.6160	18.571 ± 1.6111	353.232 ± 4.9887
2	31.726 ± 2.859	20.039 ± 1.6431	255.653 ± 5.8698
3	35.866 ± 1.2511	15.637 ± 2.2192	175.112 ± 2.7631
4	29.631 ± 5.5722	3.801 ± 0.6689	191.460 ± 2.4873
5	42.629 ± 1.1714	16.698 ± 2.3489	454.603 ± 3.9484
6	21.924 ± 1.1368	9.138 ± 1.1915	452.703 ± 4.4745
7	27.098 ± 3.5379	8.424 ± 0.2967	403.675 ± 3.3484
8	14.051 ± 2.4721	4.315 ± 0.535	172.226 ± 2.9165
9	11.937 ± 2.0736	13.307 ± 1.4065	533.011 ± 2.1510
10	25.054 ± 1.7170	6.733 ± 0.9957	333.557 ± 3.2956
11	35.656 ± 1.5895	14.623 ± 0.6898	420.419 ± 2.4551
12	69.713 ± 3.2205	24.530 ± 1.5786	486.976 ± 3.3021
13	35.890 ± 1.8999	6.168 ± 0.9492	401.861 ± 3.607
14	44.319 ± 3.7745	14.642 ± 2.0607	172.682 ± 4.1545
15	37.455 ± 3.6459	9.953 ± 1.1751	495.422 ± 6.4362
16	19.352 ± 2.7803	4.472 ± 0.6271	206.641 ± 5.4799
17	39.496 ± 2.5011	22.599 ± 2.6918	397.423 ± 6.3334
18	41.363 ± 3.7036	18.434 ± 0.8641	273.381 ± 2.8329
19	34.691 ± 1.5291	3.357 ± 0.55022	363.947 ± 3.8374
20	71.301 ± 3.5647	16.834 ± 2.2332	384.920 ± 3.6887
Maximum	**71.301 ± 5.5722**	**24.530 ± 2.6918**	**533.011 ± 6.4362**
Minimum	**11.937 ± 1.1368**	**3.357 ± 0.2967**	**172.226 ± 2.1510**
Average	**35.035 ± 2.5809**	**12.614 ± 1.3169**	**346.446 ± 3.91854**

4.0 RESULTS AND DISCUSSION

4.1 Activity Concentrations

Table 4.1 presents activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in all samples.

^{226}Ra: 11.937–71.301 Bq/kg (mean = 35.035 Bq/kg)

^{232}Th: 3.357–24.530 Bq/kg (mean = 12.614 Bq/kg)

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^{40}K: 172.226–533.011 Bq/kg (mean = 346.446 Bq/kg)

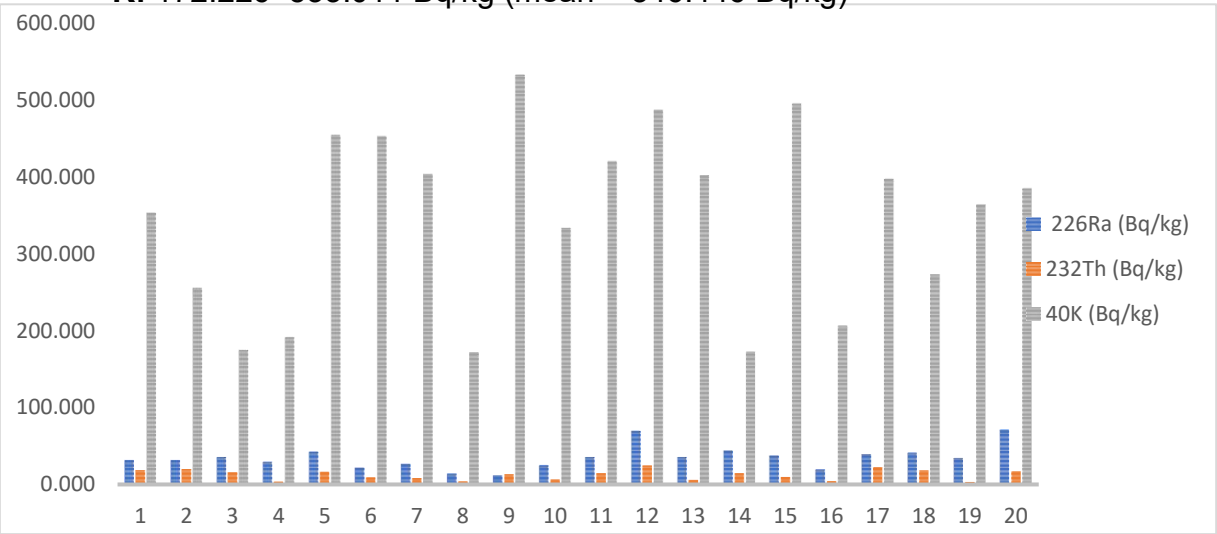


Figure 4.1: Variation of radionuclide concentrations

Mean ^{226}Ra equals the UNSCEAR world average (35 Bq/kg). While most values fall within safe levels, samples #12 and #20 show elevated ^{226}Ra, suggesting uranium-bearing mineral influence. ^{40}K exceeds the world average (400 Bq/kg) in sample #9.

4.2 Comparison with Other Regions

Country	Activity (Bq/Kg)			References
	^{226}Ra	^{232}Th	^{40}K	
Saudi Arabia (Asir)	38.7	23.5	217.9	*Althoyaib and El-Taher (2012)*
Egypt (EL-Mynia)	21	12.1	154.4	*Makhluf Sand El-Taher A. (2010)*
Turkey	85.75	51.08	771.57	*Dizmanet.al (2016)*
Jordan	57.7	18.1	138.1	*El-Taher and Al-Zahrani (2014)*
Algeria	53.2	50.03	311	*Wassila and Ahmed (2011)*
Egypt (Abou Zabal region)	31.12	10.96	264.1	*Diab et al. (2008)*
Brazil	10.22	7.27	54.75	*Becegatoet al. (2008)*
Nigeria (Jos Plateau)	-	734	115.8	*Jibiri et al. (2007)*
This study (Bindin)	35.035	12.614	346.446	
World Average	35.00	30.00	400.00	UNSCEAR (2000)

Table 4.2 shows that Bindin radionuclide levels fall within or slightly above values reported in similar mining regions worldwide. This supports the influence of mining disturbance on radionuclide mobilization.

4.3 Absorbed Dose Rate and Raeq

Absorbed dose rates ranged from **16.30–67.58 nGy/h**, averaging **38.35 nGy/h**, below the global 55 nGy/h reference.

Raeq values (Table 4.3) ranged **33.48–142.29 Bq/kg**, well below the 370 Bq/kg limit.

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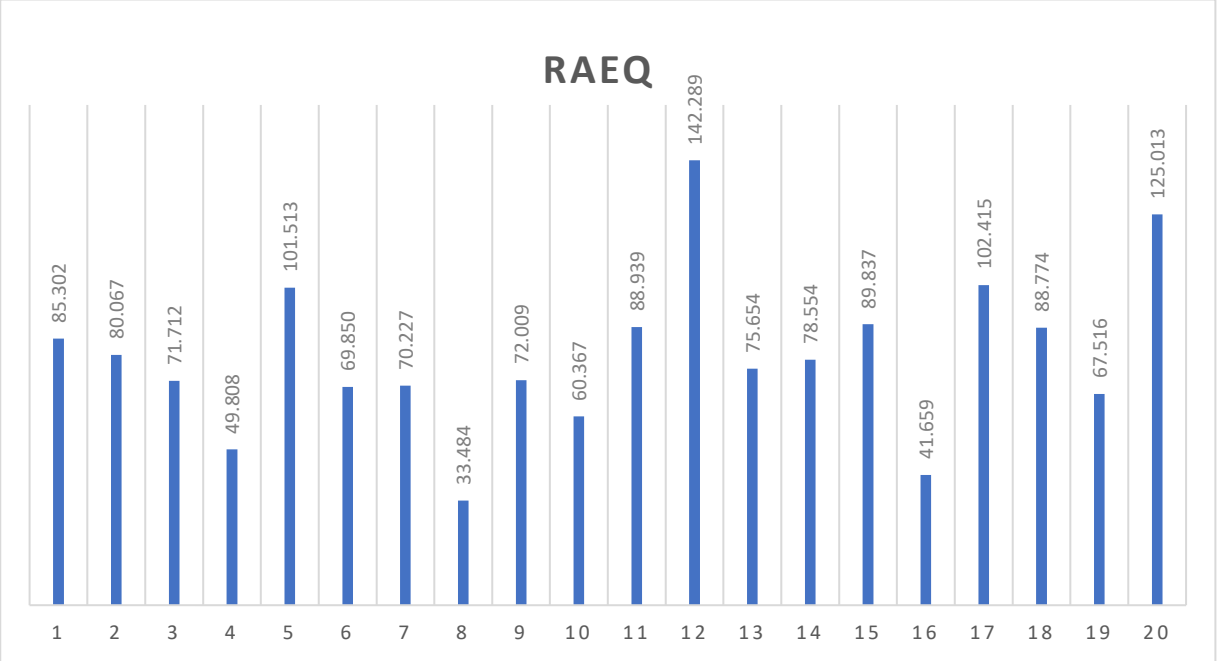
Sample	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	Ra_{eq}	H_{in}	H_{ex}	Absord Dose	Annual Effective Dose	I_γ
1	31.547	18.571	353.232	85.302	0.31566	0.23040	40.73648	0.04996	0.63151
2	31.726	20.039	255.653	80.067	0.30201	0.21627	37.69416	0.04623	0.58233
3	35.867	15.637	175.112	71.712	0.29066	0.19372	33.52631	0.04112	0.51223
4	29.631	3.800	191.460	49.808	0.21465	0.13456	23.95407	0.02938	0.36319
5	42.629	16.699	454.603	101.513	0.38942	0.27420	48.87619	0.05994	0.75425
28	21.925	9.138	452.703	69.850	0.24791	0.18866	34.54222	0.04236	0.53935
7	27.098	8.424	403.675	70.227	0.26292	0.18969	34.45238	0.04225	0.53401
8	14.052	4.315	172.226	33.484	0.12842	0.09044	16.29622	0.01999	0.25165
9	11.938	13.308	533.011	72.009	0.22672	0.19446	35.86052	0.04398	0.56800
10	25.055	6.733	333.557	60.367	0.23077	0.16306	29.55422	0.03625	0.45673
11	35.657	14.623	420.419	88.939	0.33660	0.24023	42.95301	0.05268	0.66422
12	69.714	24.530	486.976	142.289	0.57279	0.38437	67.58133	0.08288	1.03471
13	35.891	6.168	401.861	75.654	0.30137	0.20436	37.02528	0.04541	0.56886
14	44.320	14.642	172.682	78.554	0.33200	0.21222	36.70235	0.04501	0.55701
15	37.455	9.954	495.422	89.837	0.34389	0.24266	43.97867	0.05394	0.67952
16	19.352	4.472	206.641	41.659	0.16484	0.11253	20.26255	0.02485	0.31150
17	39.497	22.599	397.423	102.415	0.38338	0.27663	48.74074	0.05978	0.75425
18	41.363	18.434	273.381	88.774	0.35159	0.23980	41.87057	0.05135	0.64235
19	34.692	3.357	363.947	67.516	0.27615	0.18239	33.15180	0.04066	0.50748
20	71.301	16.834	384.929	125.013	0.53043	0.33773	59.29334	0.07272	0.90030
Maximum	71.301	24.530	533.011	142.289	0.57279	0.38437	67.58133	0.08288	1.03471
Minimum	11.938	3.357	172.226	33.484	0.12842	0.09044	16.29622	0.01999	0.25165
Average	35.035	12.614	346.446	79.750	0.31011	0.21542	38.35262	0.04704	0.59067

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4.4 Hazard Indices

- **Hex:** 0.090–0.384 (average 0.215)
- **Hin:** 0.128–0.573 (average 0.310)
- **Iγ:** 0.252–1.035 (mean 0.591)

These values are below unity, signifying acceptable radiological safety, though a few local hotspots approach cautionary thresholds.

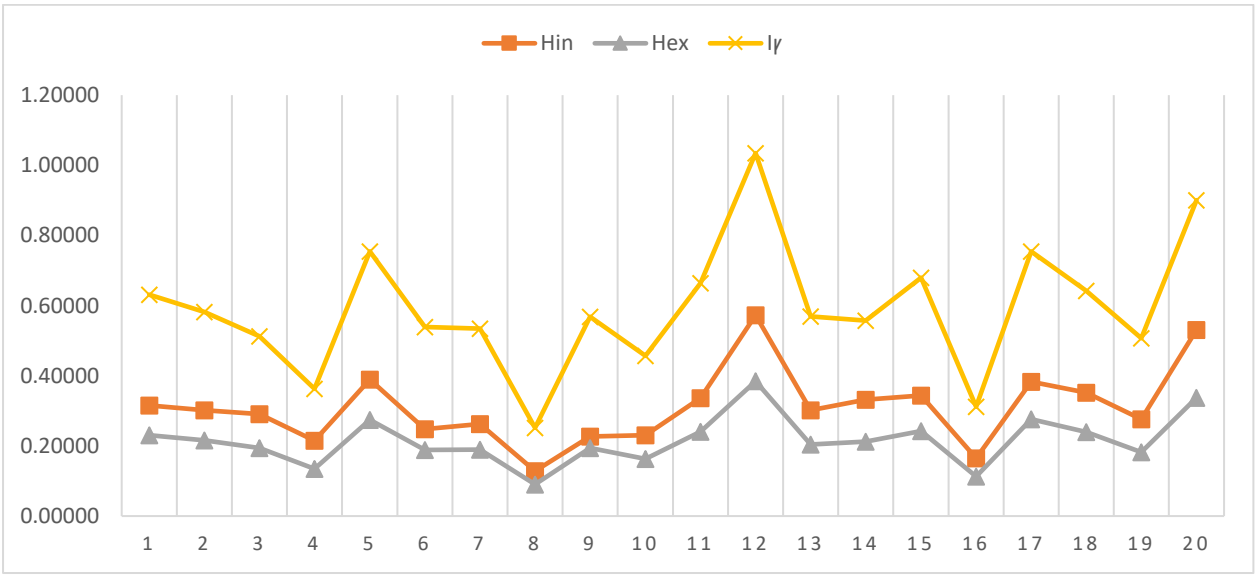


Figure 3: Radiological indices chart (Iy, Hex, Hin)

4.5 Annual Effective Dose

AEDE values ranged from **0.01999–0.08288 mSv/y**, averaging **0.04704 mSv/y**—well below the global limit of 1 mSv/y for public exposure.

4.6 CONCLUSION

This study shows that soil from Bindin artisanal mining area contains radionuclides at concentrations generally within global safety limits. However, elevated ^{226}Ra and ^{40}K levels in localized sites indicate mining-related enhancement of NORM. Although hazard indices remain below recommended limits, continuous exposure in mining zones warrants concern. Sustained monitoring and community awareness are essential for radiation safety.

4.7 RECOMMENDATIONS

Routine radiological surveillance of mining sites
Mandatory safety gear for miners
Community education on radiation exposure
Controlled management of tailings and waste
Remediation of contaminated points.

4.8 POLICY IMPLICATIONS

Nigeria requires strengthened radiological regulations for artisanal mining sites.
Pre-mining radiological assessments should be enforced nationwide.
State agencies must implement occupational radiation-health programs.
Environmental monitoring and transparent public reporting should be mandatory.
Inter-agency cooperation (NNRA, FMEnv, MCO) is necessary to enforce compliance.

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REFERENCES

AGI. (2019). What are the main methods of mining? Retrieved from American Geoscience Institute website: https://www.americangeosciences.org/critical-issues/faq/what-aremain-mining-methods

Ahmed, S. N. (2007). *Physics and Engineering of Radiation Detection* (6th Ed.). Amsterdam: Academic Press.

Candeias, C., Ávlla, P., Coelho, P., & Teixeira, J. P. (2018). Mining Activities: Health Impacts. In *Encyclopedia of Environmental Health, 2nd Edition* (pp. 1–21). Elsevier Inc. https://doi.org/10.1016/B978-0-12-409548-9.11056-5

Darko, E. O., Tetteh, G. K., & Akaho, E. H. K. (2005). Occupational radiation exposure to NORM in a gold mine. *Radiation Protection Dosimetry*, *114*(4), 538–545. https://doi.org/10.1093/rpd/nci300

Faanu, A., Adukpo, O. K., Tettey-Larbi, L., Lawluvi, H., Kpeglo, D. O., Darko, E. O., Agyeman, L. (2016). Natural radioactivity levels in soils, rocks and water at a miningconcession of Perseus gold mine and surrounding towns in Central Region of Ghana.*SpringerPlus*, *5*(1), 1–16. https://doi.org/10.1186/s40064-016-1716-5

Sabo, A., Sadiq, L. S., & Gamba, J. (2018). radiological assessment of artisanal gold mining sites in Luku, Niger State, Nigeria. *Journal of Environment Pollution and*

Human Health, *6*(2), 45–50. https://doi.org/10.12691/jephh-6-2-1

UNEP. (2016). Radiation: Effects and Sources. Retrieved March 12, 2024, from http://wedocs.unep.org/handle/20.500.11822/7790

UNSCEAR. (2000). *Sources and Effects of Ionizing Radiation. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly*. United Nations, New York.

USNRC. (2017). Natural and Man-Made Radiation Sources. Retrieved September 3, 2024. from https://www.nrc.gov/reading-rm/basic-ref/students/for-educators/06.pdf