Assessment of Natural Radioactivity and Radiological Hazards in Water, Soil, and Sediments Around a Leather Company in Challawa Industrial Area, Kano State, Nigeria.

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DOI: https://doi.org/10.51244/IJRSI.2026.1305000019

Received: 22 April 2026; Accepted: 29 April 2026; published: 21 May 2026

ABSTRACT

This study evaluates the activity concentrations of naturally occurring radionuclides (^{40}K, ^{226}Ra, and ^{232}Th) and associated radiological hazard indices in water, soil, and sediment samples collected from the vicinity of God's Little Tannery. The mean concentrations in water were 30.134 ± 10.959 Bq/kg for ^{40}K, 27.464 ± 16.175 Bq/kg for ^{226}Ra, and 26.002 ± 11.621 Bq/kg for ^{232}Th. Soil samples recorded higher values with mean concentrations of 260.942 Bq/kg for ^{40}K, 16.644 ± 6.833 Bq/kg for ^{226}Ra, and 39.536 ± 7.445 Bq/kg for ^{232}Th. Sediments showed moderate levels. Radiological hazard parameters such as absorbed dose rate, radium equivalent activity, external hazard index (Hex), internal hazard index (Hin), annual gonadal dose equivalent (AGDE), excess lifetime cancer risk (ELCR), and committed effective dose were evaluated. The mean absorbed dose rates were 29.650 nGy/h (water), 42.450 nGy/h (soil), and 21.789 nGy/h (sediment). The calculated hazard indices (Hex and Hin) for all samples were below the recommended limit of unity, indicating minimal radiological risk. Additionally, ELCR values were below the UNSCEAR recommended threshold, suggesting no significant long-term cancer risk to the exposed population. However, the relatively higher radionuclide concentrations in soil compared to water and sediment indicate possible accumulation from industrial activities. Continuous monitoring is recommended to ensure environmental safety and public health protection.

Keywords: Natural radioactivity; Radiological hazard; Tannery; Soil contamination; ELCR; Gamma spectrometry

INTRODUCTION

Natural radioactivity is a fundamental component of the environment, arising mainly from primordial radionuclides such as uranium (^{238}U), thorium (^{232}Th), and potassium (^{40}K), which are widely distributed in the earth's crust. These radionuclides contribute significantly to background radiation exposure and are present in varying concentrations in soil, water, air, and biota (UNSCEAR, 2000). Human exposure to natural radiation occurs through external irradiation from terrestrial sources and internal exposure via ingestion and inhalation pathways. Although natural in origin, elevated levels of these radionuclides may pose potential health risks, including increased probability of cancer and genetic mutations over prolonged periods of exposure (ICRP, 2007). The distribution of natural radionuclides in the environment is strongly influenced by geological formations, soil characteristics, and anthropogenic activities. In many developing regions, rapid industrialization has significantly altered the natural balance of environmental systems. Industrial operations can enhance the concentration, redistribution, and mobility of naturally occurring radioactive materials (NORMs), thereby increasing radiological exposure to humans and ecosystems (IAEA, 2003). Activities such as mining, oil exploration, fertilizer production, and tannery operations have been identified as key contributors to enhanced levels of environmental radioactivity.

The leather industry plays a vital role in rural areas, providing livelihoods and contributing to the economic upliftment of local communities. The production of finished leather goods encourages self-reliance and enterprise creation, boosting the local economy. The leather industry helps diversify the Nigerian economy,

reducing dependence on oil revenue. All living species have been and continue to be exposed to radiation from the beginning of time (UNSCEAR, 2008). Radiation has been with us since the birth of the universe. As a result, humans are constantly exposed to radiation from both natural and man-made sources (IAEA, 2007). Human activities and practices can potentially affect the degree of radiation exposure in the environment (Karahan and Bayulken, 2000). Activities such as industrialization, application of fertilizers on farmlands, oil exploration, and mining activities have been reported to influence a higher degree of radionuclides in an environment (NRC, 1999; Ajayi and Dike, 2016; Abiola et al., 2021).

The Challawa industrial area in Kano State, Nigeria, represents one of the most prominent industrial zones in northern Nigeria. It is one of the major industrial hubs in northern Nigeria, characterized by intensive activities such as tanning, textile production, and chemical processing. Among these, tannery industries are particularly notable for generating large volumes of effluents containing a mixture of organic and inorganic pollutants, including heavy metals, organic compounds, and suspended particulates, which can alter the physicochemical properties of soil and water systems, (WHO, 2011) these effluents are often discharged directly into surrounding soils and water bodies with little or no treatment, leading to environmental contamination. Although tannery waste is more commonly associated with heavy metals such as chromium, iron, and lead, industrial discharges can also influence the distribution of natural radionuclides in the environment. Studies have shown that radionuclides like ^{226}Ra, ^{232}Th, and 40K can be affected by industrial processes through mechanisms such as dilution, redistribution, and geochemical alteration in soils and sediments. Furthermore, continuous discharge of industrial effluents in areas like Challawa can modify soil properties, enhance pollutant accumulation, and facilitate the mobility of radionuclides into groundwater systems. This raises concerns about long-term environmental and public health risks, especially as these contaminants may enter the food chain through crops and water usage.

While most studies in the Challawa area have focused on chemical pollution—especially heavy metals such as chromium—limited attention has been given to the radiological implications of these industrial activities. Industrial effluents may influence the behavior of natural radionuclides by modifying soil composition, enhancing adsorption processes, and facilitating the migration of radionuclides into groundwater and sediment systems (Avwiri et al., 2013). Over time, this can lead to accumulation in environmental media and potential entry into the food chain, posing long-term risks to human health. Assessing the levels of natural radioactivity and associated radiological hazards in environmental samples such as water, soil, and sediments is therefore essential. Radiological parameters including absorbed dose rate, radium equivalent activity, hazard indices, and excess lifetime cancer risk provide valuable insight into the potential health impacts of environmental radioactivity. These indices are widely used to evaluate whether observed radiation levels fall within internationally accepted safety limits (UNSCEAR, 2000; ICRP, 2007). Despite the environmental significance of the Challawa industrial area, there remains a scarcity of comprehensive data on natural radioactivity and radiological risk in the region. Establishing baseline information is crucial for effective environmental monitoring, risk assessment, and policy formulation aimed at safeguarding public health.

Therefore, this study aims to assess the activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th in water, soil, and sediment samples collected from the vicinity of a Tannery company within the Challawa industrial area. In addition, the study evaluates key radiological hazard indices to determine the potential health risks associated with exposure to these radionuclides. The findings of this research will contribute to the existing body of knowledge and provide essential data for environmental management and regulatory control in the area.

MATERIALS AND METHODS

Study Location: The study was conducted in the Challawa industrial area (God's Little Tannery Ltd), located in Kumbotso Local Government Area of Kano State, Nigeria. The region is characterized by significant industrial activities, particularly leather processing, this is as a result of the availability of raw materials within the city and nearby villages. Kano lies within the Sudan savanna zone and has an elevation of approximately 481 m above sea level.

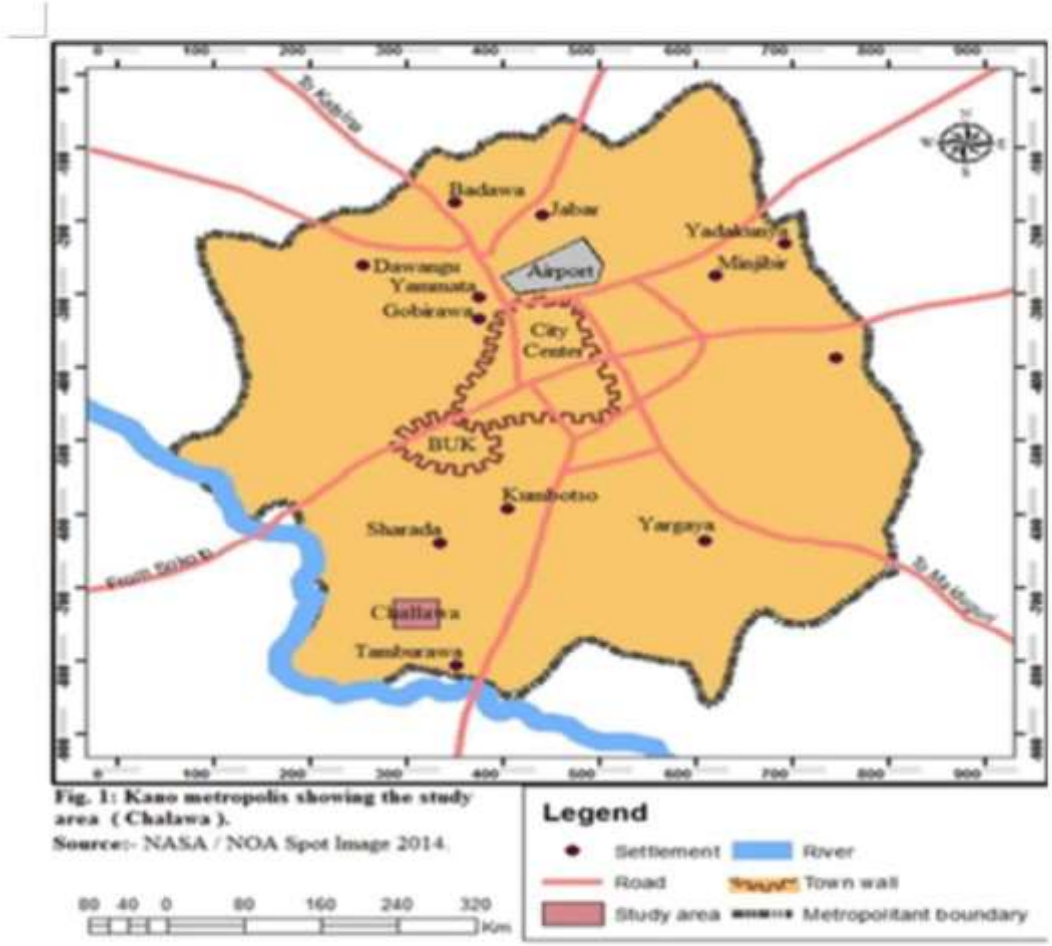

Fig. 1: Kano metropolis showing the study area (Chalawa).
Source:- NASA / NOA Spot Image 2014

Figure 1.2: Map of Kano showing challawa industrial area.

Soil Sample Preparation-

Each of soil sample collected was dried and crushed to fine powder with the use of pulverizer. The samples were packaged into radon-impermeable cylindrical plastic containers which were selected based on the space allocation of the detector vessel which measures 7.6cm by 7.6cm in dimension (geometry) was also carried out. To prevent radon-222 from escaping, the packaging in each case was triple sealed.

The sealing process included smearing of the inner rim of each container lid with Vaseline jelly, filling the lid assembly gap with candle wax to block the gaps between lid and container, and tight-sealing lid-container with masking adhesive tape. Radon and its short-lived progenies were allowed to reach secular radioactive equilibrium by storing the samples for 30 days prior to gamma spectroscopy measurements.

Evaluation of Radioactivity of Samples-

The analysis was carried out using a 76x76mm NaI (Tl) detector crystal optically coupled to a photomultiplier tube (PMT). The assembly has a preamplifier incorporated into it and a 1kilovolt external source. The detector is enclosed in a 6cm lead shield with cadmium and copper sheets. This arrangement is aimed at minimizing the effects of background and scattered radiation.

The data acquisition software is Maestro by Canberra Nuclear Products. The samples were measured for a period of 29000 seconds, for each sample. The peak area of each energy in the spectrum was used to compute the activity concentrations in each sample by the use following equation:

$$C = \frac{C_n}{C_f \cdot k}$$

where:

- C= activity concentration of the radionuclides in sample (Bq/kg or Bq/L)
- C_n= count rate (counts per seconds)
- C_f= calibration factor of the detecting system

Research Design.

The research adopted a qualitative and quantitative methodology which comprises of methods, measurement, data collection, data analysis, finding/interpretation and discussion of results. The study also employs the correlation research where interpreted results are compared with available and acceptable variables and standards.

Fourteen (14) samples (soil, sludge/sediments and water) were collected from different location points within GOD's Little tannery company in Challawa industrial area, in Kano State, Nigeria.

Sample Collection

Soil sampling

In this study, Fourteen (14) samples comprising of soil, sediments and water were collected from different locations within GOD's Little tannery company in Challawa industrial area, in Kano State, Nigeria. Each soil was collected from a pre-determined depth of 0.5m – 1.0m (Girigisu *et al*., 2013), in each of the selected points with the aid of hand auger, hand gloves and polythene bags. The collected soil samples were sealed in a black polythene bag and carefully labeled with masking tape and pen/marker, to avoid sample mix-up. The labelled soil bags were then, taken to Centre for Energy Research Centre, located at Ahmadu Bello University (ABU) Zaria in Kaduna State of Nigeria, for processing using NaI-TI gamma spectrometry measurements and analysis.

River-water and Sediment/sludge sampling

Water samples were collected from some discharging points within the premises of the selected leather company. At the sampling points, 2 liters plastic containers were used in collection of the water samples and nearly 1% air space was left on top of each of the containers for ease during thermal expansion. Sample containers were first washed and rinsed three times using the same water to be collected, this is to minimize contamination from the original content of the containers. The sample water collected were acidified immediately after collection, using 10mL of 11M of HCl per liter of water sample, this is to prevent radionuclides from being absorbed on the walls of these containers (IAEA, 19289). The water samples were tightly covered using their various covers, properly labelled and then sent to Centre for Energy Research Centre, located at Ahmadu Bello University (ABU) Zaria in Kaduna State of Nigeria for processing and NaI-TI gamma spectrometry measurements and analysis.

Sediments/sludges were collected at different points within the premises of the selected leather companies. The sediments/sludges were collected using a plastic packer, hand gloves and black polytene bags. The collected samples of sediment/sludges were carefully labelled to prevent mix-up, and then sent to Centre for Energy Research Centre, located at Ahmadu Bello University (ABU) Zaria in Kaduna State of Nigeria for processing and NaI-TI gamma spectrometry measurements and analysis.

Sample Preparation for Radioactivity Measurement

Soil and Sediments/sludges Preparation

The well mixed and homogenized soil and sediment/sludges were air dried, sieved and stored in location free from moisture. The samples were further oven dried at 80˚C - 100˚C during 24 h, to remove moisture and reduce

the samples to real constant weight. The dried samples were then grinded or pulverized with mortar and pestle, disaggregated and sieved through a 63 μm stainless steel sieve to remove coarse sand, stones, pebbles and other macro-impurities that with their large volume and mass and low radionuclide content would modify radionuclide activity concentrations (Bq ▪ kg−1) if not eliminated, and also to obtain a fine texture. Less than 63 μm grain-size fraction, the largest fraction of the sample (>4/5) and containing most radioactivity, was used for radionuclide analysis in order to allow the comparison between samples (Carvalho *et al.,* 2007). These samples were then stored in specifically made air tight cylindrical plastic containers which is tightly closed for 30 days period in order to give room for ^{238}U and its short-lived progenies to attain their secular radioactive equilibrium (Veiga *et al.,* 2006) before gamma counting.

Water Sample Preparation

For the preparation of sampled water, one liter volume capacity cylindrical containers were washed, rinsed using dilute sulfuric acid (H_2SO_4) and dried to prevent contamination with initial container content, before they are filled with known volume of sampled water and firmly covered for 30 days period in order to make sure that secular equilibrium is attained before gamma counting with NaI-TI Detector.

Radiological Risk Estimation using Radiation Models

Radiological health risk parameters are employed in radiation research to asses and evaluate the impact of exposure to radiation on health of people and their environment. These indices are usually evaluated to determine radiological effects level like pollution or degradation of the environment. Some of the radiological parameters used in this research are explained as thus.

The Annual Effective Dose Equivalent (AEDE)

To calculate Annual Effective Dose Equivalent outdoor, dose conversion index of 0.7 Sv/Gy was employed as standard by UNSCEAR, (1993) for the conversion coefficient from absorbed dose in air to effective dose received by adults, while occupant index of 0.2 for outdoor exposure and indoor occupant index of 0.8 were employed. The AEDE was ascertained with equations 2.2 and 2.3, for both outdoor and indoor exposure respectively (UNSCEAR, 1993)

$$\text{AEDE } (outdoor)\left(\frac{\mu Sv}{y}\right) = D_{(air)}\left(\frac{nGy}{h}\right) \times 8760 \left(\frac{h}{y}\right) \times 0.2 \times 0.7 \left(\frac{Sv}{Gy}\right) \times 10^{-3}$$

$$\text{AEDE } (indoor)\left(\frac{\mu Sv}{y}\right) = D_{(air)}\left(\frac{nGy}{h}\right) \times 8760 \left(\frac{h}{y}\right) \times 0.8 \times 0.7 \left(\frac{Sv}{Gy}\right) \times 10^{-3}$$

The AEDE is tissue-weighted summation of equivalent dose in all the specified tissues and organs of the body and it represents stochastic health risk, which is the chances of cancer being induced and genetic impact of ionizing radiation brought on those organs or tissues. It considers the kind of radiation and nature of body part being affected over one year time period. The AAEDE resulting from the ingestion of water could be evaluated using equation 2.4 (Sajo-Bohus *et al.,* 1997).

$$AED = A_w \times IR_w \times ID_F$$

Where;

AED, = yearly effective amount equivalent (mSv),

A_w, = amount of concentration of activity (Bq l^{-1}),

IR_w, = intake of water for person in 1 year (Adult =730 liters Children = 365 liters and Infant = 200 liters)

and ID_F = ingestion effective dose equivalent factor 3.58 x 10^{-7} mSv/year (USA-EPA, 2002).

Radium Equivalent Dose Rate

To ascertain the entire body equivalent dose rate over one year period, the National Council on Radiation Protection and Measurement recommend equation 2.5 (Avwiri *et al.,* 2013).

$$1mRh^{-1} = \frac{0.96 \times 24 \times 365}{100} mSv^{-1}$$

Absorbed Dose Rate (D_{air})

The absorb dose rates in air (D_{air}) due to gamma radiations at one meter (1m) above the ground surface for the uniform distribution of the naturally occurring radionuclides (^{238}U, ^{232}Th, and ^{40}K) were evaluated using equation 2.6 (Darwish *et al.,* 2015).

$$D(nGyh^{-1}) = 0.429A_{Ra} + 0666A_{Th} + 0.042A_k$$

Where; A_{Ra}, A_{Th} and A_k are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively (UNSCEAR 2000).

Excess Lifetime Cancer Risk (ELCR)

This index could be referred to as the excess chances of developing cancer during the time of an individual, as a result of exposure to ionizing radiation. The significance of this exposure from natural radioactive material in samples and possible danger for causing health issues and challenges particularly cancer, haven't been given needed attention within the Hydrocarbon Belt in Kano state, Nigeria. Therefore, it becomes crucial to ascertain the ELCR over lifetime of individuals (Taskin et al., 2009). Thus, it could be evaluated with equation 2.7 below;

$$ELCR\ (mSvy^{-1)} = AEDE \times (DL) \times (RF) \qquad 2.7$$

Where AEDE is the Annual Effective Dose Equivalent, DL is the average duration of life (50years) and RF is the Fatal cancer risk factor (Sv^{-1}).

For low-dose backwound radiation, which is considered to produce stochastic effects, ICRP 60 uses a fatal cancer risk factor value of 0.05 for public exposure (Rafique *et al.,* 2014; Taskin *et al.,* 2009).

Radium Equivalent Activity (Ra_{eq})

The exposure from gamma related radiation is mostly defined based on radium equivalent. The Ra_{eq} value is a hazard index that could be ascertained from activity concentrations of ^{238}U, ^{232}Th and ^{40}K of the sample media. This radiological factor is employed in determining the level of radioactivity present in any material. Radium Equivalent could be expressed with equation 3.12 (Darko *et al.,* 2011)

$$Ra_{eq} = A_{Ra} + (1.43A_{Th}) + (0.077A_K)$$

Where, A_{Ra} , A_{Th} and A_K represent activity amount of ^{226}Ra, ^{232}Th and ^{40}K in Bq/Kg. Equation 2.8was based on the presumption that 370Bq/Kg for ^{226}Ra, 259Bq/Kg for ^{232}Th and 4810Bq/Kg for 40K produce similar amount of gamma radiation dose rate. Radium equivalent is associated to both the external gamma dose and internal alpha dose from Radon and its progeny (Darwish *et al.,* 2015). The world permissible value for this index is 370Bq/Kg, and is equivalent to similar to $1mSvy^{-1}$ (UNSCEAR, 2000).

External Hazard Index (H_{ex})

This indicator expressed as (H_{ex}), is usually employed in evaluating dose rate of radiation hazard arising from being externally exposed to gamma ray by natural radioactive material from immediate environment of an individual (Hamzah et al., 2008; Olatunde, 2011). Many studies recommended a model (Model 1) that a room

in the house where the inhabitants' lives has infinitely thick walls without windows and doors, Model 1 is estimated using equation 2.9, (UNSCEAR, 2000)

$$(H_{ex})^a = \frac{ARa}{370} + \frac{ATh}{259} + \frac{AK}{4810} \leq 1$$

Where A_{Ra}, A_{Th} and A_K are concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively expressed in Bq/Kg.

Other researchers adjusted Model 1 to room that has windows and doors and evaluated (H_{ex}) with equation 2.10 (Model 2)

$$(H_{ex})^b = \frac{ARa}{740} + \frac{ATh}{518} + \frac{AK}{9620} \leq 1$$

In this second Model, the availability of windows and doors will result to some of ventilation in the presumed room, which would decrease all forms oof radiation doses. The value of this index must be lower than one so as to maintain the hazard of these radiations to insignificant level. The main goal of this index is to reduce the radiation dose to the allowable limit of $mSvy^{-1}$ (Darwish *et al.,* 2015).

Internal Hazard Index (H_{in})

Inhaling alpha radiation emitter such as 222Rn and ^{220}Rn is not healthy to respiratory tissues and organs. This hazard could be regulated by internal hazard indicator (H_{in}), given by equation 2.11 (Hamzah, eet al., 2008; Olatunde, 2011; Righi & Bruzzi, 2006)

$$(H_{in}) = \frac{ARa}{185} + \frac{ATh}{259} + \frac{AK}{4810} \leq 1$$

Where A_{Ra}, A_{Th} and A_K are concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively expressed in Bq/Kg.

Exposure Rate (ER)

The ratee of exposure to radiation was evaluated using expression 2.12

$$ER\ (\mu Rh^{-1}) = 1.904A_{Ra} + 2.82A_{Th} + 0.0179A_K$$

Where A_{Ra}, A_{Th} and A_K are concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively expressed in Bq/Kg.

Annual Committed Effective Dose

This indicator measures the total effective dose of radiation received within a lifetime (70 years) due to internal exposure, after intake of radioactive material (WHO 2008). In this research, the annual committed effective dose in water samples were evaluated for different age brackets using equation 2.13 (Darwish *et al.,* 2015)

$$CED \quad I\ x\ A\ x\ C\ x\ 365$$

Where; **I** represent daily amount of water consumed (in litre per day), **A** represents the activity concentration of the particular radionuclide (in Becquerel per litre) and **C** represents the dose conversion factor (in Sv/Bq).

Annual Gonadal Equivalent Dose (AGED)

This index measures activity concentration in reproductive organs like ovary and testes, arising from exposure to alpha and beta as a result of intake of certain radioactive materials in the water samples. The AGED for people in any community could be evaluated using equation expressed below (UNSCEAR. 2000)

$$AGED = \frac{AEDE}{Radiation\ weighting\ Factor(We) x\ Tissue\ weighting\ Factor(Wt)}$$

Where, W_e for α -activity = 20,

W_e for β - activity = 1,

W_t for Gonads = 0.20

Gonad dose can be calculated from the radionuclide activity concentration using the equation below;

$$AGED = 3.09C_{Ra} + 8760 + 0.7Sv/Gy \times 0.25 \times 10^{-9}$$

RESULTS AND DISCUSSION

Results: The results for the activity concentration and radiological parameters were represented in table 3.1 and 3.2 respectively, and the calculated values for gamma dose, annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR) of the fourteen samples collected within the study area are presented together in Table 3.2. Figures 3.1 to 3.3 show the comparison of the calculated parameters with average world standard. For each of the samples collected. Figure 3.4 represents the contour map of all the samples within the study company.

Table 3.1: Activity concentrations for God's little Tannery; water, soil and sediment

Sample ID	K-40	Ra-226	Th-232
Water			
GWA1	24.94557	16.77752	12.32497
GWA2	20.96423	40.10892	24.44014
GWA3	22.19285	49.03013	18.39909
GWA4	46.6563	19.60603	41.42531
GWA5	35.9098	11.7949	33.42075
Mean	30.134±10.959	27.464±16.175	26.002±11.621
Soil			
GLTS1	275.3437	10.85979	45.10718
GLTS2	285.4121	23.65469	48.74572
GLTS3	280.9642	24.20973	35.90764
GLTS4	226.0407	10.21611	30.0179
GLTS5	236.9488	14.27926	37.9008
Mean	260.942±	16.644±6.833	39.536±7.445

Sediments			
GSED1	60.43546	20.55504	15.74572
GSED2	116.3659	11.56315	10.95553
GSED3	83.14152	18.00579	16.20182
GSED4	74.58787	17.02781	26.93729
Mean	86.648±28.130	16.708±4.634	13.301±2.906

Table 3.2: Radiological parameters for God's little water, soil and sediment

Sample ID	Absorbed Dose (nGy/h)	Radium Equivaent (Bq/kg)	External Hazard Index (Hex)	Internal Hazard Index (Hin)	Outdoor Effective Dose (mSv/yr)	Indoor Effective Dose (mSv/yr)	Annual Gonadal Dose Equivalent (μSv/yr)	Excess Lifetime Cancer Risk (ELCR)	Committed Effective Dose (mSv/yr)
Water									
GWA1	16.236	36.323	0.098	0.143	0.020	0.080	111.194	0.050	0.008
GWA2	34.166	76.673	0.207	0.316	0.042	0.168	232.679	0.105	0.017
GWA3	34.690	77.050	0.208	0.341	0.043	0.170	235.380	0.106	0.018
GWA4	36.024	82.437	0.223	0.276	0.044	0.177	248.391	0.110	0.015
GWA5	27.133	62.352	0.169	0.200	0.033	0.133	187.421	0.083	0.011
Mean	29.650	66.967	0.181	0.255	0.036	0.145	203.013	0.091	0.014
Std	±8.257	±18.678	±0.050	±0.082	±0.010	±0.041	±56.260	±0.025	±0.004
	Soil								
GLTS1	43.744	96.565	0.261	0.290	0.054	0.215	308.563	0.134	0.015
GLTS2	52.273	115.338	0.312	0.375	0.064	0.256	366.470	0.160	0.020
GLTS3	44.589	97.192	0.263	0.328	0.055	0.219	313.125	0.137	0.017
GLTS4	32.277	70.547	0.191	0.218	0.040	0.158	228.019	0.099	0.011
GLTS5	39.370	86.722	0.234	0.273	0.048	0.193	276.950	0.121	0.014
Mean	42.450	93.273	0.252	0.297	0.052	0.208	298.625	0.130	0.015
Std	±7.344	±16.374	±0.044	±0.059	±0.009	±0.036	±50.909	±0.023	±0.003
	Sediment								
GSED1	21.527	47.725	0.129	0.184	0.026	0.106	148.309	0.066	0.010
GSED2	16.812	36.190	0.098	0.129	0.021	0.082	118.063	0.052	0.006

GSED3	21.572	47.576	0.129	0.177	0.026	0.106	149.468	0.066	0.009
GSED4	27.247	61.291	0.166	0.212	0.033	0.134	188.634	0.084	0.011
Mean	21.789	48.196	0.130	0.176	0.027	0.107	151.119	0.067	0.009
Std	±4.269	±10.267	±0.028	±0.034	±0.005	±0.021	±28.929	±0.013	±0.002

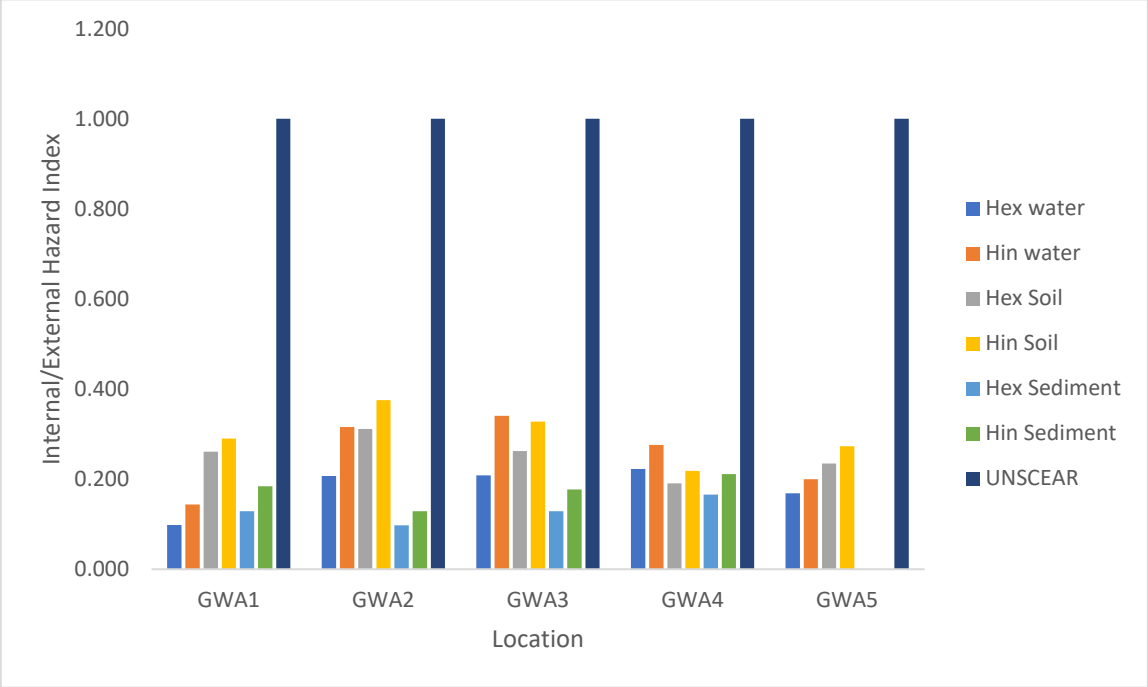

Figure 3.1: Comparison of the Internal Hazard and External Hazard index with UNSCEAR Standard value for God's Little.

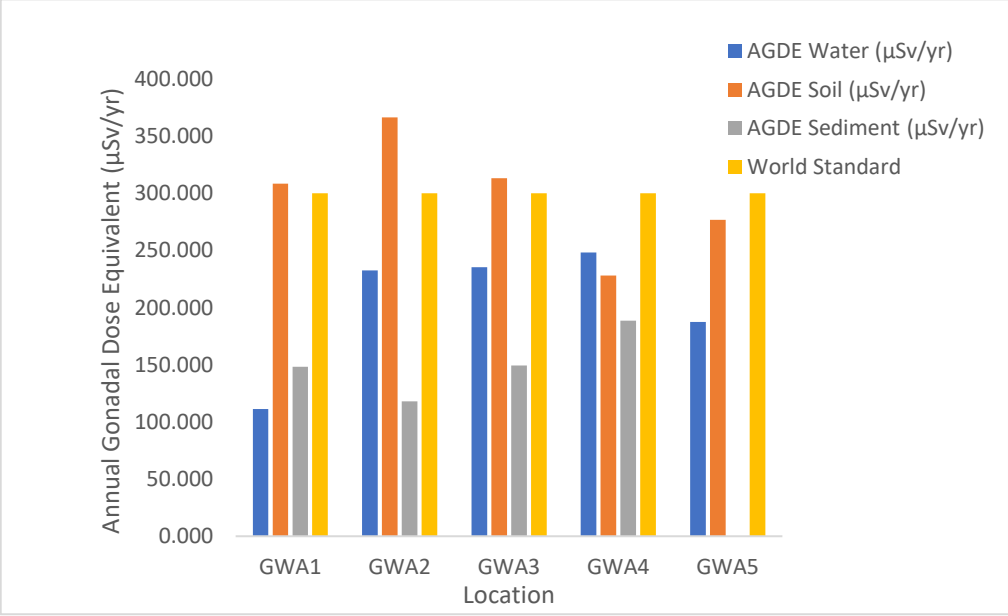

Figure 3.2: Comparison of the Annual gonadal dose equivalent with world standard value for God's Little

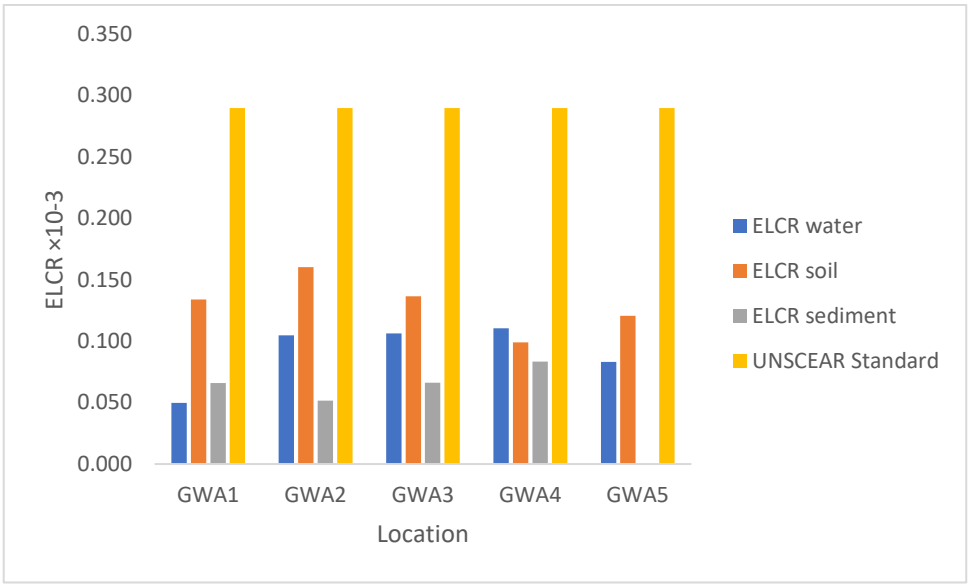

Figure 3.3: Comparison of the estimated Excess Life Cancer Risk with the UNSCEAR value standard for God's Little.

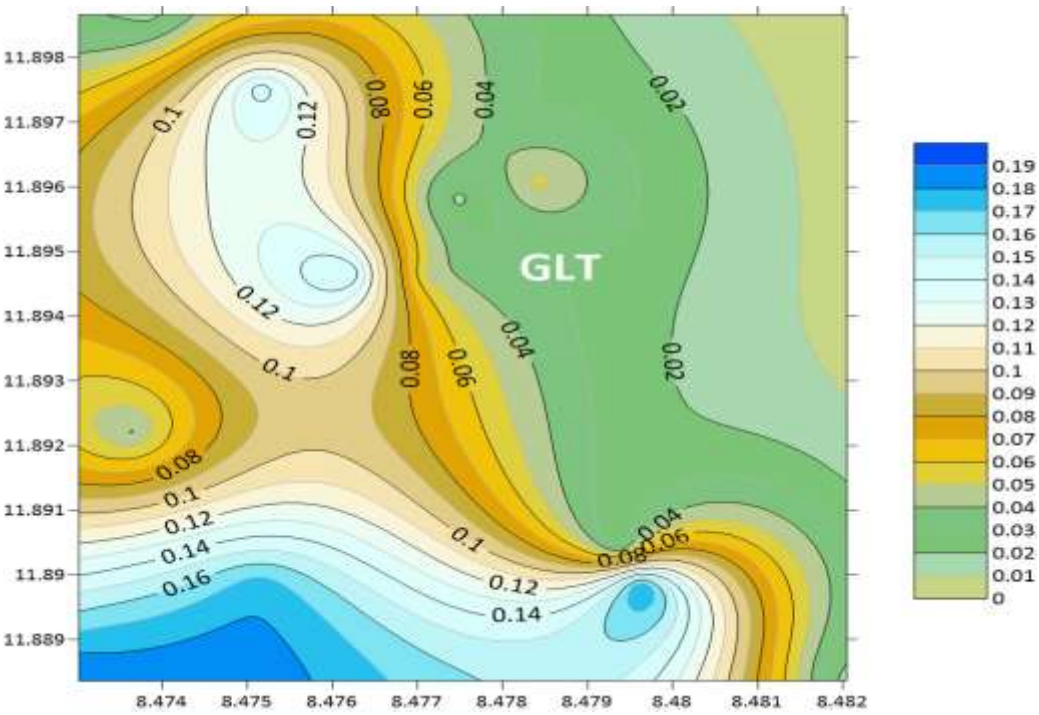

Figure 3.4: Contour Plot for Industrial Area God's Little Tannery Ltd

Discussion

The activity concentration of radionuclides content from company under study; For water samples, K-40 ranges from 20.96 – 46.66 Bq/L with an average of 30.13 ± 10.96 Bq/L; Ra-226 11.79 – 49.03 Bq/L with an average of 27.46 ± 16.18 Bq/L, while Th-232 ranges from 12.32 – 41.43 Bq/L with a mean value of 26.00 ± 11.62 Bq/L.

The soil samples show K-40 activity concentrations ranging from 226.04 – 285.41 Bq/kg with a mean value of 260.94 Bq/kg, for Ra-226 10.22 – 24.21 Bq/kg with a mean of 16.64 ± 6.83 Bq/kg, while Th-232 ranges from 30.02 – 48.75 Bq/kg with an average of 39.54 ± 7.45 Bq/kg.

For the sediment samples, the activity concentration of K-40 ranges from 60.44 – 116.37 Bq/kg with a mean of 86.65 ± 28.13 Bq/kg, Ra-226 varies from 11.56 – 20.56 Bq/kg with an average of 16.71 ± 4.63 Bq/kg, while Th-

232 ranges from 10.96 – 26.94 Bq/kg with a mean value of 13.30 ± 2.91 Bq/kg. Over geological time, these radionuclides accumulate in soils through natural decay chains and remain due to their long half-lives (Fahad et al., 2019). In water bodies, radionuclides may enter through several pathways. Natural processes such as leaching and dissolution of radionuclide-bearing minerals allow Ra-226, Th-232, and K-40 to migrate into groundwater and surface water (IAEA, 2016). Because waterborne particles easily attach to suspended solids and subsequently sink to the riverbed, sediments serve as sinks for radionuclides (Olatunji et al., 2017). Therefore, sediment contamination is a result of accumulated inputs from nearby home, industrial, and agricultural activities as well as natural geological sources. Radionuclides become more concentrated in sediment over time due to adsorption mechanisms and particle deposition than in water columns (IAEA, 2016).

The radiological parameters for the study area are as follows;

The radiological parameters from water samples for absorbed dose rate ranges from 16.236 – 36.024 nGy/h with an average of 29.650 ± 8.257 nGy/h. Soil sample, for absorbed dose 32.277 – 52.273 nGy/h with a mean of 42.450 ± 7.344 nGy/h. Sediment sample, for absorbed dose 16.812 – 27.247 nGy/h with a mean of 21.789 ± 4.269 nGy/h.

Water Sample, for radium equivalent 36.323 – 82.437 Bq/kg with an average of 66.967 ± 18.678 Bq/kg. Soil sample, for radium equivalent 70.547 – 115.338 Bq/kg with a mean of 93.273 ± 16.374 Bq/kg. Sediment sample, for radium equivalent 36.190 – 61.291 Bq/kg with a mean of 48.196 ± 10.207 Bq/kg.

Water sample, for external hazard index 0.098 – 0.223 with an average of 0.181 ± 0.050, for internal hazard index 0.143 – 0.341 with an average of 0.255 ± 0.082. Soil sample, for external hazard index 0.191 – 0.312 with a mean of 0.252 ± 0.044, for internal hazard index 0.218 – 0.375 with a mean of 0.297 ± 0.059. Sediment sample, for external hazard index 0.098 – 0.166 with a mean of 0.130 ± 0.028, for internal hazard index 0.129 – 0.212 with a mean of 0.176 ± 0.034.

Water sample, for outdoor effective dose 0.020 – 0.044 mSv/yr with an average of 0.036 ± 0.010 mSv/yr, for indoor effective dose 0.080 – 0.177 mSv/yr with an average of 0.145 ± 0.041 mSv/yr. Soil sample, for outdoor effective dose 0.040 – 0.064 mSv/yr with a mean of 0.052 ± 0.009 mSv/yr, for indoor effective dose 0.158 – 0.256 mSv/yr with a mean of 0.208 ± 0.036 mSv/yr. Sediment sample, for outdoor effective dose 0.021 – 0.033 mSv/yr with a mean of 0.027 ± 0.005 mSv/yr, for indoor effective dose 0.082 – 0.134 mSv/yr with a mean of 0.107 ± 0.021 mSv/yr.

Water sample, for annual gonadal equivalent dose 111.794 – 248.391 μSv/yr with an average of 203.013 ± 56.260 μSv/yr. Soil sample, for annual gonadal equivalent dose 228.019 – 366.470 μSv/yr with a mean of 298.625 ± 50.909 μSv/yr. Sediment sample, for annual gonadal equivalent dose 118.063 – 188.034 μSv/yr with a mean of 151.119 ± 28.929 μSv/yr.

Water sample, for excess lifetime cancer risk 0.050 – 0.110 with an average of 0.091 ± 0.025. Soil sample, for excess lifetime cancer risk 0.099 – 0.160 with a mean of 0.130 ± 0.023. Sediment sample, excess lifetime cancer risk 0.052 – 0.084 with a mean of 0.067 ± 0.013.

Water sample, for committed effective dose 0.008 – 0.018 mSv/yr with an average of 0.014 ± 0.004 mSv/yr. Soil samples, for committed effective dose 0.011 – 0.020 mSv/yr with a mean of 0.013 ± 0.003 mSv/yr. Sediment samples, for committed effective dose 0.006 – 0.011 mSv/yr with a mean of 0.009 ± 0.002 mSv/yr.

These radiological parameters are generally below recommended world standards and averages. The absorbed dose rates across all media are lower than the global average of approximately 59 nGy/h. The radium equivalent activities are well below the maximum permissible limit of 370 Bq/kg. Both external and internal hazard indices are less than the safety threshold of 1. The outdoor annual effective doses are below the world average of about 0.07 mSv/yr, and indoor values are below the world average of about 0.41 mSv/yr. The annual gonadal equivalent doses are around or below the typical world average of approximately 300 μSv/yr. The excess lifetime cancer risks (considering typical scaling in such assessments as $x10^{-3}$) are below the world average of 0.29 $x10^{-3}$. The committed effective doses for water are below the WHO guideline of 0.1 mSv/yr. Overall, the measured natural

radioactivity levels in water, soil, and sediment from all locations pose no significant radiological health risk to the population.

CONCLUSION

All measured parameters absorbed dose rate, radium equivalent activity, external and internal hazard indices, annual effective doses (outdoor and indoor), annual gonadal dose equivalent, excess lifetime cancer risk, and committed effective dose from water, soil and sediment are well within internationally recommended safety limits and, for the most part, lower than corresponding global averages.

The following results were obtained from this study:

1. The highest absorbed dose rate of 42.450 ± 7.344nGy/h was measured in soil samples, followed by 29.650 ± 8.257nGy/h in water and 21.789 ± 4.269nGy/h in sediment.

2. Minimum and maximum Radium Equivalent value of 48.196Bq/kg and 93.273Bq/kg were obtained from sediment and soil respectively, and the value from soil is higher than the world recommended limit of 370Bq/kg (UNSCEAR, 2008).

3. Mean values of 0.252 from External Hazard Index was obtained from soil sample and 0.130 from sediment, higher and lower respectively, while the Internal Hazard Index were 0.297, 0.255 and 0.176 for soil, water and sediment respectively and they were found to be lower than the world recommended limits (UNSCEAR, 2008)

4. Estimated mean values of Outdoor and Indoor Effective Dose were also higher in soil with 0.052mSv/y and 0.208mSv/y respectively and lower in sediment with 0.027mSv/y and 0.107mSv/y respectively.

5. The Annual Gonadal Dose Equivalent was higher in soil with 298.625μSv/y, while global average is 300μSv/y, (UNSCEAR 2008) this indicates that the study area is currently within permissible limits but shows early signs of radiological enrichment in soil. The Excess Lifetime Cancer Risk has its maximum mean value in soil with 0.130 x 110^{-3}, and the Committed Effective Dose also has its maximum mean value in soil with 0.015mSv/y.

However, the relatively higher radionuclide concentrations in soil compared to sediment and then to water (soil > sediment > water), suggest enhanced retention capacity of soil due to adsorption onto clay minerals and organic matter, which act as long-term reservoirs of radionuclides (International Atomic Energy Agency, 2010); sediment acting as a secondary sink; and dilution and mobility in water systems. The measured natural radioactivity levels in water, soil, and sediment from all locations points in this study pose no immediate radiological threat, but cumulative exposure risk cannot be ignored, since they could lead to some radiological problems to people living or working within the industrial area and it environ. Based on these, Continuous monitoring is recommended to ensure environmental safety and public health protection.

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