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Full Length Research Article

RADIOLOGICAL RISK ASSESSMENT OF MINED TRONA COMMONLY CONSUMED IN MINNA, NIGER STATE, NORTH-CENTRAL NIGERIA

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ABSTRACT
This study reports the concentration of naturally occurring radionuclide materials in mined salts (*Trona*) generally consumed in Minna, Niger State, north-central Nigeria. Because of the increase in the consumption of *Trona* in Minna, the government is considering enacting a policy that will regulate the radiological effects of *trona* in the general population. Eight (8) varieties of *Trona* currently in the market were purchased. The samples were analyzed using NaI(TI) gamma ray spectrometry. The radiological parameters, such as radium equivalent (Raeq), annual effective dose (AED), internal hazard index (Hin), and total cancer risk (fatality plus hereditary) were used to estimate the radiological risk associated with the ingestion of mined *Trona*. The average activity concentration of ^{40}K, ^{226}Ra, and ^{232}Th varied from 331.12 Bqkg^{-1}, 19.39 Bqkg^{-1}, and 6.42 Bqkg^{-1}, respectively. Raeq, Hin, and AED were estimated at 54.08 Bqkg^{-1}, 0.19, and 40.28 mSv/y, respectively. These results were within the acceptable limits by UNSCEAR and USEPA, and there is no apparent justification for radiological risk concern in the current *Trona* consumption rate in Minna.

Keywords: *Trona*, annual effective dose, radiological risk, gamma-spectrometry, hazard indices, Niger State.

INTRODUCTION
Naturally occurring radionuclide materials (NORMs) have been in existence since the Earth was created about 4.6 billion years ago (Al&gue & Gbpel, 1995). They are a primordial radionuclide existing naturally in the environment. The common types of primordial radionuclide are ^{40}K, ^{226}R, and ^{232}Th and their decay products, which are found in different concentrations in the earth's crust (UNSCEAR, 2008). At times, the concentration of NORMs is negligible in the environment, but human activities such as mining and exploration of mineral resources tend to enhance the concentration of the natural radionuclides and their decay progeny UNSCEAR(Bello et al., 2019; UNSCEAR, 2008).
In Nigeria, and particularly the northern part of Nigeria, *Trona* is generally called Potash (even though it contains more sodium than potassium) and traditionally known as 'Kanwa' in Hausa communities (Muhammad et al., 2020).
Trona is a mixture of various salts and inorganic compounds of mainly sodium and carbonate; hydrated basic sesquicarbonate of sodium-containing $Na_2CO_3.NaHCO_3.2H_2O$, which has some form of impurities such as Magnesium, Silicon, Iron, Aluminum, Clay, Sand, Potassium, and Titanium (Nielsen & Nielsen, 1999). When *Trona* is placed in transmitted light, it gives colorless, light yellow, and gray-white colors, which largely depend on the geochemistry of the area where it is mined (Imafidon et al., 2016).
Recently, Nigeria has experienced a rapid increase in the use of *Trona* for both domestic and industrial purposes, which could be attributed to the past and present government interest in harnessing the natural minerals in the country. This has made the use of *Trona* to expand, which cuts across its useful application in animal feeds for the treatment of fungi associated with dermatophytosis and for water purification, for both domestic and industrial uses, as an alternative to Alum (Nata'ala et al., 2018). The World Health Organization (WHO) and the International Atomic Energy Agency (IAEA) have shown serious concern about the utilization of mined minerals, especially in the developing countries of the world. In addition to this, it is generally established that most of the mined minerals are usually accompanied by NORMs in different concentrations (UNSCEAR, 2000a). Since *Trona* is a mineral that is naturally mined in the environment, it is suspected that there could be presence of NORMs in the consumed *Trona* sold in various markets in Nigeria and Niger State in particular. The deleterious effects of NORMs are reported in the literature with a high concentration of ^{40}K in some parts of Niger State (Suleiman et al., 2018). Recent studies carried out in rats on the toxicological and biochemical effects of *Trona* show a potential hepatoxic effect on its liver oxidative stress and function, with no short-term toxic effect on the functionality of the renal system. According to (Imafidon et al., 2016), *Trona* gets into the human body via two exposure pathways, which are: ingestion (when used as a cooking ingredient in vegetable soups and as food supplement) and inhalation (when snuffed together with tobacco in their powdery forms) (Garba et al., 2022; Imafidon et al., 2016). The common effects reported in literatures are physiological, physicochemical, elemental and biochemical effects of *Trona*, but there is no sufficient reports in the literature on the radionuclide effects of *Trona* in the Northern part of Nigeria and Niger State in particular. Because of the uncertainty of the concentration of NORMs consumed in *Trona* by humans, this paper aims to assess the safety of *Trona* consumption by humans by evaluating their activity concentration level to ensure that they are not above the international safety limits (Nata'ala et al., 2018).

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Location of the Study Area and Sample Collection Points

Samples of *Trona* (Kanwa) were collected from a market popularly known as Engr. Abdulkadir Abdullahi Kure-ultra Modern Market Minna (A. A. Kure Market). The sample collection points are located between $6^{o}30'$ E—$6^{o}40'$ E Longitude and $9^{o}30'$ N—$9^{o}35'$ N Latitude

in Niger State, North Central Nigeria.

Figure 1: Showing a google map view of Kure Ultra modern market, Minna were samples of *Trona* were purchased from whole sellers.

MATERIALS AND METHODS

Preliminary Market Survey

A market survey was conducted to ensure that the common types of *Trona* are readily availbale and easily accessible in the quantity needed for sampling and characterization.

Experimental Procedures And Samples Collection

The dried *Trona* (Kanwa) samples were purchased from the Kure Ultra-Modern Market (A. A. Kure Market) in Minna, Niger State (Figure 1). Each of the *Trona* samples was collected in a sealed polyethylene bag and labeled T1 to T13 for easy identification (Table 1). A total of thirteen (13) composite *Trona* samples (Kanwa) were collected from various suppliers. These comprise different types of *Trona* mined from different places within and outside Nigeria (see Table 1). Composite sampling was adopted in this research to ensure that most of the commonly consumed *Trona* are well represented, and the samples were immediately transported to Ladoke Akintola University of Technology for Gamma spectrometry analysis.

Figure 2 shows some selected samples of *Trona* commonly consumed in Niger State, North Central Nigeria. Identification of the different varieties of *Trona* was achieved with the help of the vendors selling the products in the market.

Table 1: *Trona* (Kanwa) Samples Information

S/N.	Sample ID	Local Name	Mined from (Place of Origin)	Country of Origin
1	T1	Niger Farar Kanwa	Niger	Nigeria
2	T2	Niger Jan Kanwa	Niger	Nigeria
3	T3	Sokoto Farar Balma	Sokoto	Nigeria
4	T4	Sokoto Jan Balma	Sokoto	Nigeria
5	T5	Chad Jan Kanwa	Chad	Chad
6	T6	Chad Ngurnu	Chad	Chad
7	T7	Katsina Manda	Katsina	Nigeria
8	T8	Yobe Farar Kanwa	Yobe	Nigeria
9	T9	Jigawa Manda	Jigawa	Nigeria
10	T10	Kano Mangul	Kano	Nigeria
11	T11	Libya Dan Libya	Libya	Libya
12	T12	Borno Farar Kanwa	Borno	Nigeria
13	T13	Niger Agadez	Niger	Niger Republic

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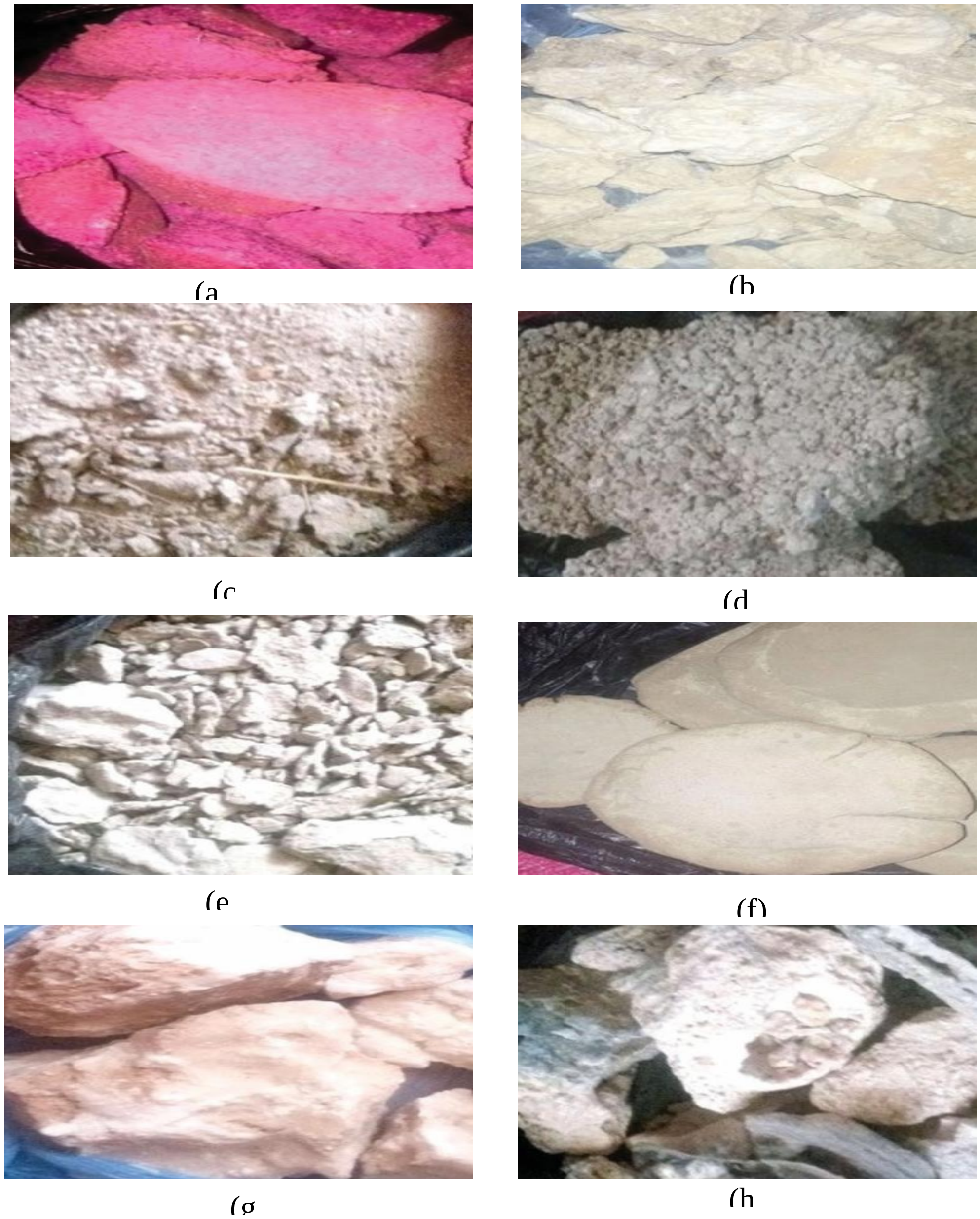

Figure 2: Some selected samples of *Trona* commonly consumed in Niger State, North Central Nigeria with each label representing: (a) Farar Balma (b) Ngurnu (c) Yar Agadez (d) Jar Balma (e) Farar Kanwa (f) Manda (g) Dan Libya (h) Jan Kanwa.

The dried *Trona* samples were crushed with a mortar and pestle into a fine powder and air-dried. After the samples were air-dried for 24 hours at 100 ^{o}C to eliminate all moisture (if any), the samples were then sieved through a screen smaller than 1 mm to homogenize large grains. In order to allow all the radionuclides' daughters with short half-lives to decay and leave the radionuclide of interest (^{40}K, ^{226}Ra, and ^{232}Th) to reach secular equilibrium before the gamma spectrometry analysis, the *Trona* samples were stored in a Marinelli standard beaker (Fairstein & Wagner, 1996) for 30 days at the radiation laboratory (El-Dine et al., 2001).

Sample Counting Procedure

The gamma-ray spectrometry analysis was conducted with a detector of 3×3 inch NaI(Tl) produced by Princeton Gamma Tech., USA. A cylindrical lead shield was used to cover the detector all through to avoid the harmful effects of background radiation on the surrounding environment. The detector and a Gamma spectacular Multichannel analyzer with model number GS-2000 Pro were attached to a computer for the display of spectra. The standard of the International Atomic Energy Agency (IAEA) sources was used for calibration (IAEA, 2014). The gamma spectrum analysis and the obtained data were generated with the help of Thermino software, and the energy calibration was achieved using the RSS8 gamma source LLC, USA. This was performed by measuring the peak of the gamma radiation given out by a point source of defined energies. This was accompanied by calibrating the detector efficiency using a standard reference radionuclide source of well-known activities. Before the commencement of measurement of the gamma-ray emitted by the *Trona* samples, an empty Marinelli container was counted for a period of 3600 s to obtain the background radiation count. The analysis was carried out by allowing each sample to attain secular equilibrium for 30-days before placing each sample in succession on the detector. During counting, equal time was allotted to each sample as that of the empty Marinelli container and the Minimum Detector Activity was estimated from the background radiation spectrum. The activity concentration A of each radionuclide in the *Trona* samples was calculated using:

$$A = \frac{C_{net}}{P_\gamma \times \varepsilon \times m \times t} \qquad (1)$$

where m is the mass of the *Trona* samples, t is the counting time in seconds, ε is the efficiency of the full energy peak of the radionuclides, P_γ is the probability of gamma-ray emission, and C_{net} is the net peak count for each radionuclide in the sample (Asgharizadeh et al., 2011; Muhammad & Abbasi, 2025).

Estimation of Radium Equivalent Activity

Estimation of radiological hazards to the environment involves knowing the activity of gamma radiation outputs from a radiation source. Radium equivalent is the term used to characterize the gamma outputs from a sample that contains a mixture of several radiation sources, such as Thorium, Uranium (also known as Radium daughter), and Potassium, respectively. One way to express the Radium equivalent activity is expressed by (Asgharizadeh et al., 2012):

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \qquad (2)$$

where A_{Ra}, A_{Th} and A_K represent the individual activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

Eq. (2) assumed that 0.07 Bqkg^{-1} of ^{232}Th, 1 Bq kg^{-1} of ^{226}Ra, and 13 Bq kg^{-1} of ^{40}K, respectively give the same gamma-ray dose rate (Beretka & Mathew, 1985).

For safe use in building materials and other household applications, the maximum Ra_{eq} in *Trona* must be less than 370 Bq kg^{-1} in order to maintain the external dose rate at less than 1.5 mGy y^{-1} (Beretka & Mathew, 1985)

Estimation of Internal Hazard Index (H_{in})

The effects of radiation source such as carcinogenic radon gas and its decay progeny or any other gamma-emitting radionuclide, when inhaled or ingested within the body is calculated using the internal hazard index criterion as stipulated in Eq. (3) by (UNSCEAR, 2008):

where A_{Ra}, A_{Th} and A_K have similar meaning as in Eq. (2).

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \qquad (3)$$

Estimation of External Hazard Index (H_{ex})

A criterion for estimating the effects of exposure to radiation emitted by *Trona* samples outside the body is the external hazard index (Hex). The external hazard index can be estimated using the Eq. (4) according to (Nations, 2011); where A_{Ra}, A_{Th} and A_K have a similar meaning as in Eq. (2).

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \qquad (4)$$

Annual Effective Dose from Ingestion of *Trona*

Eq. (5) was used to calculate the annual effective dose of NORMs of interest (^{226}Ra, ^{232}Th, and ^{40}K) in the human system.

$$E = (U_{Ra}C_{Ra} + U_{Th}C_{Th} + U_K C_K)M \qquad (5)$$

where U represents the effective dose coefficients for different age categories measured in Sv/Bq for each radionuclide of interest; ^{40}K, ^{226}Ra, and ^{232}Th with values of 4.50×10^{-8}, 6.20×10^{-9}, 2.3×10^{-7}, respectively. M is the average quantity of *Trona* consumed annually by a person in Niger State, which was adopted as 9.13 kg/capi/year (Garba et al., 2022). C is the activity concentration of each radionuclide of interest in the *Trona* samples.

Estimation of Cancer and Hereditary Risks from the consumption of *Trona*

The gamma radiations emanating from the *Trona* samples can sometimes have carcinogenic effects when humans are exposed to it for a long time, both indoors and outdoors. For this reason, the outdoor fatality cancer risk (FCR) was evaluated over a lifetime (LT 70 years) and the cancer risk coefficient adopted from the ICRP cancer norminal risk factor (CNRF 0.05 Sv^{-1}) (Clarke et al., 1990). Abbasi and Bashiry (Abbasi & Bashiry, 2020) opined that CNRF can be evaluated using Eq. (6).

$$\text{Fatality Cancer Risk} = Sum\ of\ AED \times CNRF \qquad (6)$$

Also, the hereditary risk was estimated by adopting the nominal risk coefficients of 0.2×10^{-2} for low doses from the ICRP reports based on life impairment. The estimate of hereditary is given by the equation:

$$\text{Hereditary Cancer Risk} = Sum\ of\ AED \times \text{hereditary nominal risk factor} \qquad (7)$$

where AED stands for Annual Effcetive Dose

RESULTS AND DISCUSSION

The Minimum Detector Activity estimated from the background radiation spectrum were 0.095 (^{40}K), 0.036 (^{226}Ra), and 0.0079 (^{232}Th) Bq kg^{-1}, respectively. The identified photo-peaks of each daughter radionuclides were: ^{214}Pb (295.3 keV) and ^{214}Bi (1764.5 keV) for ^{226}Ra (^{238}U); ^{212}Pb (238.6 keV) and ^{238}Ac (911.1 keV) and ^{208}Tl (2614.7 keV) for ^{232}Th and ^{40}K (1460.0 keV).

The activity concentration of the thirteen (13) naturally occurring radionuclide materials (NORMs) present in different varieties of *Trona* is presented in Table 2 with each measured in Bqkg^{-1}. Table 2 shows that ^{40}K had the highest activity concentration followed by ^{226}Ra, with ^{232}Th having the lowest activity concentration. The high activity concentration of ^{40}K recorded in the *Trona* samples could be as a result of its abundance in the natural environment especially in rocks and its supplementary usage in human diet. The average activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in the various *Trona* samples was estimated to be 19.39±1.01, 6.42±1.22, and 331.12±8.19 Bqkg^{-1}, respectively.

It was found that Dan Libya (T11) had the highest concentration of ^{40}K in *Trona* with estimated value of 447.77 ± 4.30 Bqkg^{-1}, while Niger Jan Kanwa (T2) with highest activity concentration of ^{226}Ra was found to be 28.05 ± 2.14 Bqkg^{-1}. Additional, Niger Agadez (T13) was found to have the highest activity concentration of ^{232}Th estimated at 10.28 ± 1.15 Bqkg^{-1}. The highest concentrations found for ^{226}Ra in Niger Jan Kanwa were in agreement with the results obtained by (Garba et al., 2022). The lowest activity concentrations of NORMs in *Trona* was found in samples T1 (246.76 Bq kg^{-1}) for ^{40}K, T5 (11.20 Bq kg^{-1}) for ^{226}Ra and T4 (3.53 Bq kg^{-1}) for ^{232}Th, respectively.

Table 3 presents the estimated results for the radiological parameters of NORMs in *Trona.* According to a report by (Garba et al., 2022), the annual *Trona* intake by a person in Nigeria and, by implication, in Niger State, is rated at 14 kg/year, while the annual average effective dose due to the ingestion of *Trona* by humans was estimated to be 40.28 $\mu Sv/y$. Comparing the annual effective committed dose with the world average limit (0.3 $\mu Sv/y$) for the ingsetion of NORMs (UNSCEAR, 2000a). It shows that the annual effective dose is far below the world avearge by an estimated factor of 1000 times with the exception of patients using *Trona* as routine medicine, leading to higher consumption of *Trona* than what is reported by (Garba et al., 2022)Furthermore, Figure 3 shows the relationship between the annual ingestion rate of NORMs in *Trona* by an avearge person to the average annual effective dose rate.

Table 2: Activity concentration of NORMs in *Trona* samples consumed in Niger State.

Sample code	**Activity concentration (Bq kg^{-1})**		
	^{40}K	**^{226}Ra**	**^{232}Th**
T1	246.76 ± 5.56	22.48 ±1.83	4.62 ± 1.19
T2	256.37 ± 7.11	28.05 ± 2.14	4.12 ± 0.25
T3	297.04± 9.72	23.84 ± 0.70	6.81 ± 1.24
T4	292.84± 9.10	18.20 ± 0.48	3.53 ± 1.21
T5	260.48± 13.53	11.20 ± 0.80	8.12 ± 0.93
T6	292.91 ± 8.68	15.01 ± 0.37	5.66 ± 0.80
T7	291.78 ± 5.81	16.26 ± 0.39	4.07 ± 1.72
T8	279.12 ± 4.77	15.40 ± 0.62	8.47 ± 1.13
T9	433.04 ± 5.22	21.39 ± 1.04	5.97 ± 1.79
T10	433.37 ± 6.36	19.86 ± 1.03	6.21 ± 1.64
T11	447.77 ± 4.30	21.98 ± 1.06	7.02 ± 1.71
T12	397.10± 13.15	18.34 ± 1.23	8.64 ± 1.13
T13	376.00± 13.25	20.15 ±1.45	10.28 ± 1.15
Average±Error	**331.12±8.19**	**19.39±1.01**	**6.42±1.22**

It also indicates when the ingestion rate is less or greater than the 0.3 $\mu Sv/y$ world average effective dose.It could be observed in Figure 3 that the *Trona* consumption rates estimated between $0-20$ kg/y correspond to the AED rate of 0.3 mSv/y, which is within the acceptable limit by UNSCEAR. However, consumption rate slightly above 20 kg/y will result in higher AED rate above the acceptacle limit which would pose a significant radiological hazards which could potentially put members of public at risk, due a prolong consumption of this *Trona.* Therefore, in order to protect the general public from the harmful effects of NORMs in *Trona* and to ensure that their radiation dose does not exceed the international set limits for humans, UNSCEAR had specified that Ra_{eq} should not exceed 370 Bq/kg, H_{in} (internal harzard index), H_{ex} (external hazard index) should not exceed the limit of unity and AED for both plants and animals should equally not exceed 0.3 mSv/y, respectively (UNSCEAR, 2000b).

Table 3: Radiological risk of NORMs in *Trona* samples

Radiological Parameter					Cancer Risk ($\times 10^{-6}$)		
Sample ID	Ra_{eq} (Bqkg^{-1})	H_{in}	H_{ex}	AED (mSv/y)	**Fatality**	**Hereditary**	**Total**
T1	48.08712	0.190653	0.129896	32.91	1.8	38000	38001.8
T2	53.68209	0.220828	0.145018	34.67	1.9	44000	44001.9
T3	56.45038	0.216913	0.152481	40.91	2.3	43000	43002.3
T4	45.79658	0.172889	0.1237	32.47	1.7	35000	35001.7
T5	42.86856	0.146046	0.115775	36.39	2.0	29000	29002.0
T6	45.65787	0.163884	0.123317	34.63	1.9	33000	33001.9
T7	44.54716	0.164267	0.120321	31.74	1.7	33000	33001.7
T8	49.00434	0.173975	0.132353	39.91	2.2	35000	35002.2
T9	63.27118	0.228701	0.17089	45.84	2.5	46000	46002.5
T10	62.10979	0.221426	0.16775	45.73	2.5	44000	44002.5
T11	66.49689	0.239007	0.179601	49.11	2.7	48000	48002.7
T12	61.2719	0.215051	0.165484	48.17	2.6	43000	43002.6
T13	63.8024	0.226781	0.172321	51.15	2.8	45000	45002.8
Average	**54.08**	**0.19**	**0.15**	**40.28**	**2.2**	**40000**	**39694.5**

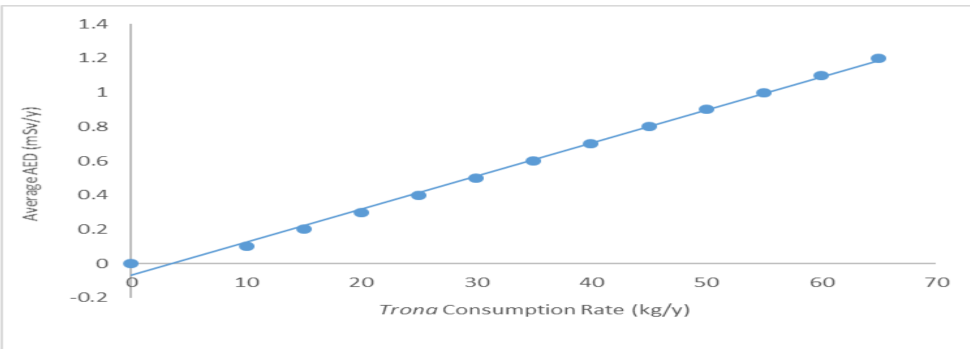

Figure 3: Showing the annual effective dose due to consumption of NORMs in *Trona*

The average radiological indexes for Ra_{eq}, Hin, Hex were found to be 54.08 Bq/kg, 0.19 Bq/kg and 0.15 Bq/kg, respectivey; all within the acceptable limit set by UNSCEAR. According to USEPA, maximum acceptable cancer risk should not exceed 1×10^{-4}. From the results obtained in this research, the hereditary cancer risk is far below the cancer risk limit, which implies that *Trona* consumption by the residence of Minna in Niger State does not pose any radiological risk.

T11 had the highest radium equivalent activity, annual effective dose, and excess cancer risk values of 66.50 Bq/kg^{-1}, 51.15 mSv/y and 6.29×10^{-4} and Sokoto Jan Balma had the lowest value of radium equivalent activity, annual effective dose, and excess cancer risk of 45.80 Bq/kg^{-1}, 32.47 mSv/y, and 4.33×10^{-4}, respectively.

Table 4: Average activity concentration of NORMs in *Trona* samples.

Sample ID	**Radiological Parameter**				**Cancer Risk ($\times 10^{-6}$)**		
	Ra_{eq} (Bqkg^{-1})	H_{in}	H_{ex}	AED (mSv/y)	Fatality	Hereditary	Total
Niger Farar Kanwa	52.79	0.19	0.14	40.33	0.09	127	127.09
Niger Jan Kanwa	48.28	0.18	0.13	35.53	1.95	365	366.95
Katsina Manda	53.91	0.20	0.15	38.79	1.15	165	166.15
Sokoto Farar Balma	56.45	0.22	0.15	40.91	2.30	430	432.30
Sokoto Jan Balma	45.80	0.17	0.12	32.47	1.70	350	351.70
Kano Mangul	62.11	0.22	0.17	45.73	0.05	440	440.05
Libya Dan Libya	66.50	0.24	0.18	51.15	0.06	480	480.06
Niger Agadez	63.80	0.23	0.17	49.11	0.06	450	450.06

the

Ingestion of Libya Dan Libya had the highest Hin (0.24) and Hex (0.18), while consumption of Sokoto Jan Balma had the lowest Hin (0.17) and Hex (0.12), respectively. For the purpose of identifying radiological content of each type of radionuclide, the thirteen (13) *Trona* samples analyzed were grouped into eight varieties. Table 4 shows the average activity concentration and Table 5 shows the average radiological risk of NORMs. It can be seen from Table 4 that Libya Dan Libya had the highest ^{40}K concentration of 447.77 Bq/kg^{-1}, Sokoto Farar Balma had the highest ^{226}Ra concentration of 23.84 Bq/kg^{-1}, and Niger Agadez had the highest ^{232}Th concentration of 10.28 Bq/kg^{-1}, respectively. In addition, Niger Jan Kanwa had the lowest ^{40}K concentration of 258.43 Bq/kg^{-1}, Sokoto Jan Balma had the lowest ^{226}Ra and ^{232}Th concentrations of 18.20 and 3.53 Bq/kg^{-1}, respectively. Out of the eight samples of *Trona* studied, Libya Dan Libya has the highest concentrations of Ra_{eq}, Hin, Hex, ELECR, and Hereditary of 66.50 Bqkg^{-1}, 0.24, 0.18, 51.15 mSv/y, and 4.8×10^{-4}, respectively, while Sokoto Jan Balma has the lowest concentration of Ra_{eq}, Hin, Hex, ELECR, and Hereditary of 45.80 Bqkg^{-1}, 0.17, 0.12, 32.47, and 3.50×10^{-10}, respectively. However, due to scanty radiological data in the literature in relation to the concentration of NORMs in mined *Trona* reported in this region of Nigeria, epideological studies could not be carried out to compare as well as check the medical effects of ingestion of mined *Trona* in the general population.

Table 5: Radiological risk of ingestion of NORMs in different *Trona* samples.

S/N	Sample	Variety	K-40 (Bq kg^{-1})	Ra-226 (Bq kg^{-1})	Th-232 (Bq kg^{-1})
1	T1, T8, T12	Niger Farar Kanwa	307.66	18.74	7.24
2	T2, T5	Niger Jan Kanwa	258.43	19.63	6.12
3	T7, T9	Katsina Manda	362.41	18.83	5.02
4	T3	Sokoto Farar Balma	297.04	23.84	6.81
5	T4	Sokoto Jan Balma	292.84	18.20	3.53
6	T10	Kano Mangul	433.37	19.86	6.21
7	T11	Libya Dan Libya	447.77	21.98	7.02
8	T13	Niger Agadez	376.00	20.15	10.28

Conclusion

The study shows that the results of Raeq, Hin and Hex were within the acceptable limits set by UNSCEAR with threshold values of 370 Bqkg^{-1}, 1 and 1, respectively. In addition, the results obtained for the total cancer risk due to fatality and hereditary effects that could result from the ingestion of *Trona* was approximately 100 times less than the USEPA acceptable threshold values of 1×10^{-4}, when compared with the results in Table 5. The results of the analysis further indicate that Liba Dan Libya had the highest Raeq, Hin, AED, and total cancer risk, while Sokoto Jan Balma had the lowest Raeq, Hin, and AED due to consumption of radionclides in *Trona*. Comparing the results in this report with the present *Trona* ingestion rate of 14 kgy^{-1}, the average AED due to ingestion of *Trona* in Nigeria was approximately 1000 times lower than the world annual committed dose of 0.3 mSvy^{-1} (UNSCEAR, 2000b). Therefore, the present ingestion rate of *Trona* in Niger State and Minna in particlar has no potential for radiological harm.

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