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**Research Article**

# Assessment of Radiological Levels in Soils from Artisanal Gold Mining Exercises at Awwal, Kebbi State, Nigeria

[1]S. Girigisu, [2]I.G.E. Ibeanu, [2]D.J. Adeyemo, [2]R.A. Onoja, [2]I.A. Bappah and [3]S. Okoh
[1]Physics Department, Federal College of Education (Technical) Gusau, Zamfara State,
[2]Health Physics and Radiation Bio-physics Section,
[3]Materials Science and Development Section, Centre for Energy Research and Training,
Ahmadu Bello University, Zaria, Nigeria

**Abstract:** This study assessed the radiological levels from Awwal artisanal gold mining exercises in Kebbi State. Results show mean values of activities of $^{40}K > ^{226}Ra > ^{232}Th$ numerically as 425.96±5.56, 23.85±2.01 and 18.80±1.21 Bq/kg, respectively. The average outdoor gamma dose was 34.26 nGy/h while the mean annual effective dose rate was 42.15 μSv/year (= 0.042 mSv/year), which is less than 0.07 mSv/year benchmark given in UNSCEAR (1993). Radio logically, the values obtained are low and do not imply any significant health concerns effects on the local population. However, the observed unprofessional practices such as lack of use of gas mask while working in the dust-filled mine cafes and at the mills could expose workers to possible risks from inhalation of respiratory crystalline silica as well as exposure to radon gas.

**Keywords:** Artisanal mining activity concentrations, awwal, health effect

## INTRODUCTION

Living organisms are exposed to numerous natural and man-made agents that interact with molecules, cells and tissues, causing reversible deviations from homeostatic equilibrium (GRPC, 1977). Many aspects of aging and many diseases are thought to stem from these exogenous and endogenous deleterious agents acting on key components of cells within the body. (GRPC, 1977). One of the natural and exogenous deleterious agents is Ionizing radiation and the possible proliferation of its release due to human activities in the environment is the concern of this study with a particular focus on radiation issues related to mining in Awwal, Kebbi State of Nigeria. Natural environmental radioactivity and the associated external exposure due to gamma radiation depends primarily on the geological and geographical conditions and appear at different levels in the soils of each region in the world (UNSCEAR, 2000). Awwal is located on the southern part of Kebbi State half of between longitudes 4°.45' and 4°0.50' East of the prime meridian and latitudes 11°0.35' and 11°0.40' North of the equator. Nigeria, half of its land area of 923,768 km$^2$ by sedimentary rocks which is dominated by schist, Phillies, quartzite and marble, of which the study area falls.

Assessment of radio nuclides in soils and rocks in many parts of the world has been on the increase in the past two decades because of their hazard on the health of the populace (Belivermis *et al*., 2009). However, research in the area of natural radionuclide in the soils and rocks of North-Western Nigeria has been low. To contribute to this area, a number of radiological indices were measured based on samples taken from the mining field under consideration.

## MATERIALS AND METHODS

**Soil sample collection:** An initial survey was undertaken of the mine site to map out the three mining stages where radiation measurements will be carried out. About 500 g of soil from each spot was collected. All the samples were mixed thoroughly to form a composite sample representative of the sampling stages. They were then transferred into polythene bag, labeled and double-bagged to avoid cross-contamination.

**Soil sample preparation:** Each of the soil/tailing samples collected were dried and grinded to fine powder with the use of a pulverize. The process was followed by packaging into radon-impermeable cylindrical plastic containers which were selected based on the geometry of the detector vessel which measures 7.6 by 7.6 cm in dimension. To prevent radon-222 escape, the packaging in each case were triple-sealed, The sealing process included smearing of the inner rims of each container lid with Vaseline jelly, filling the lid assembly gap with candle wax to block the gaps

**Corresponding Author:** S. Girigisu, Physics Department, Federal College of Education (Technical) Gusau, Zamfara State, Ahmadu Bello University, Zaria, Nigeria

between lid and container and tight-sealing lid-container with a masking adhesive tape. The prepared samples were then stored for a period of about 30 days to allow for radon and its short-lived progenies to reach secular radioactive equilibrium prior to gamma ray measurement.

**Evaluation of radioactivity of samples:** The soil samples were analyzed using a 76×76 mm NaI (TI) detector crystal optically coupled to a Photomultiplier Tube (PMT). The assembly has an incorporated preamplifier and a 1kilovolt external source. The detector is enclosed in a 6 cm Lead shield lined with cadmium and copper sheets. The stated arrangement is aimed at minimizing the effects of background and scattered radiation. The data acquisition software is a basic spectroscopy package Maestro by Camberra Nuclear Products, 1990 version. The samples were measured for a period of 29,000 sec, after which the net area under the corresponding γ-ray peaks in the energy spectrum were used to compute the activity concentrations in the samples by the use of equation:

$$C\ (\text{Bg/Kg}) = \frac{C_n}{C_{fk}} \quad (1)$$

(Ibeanu, 1999)

where,

C = Activity concentration of the radionuclide in the sample given in Bq/kg

$C_n$ = Count rate (counts per second)

$C_{fk}$ = Calibration factor of the detecting system

**Standards:** The standards used in this study were the IAEA gamma spectrometric reference materials RGK-1 for k-40, RGU-1 for Ra-226 (Bi-214 peak) and RTG-1 for Th-212 (Ti-208).

**Background:** The background count rate for 5 h count time was 0.3 cps for Ra-226, 0.16 cps for Th-232 and 0.25 cps for K-40.

**Calibration and efficiency determinations:** Calibrations for energy and efficiency were carried out with two calibration sources; Cs-137 and Co-60. These were achieved with the amplifier gain that gives 72% energy resolution for the 66.16 keV of Cs-137 and counted for 30 min.

## RESULTS AND DISCUSSION

**Specific radioactivity:** Radionuclide concentrations for the collected surface soil samples indicated the nature of geological formation for the area studied. Table 1 present the associated spectra energy windows, calibration factors and detection limits as related to the research conducted, Table 2 and 3 summarized the specific activity of $^{226}$Ra, $^{232}$Th and $^{40}$K, air absorbed dose rates as well as their corresponding effective dose rates and hazard indices in the soils/tailings of the studied area, while Table 4 showed a compacted radiological result. The $^{40}$K activity is distinctly higher

Table 1: Spectra energy windows, calibration factors and detection limits

| Element | Gamma energy (KeV) | Energy window (KeV) | Calibration factor (cps/Bq/kg) | Detection limit (Bq/kg) |
|---|---|---|---|---|
| Ra-226 | 1764.0 | 1620-1820 | 8.632 | 3.84 |
| Th-232 | 2614.5 | 2480-2820 | 8.768 | 9.08 |
| K-40 | 1460.0 | 1380-1550 | 6.430 | 14.54 |

Table 2: Activity concentrations of $^{226}$Ra, $^{232}$Th and $^{40}$K and dose rates in the three stages of the mining exercises

| Sample code | K-40 (Bq/Kg) | Ra-226 (Bq/Kg) | Th-232 (Bq/Kg) | Dose rates (nGy/h) | Effect dose rates (μSv/year) |
|---|---|---|---|---|---|
| C-1, S-1 | 994.70±4.34 | 43.39±2.71 | 74.52±0.91 | 107.81±2.00 | 132.61±2.46 |
| C-1, S-2 | 792.92±1.92 | 13.54±0.72 | 15.84±1.54 | 49.16±1.37 | 60.47±1.69 |
| C-2, S-1 | 680.66±11.32 | 41.77±2.73 | 18.09±1.22 | 58.91±2.49 | 72.46±3.06 |
| C-2, S-2 | 516.90±3.83 | 20.06±0.05 | 15.99±0.81 | 40.75±0.68 | 50.12±0.84 |
| C-3, S-1 | 1176.96±10.08 | 6.07±0.24 | N.D | 51.88±0.53 | 63.81±0.65 |
| C-3, S-2 | 768.00±0.47 | 21.78±0.75 | 16.12±1.06 | 52.10±1.21 | 64.08±1.49 |
| C-4, S-1 | 537.86±4.34 | 21.90±2.71 | 7.82±0.68 | 37.41±1.85 | 46.01±2.28 |
| M-1, S-1 | 191.21±2.72 | 27.41±4.16 | 9.75±1.73 | 26.68±3.10 | 32.82±3.81 |
| M-1, S-2 | 260.86±5.19 | 44.15±0.12 | N.D | 31.28±0.27 | 38.47±0.33 |
| M-2, S-1 | 154.04±3.79 | 42.86±12.40 | N.D | 26.22±5.89 | 32.25±7.24 |
| M-2, S-2 | 111.99±3.31 | 31.28±1.29 | 3.47±1.57 | 21.27±1.71 | 26.16±2.10 |
| M-3, S-1 | 114.32±21.68 | 16.54±2.07 | 11.09±2.60 | 19.30±3.49 | 23.74±4.29 |
| M-3, S-2 | 255.82±6.42 | 13.59±0.44 | 17.77±0.16 | 27.99±0.57 | 34.43±0.70 |
| T-1, S-1 | 322.16±5.08 | 3.79±2.32 | N.D | 15.18±1.28 | 18.67±1.57 |
| T-1, S-2 | 137.05±2.67 | 15.78±2.35 | N.D | 13.00±1.20 | 15.99±1.48 |
| T-2, S -1 | 298.80±5.43 | 19.57±0.21 | 16.39±1.05 | 25.15±0.98 | 30.93±1.21 |
| T-2, S-2 | 350.12±5.10 | 18.96±0.74 | N.D | 23.36±0.55 | 28.73±0.68 |
| T-3, S-1 | N.D | 19.25±2.15 | N.D | 8.89±0.99 | 10.93±1.22 |
| T-3, S-2 | 2.89±2.35 | 31.44±0.03 | N.D | 14.65±0.11 | 18.02±0.14 |
| Mean | 425.96±5.56 | 23.85±2.01 | 18.80±1.21 | 34.26±1.59 | 42.14±1.96 |
| Range | 2.89-1176.96 | 3.79-44.15 | 3.47-74.52 | 8.89-107.81 | 10.93-132.61 |

Table 3: Radium equivalent and related hazard indices

| Sample code | $Ra_{eq}$ (Bq/kg) | $H_{ex}$ (Bq/kg) | $H_{in}$ (Bq/kg) |
|---|---|---|---|
| C-1, S-1 | 226.62±4.34 | 0.61 | 0.73 |
| C-1, S-2 | 97.24±3.07 | 0.26 | 0.29 |
| C-2, S-1 | 120.05±5.34 | 0.32 | 0.44 |
| C-2, S-2 | 82.73±1.50 | 0.61 | 0.28 |
| C-3, S-1 | 96.72±1.02 | 0.31 | 0.27 |
| C-3, S-2 | 103.97±2.31 | 0.25 | 0.34 |
| C-4, S-1 | 74.50±4.08 | 0.25 | 0.26 |
| M-1, S-1 | 56.07±6.84 | 0.15 | 0.23 |
| M-1, S-2 | 64.24±0.52 | 0.17 | 0.29 |
| M-2, S-1 | 54.72±12.69 | 0.15 | 0.26 |
| M-2, S-2 | 44.86±3.79 | 0.11 | 0.20 |
| M-3, S-1 | 41.20±7.46 | 0.10 | 0.15 |
| M-3, S-2 | 58.70±1.16 | 0.16 | 0.19 |
| T-1, S-1 | 28.60±2.71 | 0.08 | 0.09 |
| T-1, S-2 | 26.33±2.76 | 0.07 | 0.12 |
| T-2, S -1 | 66.11±2.13 | 0.17 | 0.23 |
| T-2, S-2 | 45.92±1.03 | 0.12 | 0.17 |
| T-3, S-1 | 19.25±2.15 | 0.05 | 0.10 |
| T-3, S-2 | 31.56±0.21 | 0.08 | 0.17 |
| Mean | 70.50±3.42 | 0.21 | 0.25 |
| Range | 19.25-226.62 | 0.05-0.61 | 0.09-0.73 |

Table 4: Radiological summary of researched area and benchmark values

| Radiological indices | Research site (awwal) | Benchmarks | References |
|---|---|---|---|
| Activity conc. (Bq/Kg) | | | |
| K-40 | 425.96 | 140.0-850.0 | UNSCEAR (2000) and USNCR, Washington (2007) |
| Ra-226 | 23.85 | 17.0-60.0 | UNSCEAR (2000) and USNCR, Washington (2007) |
| Th-232 | 18.80 | 11.0-64.0 | UNSCEAR (2000) and USNCR, Washington (2007) |
| Dose rates (nGy/h) | 34.26 | 56 | UNSCEAR (1993) |
| Effect dose rates (μSv/year) | 42.15 | 70 | UNSCEAR (1993) |
| $Ra_{eq}$ (Bq/Kg) | 70.50 | 370 (max.) | Bertka and Mathew (1995) |
| $H_{ex}$ (Bq/Kg) | 0.21 | <1 | UNSCEAR (2000) |
| $H_{in}$ (Bq/Kg) | 0.25 | <1 | UNSCEAR (2000) |

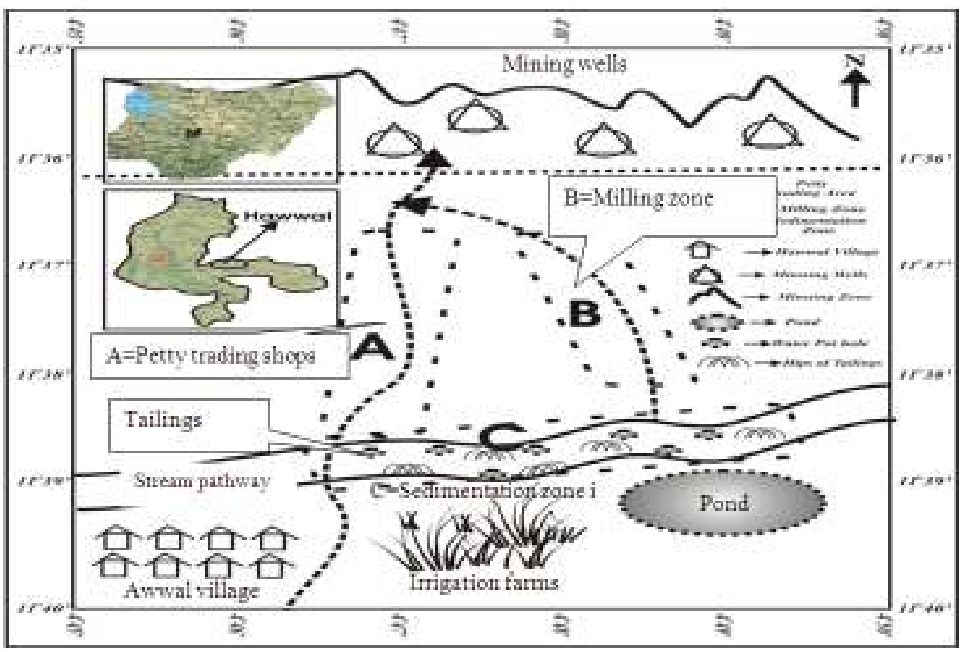


Fig. 1: Site map of research area

than the $^{232}Th$ and $^{226}Ra$ for the two sites studied, this can be attributed to fact that potassium is usually the most abundant element in the soil (Okeyode and Oluseye, 2010). Being a major element in rock-forming minerals, it occurs mainly in alumino silicates such as feldspar and micas. Figure 1 and 2 show Activity concentrations of $^{40}K$, $^{226}Ra$ and $^{232}Th$ as a function of samples for the site. The activity concentration of $^{40}K$

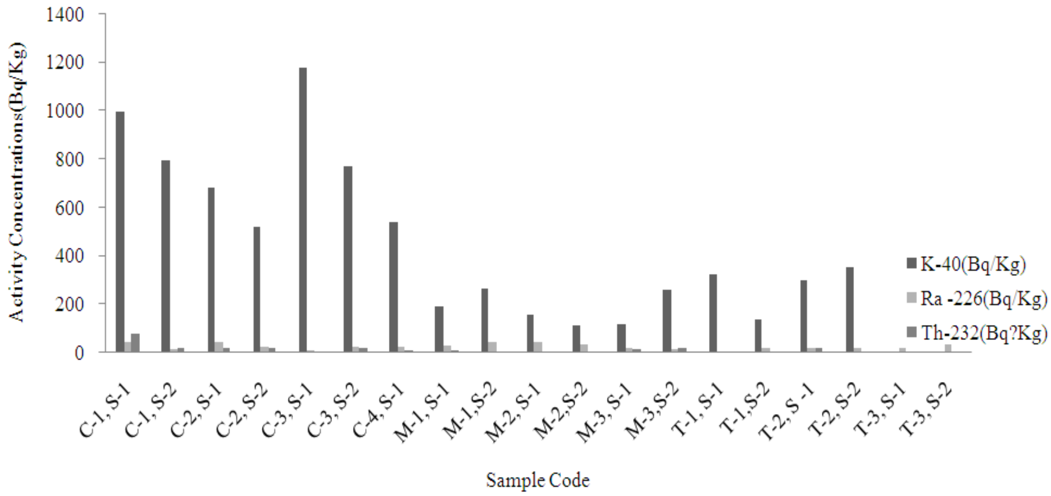


Fig. 2: Activity concentrations of $^{40}K$, $^{226}Ra$ and $^{232}Th$ as function of sample for the measurement

Table 5: Comparisons of the mean concentrations in soils of the studied area with south-western Nigeria, some world values and world average

| Regions | $^{40}K$ (Bq/kg) | $^{226}Ra$ (bq/kg) | $^{232}Th$ (Bq/kg) | References |
|---|---|---|---|---|
| Amman, Jordan | 501 | 56.40 | 28.80 | Ahmed and El-Arabi (1997) |
| Agaba-Amunan, Highway, Jordan | 208 | 44.40 | 36.30 | Al-Jundi *et al*. (2003) |
| Taiwan | 794 | 54.00 | 32.40 | Wang *et al*. (1997) |
| Rajasthan, India | 50.00-137.00 | 30.00-78.00 | 43.00-105.00 | Nageswara Rao *et al*. (1996) |
| Abeokuta, Nigeria | 51.81-82.80 | 4-11.50 | 7.62-22.80 | Gbadebo (2011) |
| Awwal, Nigeria | 425.96 | 23.85 | 18.80 | The present study |
| World average | 140.00-850.00 | 17.00-60.00 | 11.00-64.00 | UNSCEAR (2000) |

in Awwal declines with processing stages. $^{226}Ra$ and $^{232}Th$ are essentially not soluble in normal surface waters and so their transport is within particulate matter (dust) rather than by solution, (Abbady, 2005) with reference to the study site in question, the heavy dust and windy atmosphere at the period of study could have explained thorium transportation. Thorium is usually more abundant in the suspended load than in the bottom sediments (Abbady, 2005) resulting in its near absolute zero detection.

**Radiological assessments:**

**External absorbed dose rates and outdoor effective dose:** The absorbed dose rates (*D*) due to gamma radiations in air at 1m above the ground surface for the uniform distribution of the naturally occurring radionuclides ($^{226}Ra$, $^{232}Th$ and $^{40}K$) were calculated based on guidelines provided by UNSCEAR (2000), by the use of the following equation:

$$D\ (nGy/h) = 0.462\ ARa + 0.621\ ATh + 0.0417\ AK \quad (2)$$

where,
D : Air absorbed dose rates
A : Activities of the radionuclides

To estimate the mean annual effective dose rates which is sometimes referred to as Outdoor annual effective dose equivalent, the conversion coefficient from absorbed dose in air to effective dose (0.7 Sv/Gy) and outdoor occupancy factor (0.2) proposed by UNSCEAR (2000) were used. Therefore, the mean annual effective dose rate (mSv/year) was calculated by the following formula:

$$Deff.\ (\mu Sv/year) = Dose\ rate\ (nGy/h)\ \times 24\ h \times 365.25 \times 0.2 \times 0.7\ Sv/Gy \times 10^{-3}\ Sv/Gy \quad (3)$$

The results obtained from the present study were compared to the world average values shown in Table 5.

**Radium equivalent activity:** To compare the specific activities of the samples, Radium equivalent activity ($Ra_{eq}$) can be used as a common index. It is the sum of the weighted activities of $^{226}Ra$, $^{232}Th$ and $^{40}K$ based on the estimation that 10 Bq/kg of $^{226}Ra$, 7 Bq/kg of $^{232}Th$ and $^{130}$ Bq/kg of $^{40}K$ will deliver an equal or the same gamma dose rate (Tufail *et al*., 2007; Ademola, 2008a, b; Shiva Prasad *et al*., 2008). According to Diab *et al*. (2008), this index is mathematically defined by UNSCEAR (2000) as:

$$Ra_{eq}\ (Bq/kg) = A_{Ra} + 1.43A_{Th} + 0.077\ A_K \quad (4)$$

where, $A_{Ra}$, $A_{Th}$ and $A_K$ are activity concentrations of $^{226}Ra$, $^{232}Th$ and $^{40}K$, respectively.

The values of radium equivalent activities were calculated and entered into Table 3 along with the

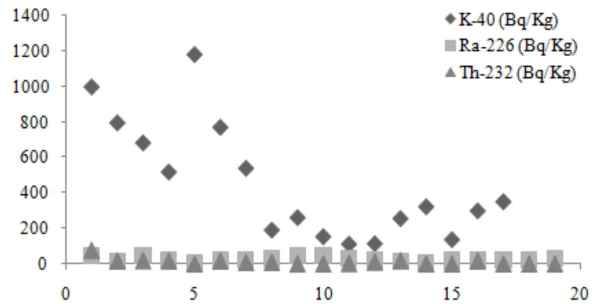


Fig. 3: Scatter plot showing relationship between the radio nuclides being studied

values of associated hazard indices. The radium equivalent of 370 Bq/kg corresponds to the dose limit of 1 mSv for the general population (Jibiri *et al*., 2008).

**Radiation hazard indices:**

**Eternal hazard index ($H_{ex}$):** External hazard index is a relation that quantifies the exposure factor. According to UNSCEAR (2000) it is defined as follows:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} = \leq 1 \quad (5)$$

**Internal hazard index ($H_{in}$):** The hazardous effect of radon and its short-lived products to the respiratory organs need be taken into consideration. The internal exposure to radon and its daughter products is quantified by the internal hazard index $H_{in}$, which is given by the equation:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} = \leq 1 \quad (6)$$

Equation (5) and (6) were used to compute the $H_{ex}$ and $H_{in}$ values for the site studied.

**Correlation studies:** Performance of correlation studies is an important tool for determining the existence of this radionuclide together at a particular location. A very poor correlation is observed between Thorium and Potassium as well as between Radium and Potassium.

Analysis of the results showed as seen in Fig. 3 that there is strong correlation in the concentration of Thorium and radium in all samples at stages of the mineral processing activities and both contributing to near zero values.

**Radiological assessment summary:** The result of the radiological events is captured in Table 4. It can be seen at a glance that the specific activities of the radio nuclides are all within regulatory benchmarks.

Correspondingly, dose rates and other related indices as indicated in the table are all within regulatory limits.

## CONCLUSION

From Radiological point of view, the values are low and may not imply any significant health effect of the local population, results thus form radiological baseline data for Awwal. However, this output does not imply clean bill for the overall present practice, the lack of use of protective devices which is the practice of the miners, the high density of dust generated by the blasting, crushing and related activities of the miners which expose them to possible latent hazards from radon and respiratory crystalline silica. Conclusively, the exercise is laden with health implications going by the present unprofessional practices and not determined radiological values, the miners should be educated and, safety culture inculcated in the mining practice of the area. The mining activities should be organized, the miners activities supervised and regulated by appropriate agency.

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