Activity concentrations of natural radioactivity and radiological dosimetry of virgin and agricultural soils in Kano State, Nigeria

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Received 19 November 2023, Revised 25 March 2024, Published 30 March 2024

Abstract: Natural radiation exposure from varying number of radionuclides in the soil is a major source of radiation dose around the world. These radionuclides are taken up by plants and transferred to crops leading to their concentrations in foods/crops. Activity concentrations of natural radioactivity in uncultivated and agricultural soils were analyzed in six rice producing Local Government Areas (Bagwai, Bunkure, Dambatta, Garko, Kura and Wudil) of Kano State, Nigeria using gamma-ray Spectrometer with Sodium-Iodide Scintillation detector. The activity concentrations, in Bq.kg^{-1}, of ^{40}K, ^{238}U and ^{232}Th ranged from 262.03 – 848.64 (mean: 547.76 ± 27.16), 11.27 – 65.14 (mean: 31.60 ± 3.32) and BDL – 25.11 (mean: 8.75 ± 0.50) in virgin soils; and 249.01 – 1098.91 (mean: 509.51 ± 25.21), 0.97 – 59.92 (mean: 25.46 ± 2.73) and 3.28 – 24.13 (mean: 12.26 ± 0.70) in agricultural soils in the study areas. Concentrations of ^{40}K and ^{238}U in virgin soils were generally higher than their corresponding values recorded in agricultural soils but higher values of ^{232}Th were obtained in agricultural soils. The mean values of Radium equivalent activity, 86.29 Bq.kg^{-1} (virgin soils), and 82.22 Bq.kg^{-1} (agricultural soils) were lower than the world average value: 370 Bq.kg^{-1}. The average Hazard indices (external and internal) values of virgin soils (0.233, 0.3210) and agricultural soils (0.222, 0.291) were all less than unity, which is the maximum permissible limit. However, slightly higher values of Hazard indices were obtained in virgin soils. The mean absorbed dose rate (D), annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ECLR) were: 42.73 nGyh^{-1}, 0.0524 mSv.y^{-1} and 0.119 x 10^{-3}, respectively for virgin soils and, 40.41 nGyh^{-1}, 0.0500 mSv.y^{-1} and 0.113 x 10^{-3} respectively for agricultural soils. These estimated values for both virgin and agricultural soils are all less than the world average of 59.0 nGyh^{-1}, 0.070 mSv.y^{-1} and 0.29 x 10^{-3}. Slightly lower values of D, AEDE and ECLR in agricultural soils is as a result of continuous human activities due to farming practices.

Keyword : Assessment, NORMs, Transfer Factor, Rice Plant, Kano State.

1. Introduction

The Earth's crust, also known as surface of the earth, is the outermost layer of the earth and is made up of solid rock mostly basalt and granite. It has an average thickness of about 30 km below the land. Primordial radionuclides in the earth's crust and the high energy cosmic ray particles striking the air molecules in the atmosphere are the two major sources of radiation of natural origin (ICRP, 2007; UNSCEAR, 2008). Through weathering and leaching of the earth crust, primordial radionuclides enter the soil (Alharbi & El-Taber, 2013). All soil everywhere in the world contains radionuclides to a greater or lesser extent. Typical soils (IA89a) contain approximately 300kBq/m^3 of ^{40}K to a depth of 20cm. By far, the largest source of natural radiation exposure comes from varying amounts of Uranium, Thorium and their progenies in the soil around the world. Soil plays major roles in the ecological balance, hydrological buffer, exploration and mining operations, agricultural processes and other sustainable development activities (industrial activities, energy needs fulfillment activities, etc.) for human survival (Ademola et. *al*., 2014). Farming (or crop and animal production processes) remains one of the oldest and a major activity needed for survival, healthy living and sustenance of humans in the world.

A virgin soil is a soil that has not be cultivated (or used for agricultural purposes) at all or for a period of time (usually a period of over ten years pertaining to this study). It is a soil that is devoid of exploration and mining activities, agricultural activities (weeding, application of soil productivity enhancement products, herbicides and/or pest control processes), and other human related sustainable activities that have direct or indirect impact on natural evolution and constituents of soil (soil nutrients, soil pH, soil content, soil texture, cation exchange capacity, soil electrical conductivity and organic matter). While an agricultural or farm soil is the one that have been consistently put into use in the cultivation of crop(s) continuously over a period of time. Human activities such as mining, farming, industrial activities, indiscriminate dumping of refuse/waste, as well as industrial and laboratory waste, studies have shown, have direct consequence on and can enhance the natural radioactivity of the environment (UNSCEAR, 2000). Alzubaidi *et. al*., (2016), assessed the natural radioactivity levels and radiation hazards in virgin and agricultural soils in the State of Kedah. North Malaysia. Similar study was carried out by Almayahi *et. al*., (2012), in Pentang; Saleh *et. al*., (2013), in Pontian; and, Ahmad *et. al*., (2015), in Kedah, all in Malaysia. The aim of this study, therefore, is to determine the activity concentrations of primordial radionuclides in uncultivated (virgin) and cultivated (farm) soils in Kano State, Nigeria and the objectives include, amongst others:

- to evaluate the hazard indices and radiation exposure indicators of cultivated soil in Kano State, Nigeria;
- to determine the hazard indices and radiological parameters of uncultivated soil in Kano State, Nigeria; and,
- to determine whether there is any significant variation in estimated values of hazard indices and radiological parameters obtained in uncultivated and

Journal of Physics: Theories and Applications E-ISSN: 2549-7324 / P-ISSN: 2549-7316
J. Phys.: Theor. Appl. Vol. 8 No. 1 (2024) 10-24 doi: 10.20961/jphystheor-appl.v8i1.80550

cultivated soils in Kano, Nigeria, on one hand, and in similar studies conducted in other countries of the world, on the other hand.

1.1. Location and Geology of the Study Areas

1.1.1. Location of the study area

Kano State is located at 481 meters (or about 1580 feet) above sea level covers a land area of approximately 20,760 square kilometers, consisting of 1,754,200 hectares of agricultural land and over 92,250,081 hectares of forest vegetation and grazing land. Kano is bounded on the west by the Katsina State, on the South west by Kaduna State, on the east by Jigawa and Bauchi State and on the north by Niger Republic. The region is located approximately between longitudes 8° 45 E and 12° 05 E latitudes 10° 30 N and 13° 02 N and as such is a part of the Sudano-Sahelian zone of Nigeria. Kano State is made up of forty-four (44) Local Government Areas and sub-divided into three (3) main regions or senatorial districts, namely: Kano-North; Kano-Central and Kano-South.

Map of Kano State showing the Study Area

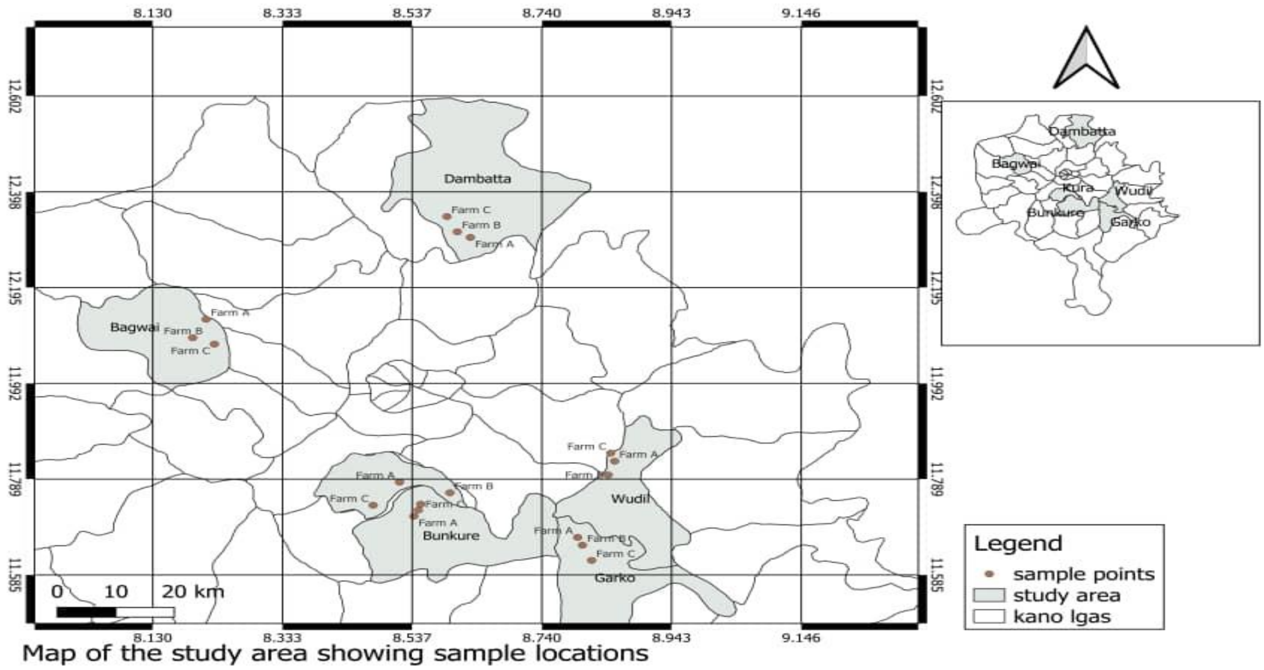

Figure 1. Map of study area showing sample sites/locations.

1.1.2. Geology of the study area

Pre-Cambrian rock of the basement complex which comprises of gneisses, amphibolites, marbles and the older granites which underlie large part of Nigeria, underlies 80% of the Kano State. Geological studies show that more than four-fifth of Kano is underlain by quartzite, undifferentiated Metasediments and basement complex rocks of Precambrian origin (Kankara, 2019). Jakara River is underlain by crystalline Basement complex of pre-cambrain origin which losses its identity by disappearing into the Chad Formation. The Basement complex consists of granite rocks extending up to Yadai towards the North and Gabasawa towards the East. The Granites are generally Gneissic and commonly developed in a mixture of Pegmatite of schist granite, Gneiss and irregular mass of pegmatite. The Aeolian sand derived from wind deposits cover most part of the area with thickness of about 5 meters in the upland and 10 meters along the lowland plains (Olofin, 1987). The geological structure influences the relief as well as landforms which are relatively flat, with some undulation especially around upstream. The relief of the Region can be categorized into four types: South and south eastern highlands, the middle and western high plain, the central lowland and the Chad plain. The highlands occupy more than 50% of the surface area of the Kano Region and lie on the elevation ranging between 450 m to 650 m (Kankara, 2019).

2. Materials and Method

The following materials were used in the conduct of this study: Hand trowel; Shovel; Soil auger; Polythene bags; Laboratory coat, rain boot; Temporary Markers; Distilled water; 2mm mesh sieve; Temperature-controlled Oven; Agate mortar and pestle, cylindrical plastic containers; gamma ray spectrometer (model: 802; serial number: 13000850), Data Acquisition System etc.

2.1. Collection and Preparation of Samples

Thirty-two (36) farm and uncultivated soil samples (18 farm soil and 18 uncultivated soil samples) were collected from 32 locations in six (6) selected rice-producing Local Government Areas in Kano (Bagwai, Bunkure, Dambatta, Garko, Kura, and Wudil). In each location, soil was collected from different spots and were thoroughly mixed together to form a good representative sample of the location. Soil samples were collected between August and September, 2021. The sample were first dried in the Sun for 4 or 5 days before they were later dried in a temperature-controlled oven at 105°C for 24 hours for constant weight of the sample to be attained. Dried samples were then pulverized or crushed into powder form using Agate mortar and pestle. The crushed samples were then sieved with a 2 mm mesh sieve to obtain homogeneous sample (Hossain *et. al*., 2012). About 200 g of each of the samples were weighed and transferred into a marked, thoroughly cleaned, and uncontaminated cylindrical plastic container of uniform size and sealed for 4 weeks to allow Radon and its short-lived progenies reach secular equilibrium at ambient temperature prior to gamma spectroscopy measurements (Ajayi, 2009; Issa, 2013).

2.2. Measurement of Radioactivity of Soil samples

The activity concentrations of primordial radionuclides in the soil samples were measured using the gamma spectrometric method. NaI doped with Thallium detector (model: 802) of dimension 7.62 cm by 7.62 cm housed in a 6cm thick lead shield and lined with Cadmium (Cd) and Copper (Cu) sheets, in order to resist background radiation, was connected to a personal computer-based data acquisition system, which has Genie 2000 (VI.3) software from Canberra through 16,000 Multi-Channel-Analyzer (MAC). The detector was calibrated before using for the analysis. Energy and efficiency calibrations were performed. The energy calibration of the detector was done using different gamma sources of ^{60}Co (1173.2 and 1332.5 KeV), ^{137}Cs (661.9 KeV) and ^{22}Na (511 and 1274 KeV). The full width at half maximum (FWHM) corresponds to the resolution for the detector, and it has been shown that the resolution of a detector is directly proportional to the gamma ray energy (Hossain *et. al.*, 2012; Akkurt *et. al.,* 2014).

The samples (18 virgin soil and 18 agricultural soil samples) were placed on the NaI(Tl) detector and each sample was set to counting time of 29,000s. This time is long enough for the detector to analyse the spectrum with the peaks of interest clearly shown and well distinguished. In NaI(Tl) analysis, the count rate of ^{238}U in the soil sample was estimated from the gamma-ray peak of ^{214}Bi (1.760 MeV), ^{232}Th from gamma-ray peak of ^{208}Tl (2.615 MeV), and ^{40}K from gamma-ray peak of ^{40}K (1.460 MeV) itself. The count rates under the photo peak of each of the primordial radionuclide for both detectors were converted to activity concentration, A using the Eqn. 1; (Isinkaye & Emelue, 2015; Akkurt *et. al.*, 2014):

$$A = \frac{\mathrm{N\ x\ 1000}}{\epsilon_\gamma I_\gamma m t} (Bq/kg) \quad (1)$$

where A is the activity concentration of the radionuclide in the sample, N is the net counts or counting area under photo peak, ϵ_γ is the efficiency of the detector for a particular γ-ray energy, m is the mass of each sample, I_γ is the intensity of the emitted gamma-ray, and t is the counting time.

2.3. Estimation of Radiation Exposure Indicators

2.3.1. Radium Equivalent Activity (Ra_{eq})

Ra_{eq} is an index indicator that accounts for the contribution of each of the natural radioactivity to the total dose of the sample being investigated. It is the weighted sum of the activities of ^{40}K, ^{238}U and ^{232}Th in the sample being investigated with the assumption that 4810 Bq.kg^{-1} of ^{40}K, 370 Bq.kg^{-1} of ^{238}U, and 259 Bq.kg^{-1} of ^{232}Th contribute the same gamma dose rate. Ra_{eq} was calculated using Eqn. 2, (Ajayi, 2009; Srilatha, 2015):

$$R_{a_{eq}}(Bq.Kg^{-1}) = A_U + 1.43 A_{Th} + 0.077\, A_K \quad (2)$$

Where A_U , $A_{Th}$and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively.

2.3.2. Absorbed Dose Rate in air (D)

The absorbed dose rate (outdoor), in nGy.h^{-1}, at a height of 1.0 m above the surface of the earth or ground in the study locations were estimated using Eqn. 3, (UNSCEAR, 2000; Raghu *et al*., 2016):

$$D(nGyh^{-1}) = 0.462 A_U + 0.604 A_{Th} + 0.0417 A_K \quad (3)$$

Where A_U , A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively measured in Bq.kg^{-1}.

2.3.3. Annual Effective Dose Rate (AEDE)

The outdoor annual effective dose equivalent due to activity concentrations of natural radioactivity obtained in the soil samples was calculated using Eqn. 4, (UNSCEAR, 2000; Olatunji *et al*., 2022):

$$\text{AEDE (mSv.y}^{-1}) = \text{D x T x DCF x OF} \tag{4a}$$

where D is absorbed dose rate; DCF, the dose conversion factor is 0.7 SvGy^{-1}, OF, the outdoor occupancy factor is 0.2, and T, the annual exposure time is 8760 hyr^{-1}(IAEA, 1994). So, substituting these values in Eqn. 4a, we have:

$$\text{AEDE} = D(nGyh^{-1}) \times 8{,}760\text{hry}^{-1} \times 0.7 \times 0.2 \times (10^3\text{mSv}/10^9)\text{nGy} \tag{4b}$$

2.3.4. External Hazard Index (H_{ex})

The external hazard index is a useful indicator for safety standard regulation and radiation protection from the emission of gamma radiation by various radioactive substances, and it was determined using Eqn. 5 as follows (UNSCEAR, 2000; Raghu et al., 2016):

$$H_{ex} = \frac{A_K}{4810} + \frac{A_U}{370} + \frac{A_{Th}}{259} \tag{5}$$

Where A_U , A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively.

2.3.5. Internal Hazard Index (H_{in})

The internal exposure to radon and its daughter product is quantified by the internal hazard index which is given by Eqn. 6, (UNSCEAR, 2000; Raghu et al., 2016):

$$H_{in} = \frac{A_K}{4810} + \frac{A_U}{184} + \frac{A_{Th}}{259} \tag{6}$$

Where A_U , A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively.

2.3.6. Gamma Index (I_γ)

Gamma index is the estimation of the level of gamma radioactivity associated with different concentrations of specific radionuclides (Ononugbo et al., 2016):

$$I_\Upsilon = \frac{A_K}{3000} + \frac{A_U}{300} + \frac{A_{Th}}{200} \tag{7}$$

Where A_U , A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively.

Materials with $I_\Upsilon > 1$ should be avoided in building construction as such will deliver dose rate higher than 1 $mSvy^{-1}$ to the occupant of such buildings (WHO, 2008).

2.3.7. Annual Gonad Equivalent Dose (AGED)

Annual gonad equivalent dose is concern with the exposure received by body organs in the study areas due to specific activities of natural radioactivity in the soil. The gonads, the active bone marrows and the bone surface cells are considered as the organs of interest. AGED is determined using Eqn. 8, (Issa, 2013):

$$AGED\ (mSvy^{-1}) = 3.09A_{Ra} + 4.18A_{Th} + 0.314A_K \quad (8)$$

Where A_U, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively

2.3.8. Excess Lifetime Cancer Risk (ELCR)

Excess Lifetime Cancer Risk is the probability of developing cancer over a life time at a given level of exposure a higher value of ECLR implies higher probability induction of cancer of the individual that was exposed. It calculated using Eqn. 9, (Ononugbo *et al*., 2016):

$$ELCR = AEDE \times DL \times RF \times 10^{-3} \quad (9)$$

Where the average lifetime, DL = 45.5 years in Nigeria (WHO, 2008); and the Risk Factor, RF = 0.05.

2.3.9. Activity Utilization Index (AUI)

AUI is the parametric model that enables us to determine the doses rates in air of natural radionuclides in air, and this is given as, (UNSCEAR, 2000; Raghu et al., 2016):

$$AUI = \left(\frac{A_U}{\frac{50Bq}{kg}}\right)F_U + \left(\frac{A_{Th}}{\frac{50Bq}{kg}}\right)F_{Th} + \left(\frac{A_K}{\frac{50Bq}{kg}}\right)F_K \quad (10a)$$

$$AUI = \left(\frac{A_U}{\frac{50Bq}{kg}}\right)0.462 + \left(\frac{A_{Th}}{\frac{50Bq}{kg}}\right)0.604 + \left(\frac{A_K}{\frac{50Bq}{kg}}\right)0.041 \quad (10b)$$

Where A_U, A_{Th} and A_K are the activity concentrations, in Bq.kg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively and F_U, F_{Th} and F_K are fractional contributions to the total dose rate in air due to gamma radiation from the actual concentrations of these primordial radionuclides (UNSCEAR, 2000; Raghu et al., 2016). The values of F_U, F_{Th} and F_K are given as 0.462, 0.604 and 0.041 for radium, thorium and potassium respectively. AUI less than 2 correspond to an annual effective dose of < 0.3 mSv.y^{-1} which is considered safe for the environment (UNSCEAR, 2000).

3. Results and Discussion

Table 1 shows the activity concentrations of ^{40}K, ^{238}U and ^{232}Th, as well as that of Radium equivalent activity, Ra_{eq} of the uncultivated soil samples in the study areas. The mean activity concentrations of ^{40}K, ^{238}U and ^{232}Th were: 320.83 ± 15.81, 22.51 ± 2.23 and 6.32 ± 0.36 Bq.kg^{-1} respectively in Bagwai; 553.24 ± 27.45, 42.57 ± 4.27 and 5.21 ± 0.30 Bq.kg^{-1} respectively in Bunkure; 601.20 ± 29.90, 27.48 ± 3.08 and 6.72 ± 0.39 Bq.kg^{-1} respectively in Dambatta; 606.58 ± 30.05, 26.50 ± 2.92 and 13.50 ± 0.77 Bq.kg^{-1} respectively in Garko; 420.33 ± 20.95, 38.05 ± 4.00 and 8.35 ± 0.48 Bq.kg^{-1} respectively in Kura; and, 784.40 ± 38.82, 32.50 ± 3.44 and 12.39 ± 0.72 Bq.kg^{-1} respectively in Dambatta.

All the values of activity concentrations of ^{40}K obtained in all the study areas, except that of Bagwai, were greater than the world average of value of 400 Bq.kg^{-1}

(UNSCEAR, 2000; Olatunji *et al*., 2022); while the activity concentrations of ^{238}U obtained in the study locations were lower than the world average value with the exception of Bunkure and Kura LGAs which are higher than the world average value of 35 Bq.kg^{-1}, however the concentrations of ^{232}Th in virgin soil samples in all the study locations were lower than the world average values of 30 Bq.kg^{-1} (UNSCEAR, 2000). The mean Ra_{eq} estimated values in Bagwai, Bunkure, Dambatta, Garko, Kura and Wudil LGAs were: 56.25, 92.62, 83.38, 92.51, 82.35 and 110.61 Bq.kg^{-1} respectively and were all less than the world permissible limit of 370 Bq.kg^{-1} (UNSCEAR, 2000).

Table 1. Activity Concentrations of Natural Radionuclides and Radium Equivalent Activity (Ra_{eq}) in Virgin Soil (SLV) in Kano State

LGA	Description	^{40}K (BqKg^{-1})	^{238}U (BqKg^{-1})	^{232}Th (BqKg^{-1})	Ra_{eq} (BqKg^{-1})
Bagwai (BGW)	SLV/BGW 01	275.75 ± 13.72	16.59 ± 2.01	8.64 ± 0.50	50.18
	SLV/BGW 02	294.58 ± 14.18	32.99 ± 2.45	9.93 ± 0.55	69.87
	SLV/BGW 03	392.16 ± 19.52	17.94 ± 2.23	0.39 ± 0.02	48.70
	Range	262.03 - 411.68	14.58 – 35.44	0.37 – 10.48	48.70 – 69.87
	Mean ± STD	**320.83 ±15.81**	**22.51 ± 2.23**	**6.32 ± 0.36**	**56.25**
Bunkure (BKR)	SLV/BKR 01	358.48 ± 17.86	59.69 ± 5.45	1.69 ± 0.10	89.71
	SLV/BKR 02	496.09 ± 24.69	55.01 ± 5.68	6.97 ± 0.40	103.18
	SLV/BKR 03	805.16 ± 39.79	13.00 ± 1.64	6.97 ± 0.40	84.97
	Range	340.62 – 844.95	11.36 – 65.14	1.59 – 7.37	84.71 – 103.18
	Mean ± STD	**553.24 ± 27.45**	**42.57 ± 4.27**	**5.21 ± 0.30**	**92.62**
Dambatta (DBT)	SLV/DBT 01	538.84 ± 26.88	42.59 ± 4.30	BDL	84.08
	SLV/DBT 02	702.66 ± 34.91	21.11 ± 2.59	15.59 ± 0.90	97.50
	SLV/DBT 03	562.11 ± 27.91	18.74 ± 2.35	4.58 ± 0.27	68.57
	Range	511.96 – 737.57	16.39 – 46.89	BDL – 16.49	68.57 – 97.50
	Mean ± STD	**601.20 ± 29.90**	**27.48 ± 3.08**	**6.72 ± 0.39**	**83.38**
Garko (GRK)	SLV/GRK 01	491.11 ± 24.39	40.21 ± 4.11	7.70 ± 0.44	89.04
	SLV/GRK 02	580.74 ± 28.77	24.28 ± 2.78	9.04 ± 0.52	81.93
	SLV/GRK 03	747.89 ± 37.00	15.00 ± 1.86	23.75 ± 1.36	106.55
	Range	466.72 – 784.89	13.14 – 44.32	7.26 – 25.11	81.93 – 106.55
	Mean ± STD	**606.58 ± 30.05**	**26.50 ± 2.92**	**13.50 ± 0.77**	**92.51**
Kura (KUR)	SLV/KUR 01	347.81 ± 17.37	44.06 ± 4.58	8.21 ± 0.47	82.58
	SLV/KUR 02	342.69 ± 17.12	35.27 ± 3.65	5.64 ± 0.33	69.73
	SLV/KUR 03	570.49 ± 28.36	34.82 ± 3.78	11.18 ± 0.64	94.74
	Range	325.57 – 598.85	31.04 – 48.64	5.31 – 11.82	69.73 – 94.74
	Mean ± STD	**420.33 ± 20.95**	**38.05 ± 4.00**	**8.34 ± 0.48**	**82.35**
Wudil (WDL)	SLV/WDL 01	766.29 ± 37.81	12.89 ± 1.62	14.22 ± 0.82	92.22
	SLV/WDL 02	778.36 ± 38.57	55.88 ± 5.38	15.88 ± 0.92	138.52
	SLV/WDL 03	808.56 ± 40.08	28.73 ± 3.31	7.07 ± 0.41	101.10
	Range	728.48 – 848.64	11.27 – 61.26	6.66 – 16.80	92.22 – 138.52
	Mean ± STD	**784.40 ± 38.82**	**32.50 ± 3.44**	**12.39 ± 0.72**	**110.61**

Table 2 reveals the values of activity concentrations of ^{40}K, ^{238}U and ^{232}Th, and that of Radium equivalent activity, Ra_{eq} of the agricultural (farm) soils in the study areas. The average activity concentrations of ^{40}K, ^{238}U and ^{232}Th were: 474.23 ± 23.64, 43.57 ± 4.37 and 12.82 ± 0.74 Bq.kg^{-1} respectively in Bagwai; 509.87 ± 25.06, 11.56 ± 1.34 and 10.76 Bq.kg^{-1} respectively in Bunkure; 473.46 ± 23.52, 22.70 ± 2.57 and 13.67 ± 0.79 Bq.kg^{-1} respectively in Dambatta; 353.22 ± 17.44, 35.53 ± 3.52 and 14.01 ± 0.80 Bq.kg^{-1} respectively in Garko LGA; 401.16 ± 20.00, 14.27 ± 1.69 and 5.32 ± 0.31 Bq.kg^{-1} respectively in Kura; and, 845.12 ± 41.60, 25.13 ± 2.91 and 16.95 ± 0.97 Bq.kg^{-1} respectively in Wudil LGA. Except in Garko LGA, all the values of mean activity concentrations of ^{40}K in all the study locations were greater than the world average value of 400 Bq.kg^{-1} (UNSCEAR, 2000).

Activity concentrations of ^{238}U in Bagwai and Garko LGAs were higher than the world average of 35 Bq.kg^{-1} (UNSCEAR, 2000) but lower values are recorded in other

LGAs, while the concentrations of ^{232}Th in farm soils in all the sample location were lower than the world average value of 30 Bq.kg^{-1}. The average Ra_{eq} in the study areas were: 98.42, 66.21, 78.70, 82.77, 52.77 and 114.44 Bq.kg^{-1} respectively in Bagwai, Bunkure, Dambatta, Garko, Kura and Wudil, which are lower than the world permissible limit of 370 Bq.kg^{-1} (UNSCEAR, 2000).

Table 2. Activity Concentrations of Natural Radionuclides and Radium Equivalent Activity (Ra_{eq}) in Farm Soil (SLH) in Kano State

LGA	Description	Longitude & Latitude	^{40}K (BqKg^{-1})	^{238}U (BqKg^{-1})	^{232}Th (BqKg^{-1})	Ra_{eq} (BqKg^{-1})
Bagwai	SLH/BGW 11	12.128084, 8.213752	544.76 ± 27.18	40.51 ± 3.93	20.16 ± 1.16	111.29
(BGW)	SLH/BGW 12	12.126780, 8.234755	504.81 ± 25.08	35.57 ± 3.91	9.29 ± 0.54	87.72
	SLH/BGW 13	12.125617, 8.235661	373.13 ± 18.66	54.64 ± 5.28	9.01 ± 0.52	96.25
	Range		354.47 – 571.94	31.66 – 59.92	8.49 – 21.32	87.72 – 111.29
	Mean ± STD		474.23 ± 23.64	43.57 ± 4.37	12.82 ± 0.74	98.42
Bunkure	SLH/BKR 11	11.709982, 8.539434	519.68 ± 25.00	1.06 ± 0.09	12.73 ± 0.71	59.28
(BKR)	SLH/BKR 12	11.723021, 8.546230	525.31 ± 26.13	20.79 ± 2.42	8.63 ± 0.50	73.58
	SLH/BKR 13	11.735650, 8.559932	484.62 ± 24.04	12.84 ± 1.52	10.91 ± 0.63	65.76
	Range		460.58 – 551.44	0.97 – 23.21	8.13 – 13.44	59.28 – 73.58
	Mean ± STD		509.87 ± 25.06	11.56 ± 1.34	10.76 ± 0.61	66.21
Dambatta	SLH/DBT 11	12.236980, 8.511315	484.83 ± 24.09	25.73 ± 2.86	13.00 ± 0.75	81.65
(DBT)	SLH/DBT 12	12.319731, 8.524013	551.98 ± 27.44	22.63 ± 2.62	11.94 ± 0.69	82.20
	SLH/DBT 13	12.341085, 8.545123	383.58 ± 19.04	19.74 ± 2.24	16.06 ± 0.92	72.25
	Range		364.54 – 579.42	17.50 – 28.59	11.25 – 16.98	72.25 – 82.20
	Mean ± STD		473.46 ± 23.52	22.70 ± 2.57	13.67 ± 0.79	78.70
Garko	SLH/GRK 11	11.665143, 8.796024	290.60 ± 13.98	19.22 ± 1.49	13.68 ± 0.76	61.16
(GRK)	SLH/GRK 12	11.648574, 8.803530	506.90 ± 25.21	38.81 ± 4.12	12.20 ± 0.70	95.29
	SLH/GRK 13	12.015431, 8.718003	262.15 ± 13.14	48.55 ± 4.96	16.16 ± 0.93	91.85
	Range		249.01 – 532.11	17.73 – 53.51	11.5 – 17.09	61.16 – 95.29
	Mean ± STD		353.22 ± 17.44	35.53 ± 3.52	14.01 ± 0.80	82.77
Kura	SLH/KUR 11	11.782455, 8.516820	362.14 ± 18.11	13.89 ± 1.61	3.48 ± 0.20	46.75
(KUR)	SLH/KUR 12	11.752820, 8.521245	350.64 ± 17.47	15.34 ± 1.81	5.73 ± 0.33	50.53
	SLH/KUR 13	11.801012, 8.506720	490.69 ± 24.41	13.59 ± 1.65	6.76 ± 0.39	61.04
	Range		333.17 – 515.10	11.94 – 17.15	3.28 – 7.15	46.75 – 61.04
	Mean ± STD		401.16 ± 20.00	14.27 ± 1.69	5.32 ± 0.31	52.77
Wudil	SLH/WDL 11	11.837078, 8.837740	1047.44 ± 51.47	24.23 ± 2.85	15.39 ± 0.88	126.89
(WDL)	SLH/WDL 12	11.800086, 8.830480	872.77 ± 43.10	21.43 ± 2.40	12.64 ± 0.73	106.71
	SLH/WDL 13	11.844069, 8.847283	615.15 ± 30.40	29.72 ± 3.49	22.82 ± 1.31	109.72
	Range		584.75 – 1098.91	19.03 – 33.21	11.91 – 24.13	106.71 – 126.89
	Mean ± STD		845.12 ± 41.60	25.13 ± 2.91	16.95 ± 0.97	114.44

Table 3 shows the estimated values of Hazard indices ($H_{ex.}$ and $H_{in.}$), Gamma (Radioactivity Level) Index (I_γ), Activity Utilization Index (AUI), Absorbed Dose Rate (D), Annual Gonad Dose Equivalent (AGDE), Annual Effective Dose Rate (AEDR) and Excess Lifetime Cancer Risk (ECLR) of virgin soils in the selected Local Government Areas of Kano. The calculated values of external hazard index, $H_{ex.}$; internal hazard index, $H_{in.}$; gamma index, I_γ; and activity utilization index, AUI; obtained in virgin soils in all locations ranged from: 0.132 – 0.374 (mean: 0.233); 0.180 – 0.525 (mean: 0.321); 0.190 – 0.525 (mean: 0.329) and, 0.488 – 1.357 (mean: 0.855) respectively. All the mean values of $H_{ex.}$; $H_{in.}$; I_γ; and AUI in virgin soils in all the study areas are less than Unity, which is the maximum permissible values for each of these indicators (UNSCEAR, 2000). However, a value slightly greater than 1 was obtained in a sample location in each of Bunkure and Garko LGAs, and two locations in Wudil LGA.

Furthermore, the estimated values of D; AGDE; AEDE and ECLR in virgin soils ranged from: 24.38 – 67.87 (mean: 42.73 nGy.h^{-1}); 173.96 – 485.45 (mean: 306.20 mSv.y^{-1}); 0.0299 – 0.0832 (mean: 0.0524 mSv.y^{-1}); and 0.068 x 10^{-3} – 0.189 x 10^{-3} (mean: 0.119 x 10^{-3}) respectively. The mean absorbed dose rate, D, of virgin soils, 42.73 nGy.h$^{-1,}$ is less than the world average, 59.0 nGy.h^{-1}; the mean AGDE, 306.20 mSv.y^{-1}, is slightly greater than world average value of 300.0 mSv.y^{-1}; the mean AEDE, 0.0524 mSv.y^{-1}, is less than the world average value of 0.07 mSv.y^{-1}, and the mean value of ECLR of virgin soils, 0.119 x 10^{-3}, is also less than that of the world average, 0.29 x 10^{-3} (UNSCEAR, 2000)

Table 3. Hazard indices, Gamma or Radioactivity Level Index (Iγ), Activity Utilization Index (AUI), Absorbed Dose Rate (D), Annual Effective Dose Rate (AEDR), Annual Gonad Equivalent Dose (AGED) and Excess Lifetime Cancer Risk of Uncultivated Soils in Kano.

LGA	Description	Hazard Indices H_{ex}	H_{in}	Gamma Index, I_γ (mSv)	Activity Utilization Index (AUI)	Absorbed Dose, D (nGy.h^{-1})	AGED	AEDE (mSv.yr^{-1})	ECLR (x 10^{-3})
Bagwai	SLV/BGW 01	0.136	0.180	0.190	0.488	24.38	173.96	0.0299	0.068
	SLV/BGW 02	0.189	0.278	0.258	0.670	33.52	235.94	0.0411	0.094
	SLV/BGW 03	0.132	0.180	0.192	0.498	24.88	180.20	0.0305	0.069
	Mean	**0.152**	**0.213**	**0.213**	**0.552**	**27.59**	**196.71**	**0.0338**	**0.077**
Bunkure	SLV/BKR 01	0.242	0.404	0.327	0.871	43.55	304.07	0.0534	0.121
	SLV/BKR 02	0.279	0.427	0.384	1.006	50.31	354.89	0.0617	0.140
	SLV/BKR 03	0.229	0.265	0.347	0.876	43.79	322.12	0.0537	0.122
	Mean	**0.250**	**0.365**	**0.353**	**0.918**	**45.88**	**327.03**	**0.0563**	**0.128**
Dambatta	SLV/DBT 01	0.227	0.342	0.262	0.843	42.15	300.80	0.0517	0.118
	SLV/DBT 02	0.263	0.320	0.383	0.969	48.47	351.03	0.0594	0.135
	SLV/DBT 03	0.185	0.236	0.273	0.697	34.86	253.55	0.0428	0.097
	Mean	**0.225**	**0.299**	**0.306**	**0.836**	**41.83**	**301.78**	**0.0513**	**0.117**
Garko	SLV/GRK 01	0.241	0.349	0.336	0.874	43.71	310.64	0.0536	0.122
	SLV/GRK 02	0.221	0.287	0.320	0.818	40.89	295.16	0.0501	0.114
	SLV/GRK 03	0.288	0.328	0.418	1.049	52.46	380.46	0.0643	0.146
	Mean	**0.250**	**0.321**	**0.358**	**0.914**	**45.69**	**328.75**	**0.0560**	**0.127**
Kura	SLV/KUR 01	0.223	0.342	0.304	0.796	39.82	279.67	0.0488	0.111
	SLV/KUR 02	0.188	0.284	0.260	0.680	33.99	240.16	0.0417	0.095
	SLV/KUR 03	0.256	0.350	0.362	0.933	46.63	333.46	0.0572	0.130
	Mean	**0.222**	**0.325**	**0.309**	**0.803**	**40.15**	**284.43**	**0.0492**	**0.112**
Wudil	SLV/WDL 01	0.249	0.284	0.369	0.930	46.50	339.88	0.0570	0.130
	SLV/WDL02	0.374	0.525	0.525	1.357	67.87	483.45	0.0832	0.189
	SLV/WDL 03	0.273	0.351	0.401	1.025	51.26	372.22	0.0629	0.143
	Mean	**0.299**	**0.387**	**0.432**	**1.104**	**55.21**	**398.52**	**0.0677**	**0.154**

Table 4 comprises of values of Hazard indices (H_{ex}. and H_{in}.), Gamma (Radioactivity Level) Index (I_γ), Activity Utilization Index (AUI), Absorbed Dose Rate (D), Annual Gonad Dose Equivalent (AGDE), Annual Effective Dose Rate (AEDR) and Excess Lifetime Cancer Risk (ECLR) of agricultural (farm) soils used for cultivation of rice in the study areas of Kano. Values of $H_{ex.}$; $H_{in.}$; I_γ; and AUI obtained in agricultural soils ranged from: 0.126 – 0.343 (mean = 0.222); 0.163 – 0.410 (mean = 0.291); 0.184 – 0.507 (mean = 0.316); and 0.472 – 1.283 (mean = 0.808) respectively. All the estimated values of: H_{ex}; $H_{in.}$; I_γ; and AUI in all the sample locations are less than Unity which is the maximum permissible limit for each of the parameters (UNSCEAR, 2000). Also, the estimated absorbed dose rate, D, of the farm soils in the sample areas range from 23.62 – 64.17 nGy.h^{-1}, with the mean value of 40.41 nGy.h^{-1}, this is less than the world average value of 59.0 nGy.h^{-1} (UNSCEAR, 2000).

The AGDE, AEDE and ECLR of farm soils ranged from: 171.18 – 468.10 (mean: 289.90 mSv.y^{-1}); 0.0290 – 0.0787 (mean: 0.050 mSv.y^{-1}); and 0.066 x 10^{-3} – 0.179 x 10^{-3} (mean: 0.113 x 10^{-3}) respectively. The average values of these dose indicators are less than their respective world average values of: 300 mSv.y^{-1}; 0.07 mSv.y^{-1} and 0.29 x 10^{-3}. An indication that there is no immediate threat to the life of people living or farming in these areas. However, the average value of AGED obtained in Bagwai and Wudil LGAs are greater than the world average.

Table 4. Hazard indices, Gamma or Radioactivity Level Index (Iγ), Activity Utilization Index (AUI), Absorbed Dose Rate (D), Annual Effective Dose Rate (AEDR), Annual Gonad Equivalent Dose (AGED) and Excess Lifetime Cancer Risk (ECLR) of Cultivated/Farm Soils in Kano.

LGA	Description	Hazard Indices H_{ex}	H_{in}	Gamma Index, I_γ (mSv)	Activity Utilization Index (AUI)	Absorbed Dose, D (nGy.h^{-1})	AGED	AEDE (mSv.yr^{-1})	ECLR (x 10^{-3})
Bagwai	SLH/BGW 01	0.301	0.410	0.417	1.072	53.61	380.50	0.0657	0.149
	SLH/BGW 02	0.237	0.333	0.333	0.862	43.10	307.25	0.0529	0.120
	SLH/BGW 03	0.260	0.408	0.352	0.925	46.25	323.66	0.0567	0.129
	Mean	**0.266**	**0.384**	**0.367**	**0.953**	**47.65**	**337.14**	**0.0584**	**0.133**
Bunkure	SLH/BKR 01	0.160	0.163	0.240	0.597	29.85	219.67	0.0366	0.083
	SLH/BKR 02	0.199	0.255	0.288	0.734	36.72	265.17	0.0450	0.102
	SLH/BKR 03	0.178	0.212	0.259	0.655	32.72	237.45	0.0401	0.091
	Mean	**0.179**	**0.210**	**0.262**	**0.662**	**33.10**	**240.78**	**0.0406**	**0.092**
Dambatta	SLH/DBT 01	0.221	0.290	0.312	0.799	39.96	286.08	0.0490	0.111
	SLH/DBT 02	0.222	0.283	0.319	0.814	40.68	293.16	0.0499	0.114
	SLH/DBT 03	0.195	0.248	0.274	0.699	34.82	248.57	0.0427	0.097
	Mean	**0.213**	**0.274**	**0.302**	**0.770**	**38.49**	**276.06**	**0.0472**	**0.107**
Garko	SLH/GRK 01	0.165	0.217	0.229	0.585	29.26	207.82	0.0359	0.082
	SLH/GRK 02	0.257	0.362	0.359	0.929	46.44	330.09	0.0570	0.130
	SLH/GRK 03	0.248	0.379	0.330	0.862	43.12	299.88	0.0529	0.120
	Mean	**0.223**	**0.319**	**0.306**	**0.792**	**39.61**	**279.26**	**0.0486**	**0.111**
Kura	SLH/KUR 01	0.126	0.164	0.184	0.472	23.62	171.18	0.0290	0.066
	SLH/KUR 02	0.136	0.178	0.197	0.503	25.17	181.45	0.0309	0.070
	SLH/KUR 03	0.165	0.202	0.243	0.616	30.82	224.33	0.0378	0.086
	Mean	**0.142**	**0.181**	**0.208**	**0.530**	**26.53**	**192.30**	**0.0325**	**0.074**
Wudil	SLH/WDL 01	0.343	0.408	0.507	1.283	64.17	468.10	0.0787	0.179
	SLH/WDL 02	0.288	0.346	0.426	1.079	53.93	393.10	0.0661	0.150
	SLH/WDL 03	0.296	0.377	0.418	1.063	53.17	380.38	0.0652	0.148
	Mean	**0.309**	**0.377**	**0.450**	**1.142**	**57.09**	**413.87**	**0.0700**	**0.159**

Table 5 shows the activity concentrations of ^{40}K, ^{238}U/^{226}Ra and ^{232}Th in uncultivated/virgin soil in the present and other similar studies conducted in different countries. The average concentration of ^{40}K recorded in this study is lower than values obtained by Almahayi *et. al.*, (2012) but higher than those reported by Alzubaidi *et. al.*, (2016); Saleh *et. al.*, (2013); and Ahmad *et. al.*, (2015). While the mean values of ^{238}U/^{226}Ra and ^{232}Th recorded in the present study (31.60 and 8.75 Bq.kg^{-1}) are lower than values obtained in all other similar studies under consideration. Also, the activity concentrations of ^{40}K, ^{238}U/^{226}Ra and ^{232}Th in agricultural/farm soil compare to ten other similar studies shows that mean activity concentration of ^{40}K in Kano is lower than value recorded by Tufail et. al., (2006); but higher than those of: Issa, 2013; Ahmad *et. al.*, (2015); Singh *et. al.*, (2005); Alzubaidi *et. al.*, (2016); Ioannides *et. al.*, (1997); Boukhenfouf & Boucenna, (2011) and values reported in Thailand and Malaysia by UNSCEAR, (2000). The mean concentration of ^{238}U/^{226}Ra of the present study is higher than that of Ioannides *et. al.*, (1997), but lower than values reported in all other studies, while the mean concentration of ^{232}Th in Kano is the least out of studies other consideration.

The higher values of activity concentrations of natural radioactivity in farm soils can be attributed to human activities like methods adopted in clearing of bushes, use of pesticides and/or herbicides, application of fertilizers etc. The average values of Hazard indices (H_{ex}. and H_{in}.), Gamma (Radioactivity Level) Index (I_γ), Activity Utilization

Index (AUI), Absorbed Dose Rate (D), Annual Gonad Dose Equivalent (AGDE), Annual Effective Dose Rate (AEDR) and Excess Lifetime Cancer Risk (ECLR) of virgin soils in the study areas are slightly higher than their corresponding values in agricultural/farm soil. This is due to the fact that farm soils are continuously being subjected to human activities for production of crops and this makes the level of ^{232}Th in farm soils to be lower than those recorded in virgin soils.

Table 5. Comparison of mean activity concentrations of natural radioactivity: ^{40}K, ^{238}U (^{226}Ra) and ^{232}Th in Uncultivated and Cultivated soils in the present study with similar research studies.

	Activity concentrations in soils						
Region/Country	**^{40}K**		**^{238}U /^{226}Ra**		**^{232}Th**		**Reference**
	Mean	**Range**	**Mean**	**Range**	**Mean**	**Range**	
Uncultivated Soils							
Malaysia/Kedah	136.98	87.10 – 180.56	65.24	42.67– 112.70	83.39	50.65– 133.38	Alzubaidi *et. al.*, (2016).
Malaysia/Penang	835.00		396.00		165.00		Almayahi *et. al*., (2012).
Malaysia/Pontian	293.00		37.00		53.00		Saleh *et. al*., (2013)
Malaysia/Kedah	125.66		51.06		78.44		Ahmad *et. al.*, (2015).
Nigeria/Kano	547.76	262.03-848.64	31.60	11.27 – 65.14	8.75	BDL – 25.11	Present Study
Cultivated (Farm) soils							
Malaysia (Kedah)	200.66		80.30		116.87		Ahmad *et. al.*, (2015).
India	124.00		64.00		93.00		Singh *et. al*., (2005)
Pakistan	602.00		30.00		56.00		Tufail *et. al.*, (2006)
Algeria	311.00		53.20		50.03		Boukhenfouf & Boucenna, (2011)
Egypt	183.00	22.00 – 319.00	43.00	5.70 – 140.00	54.00	9.00 – 139.00	Issa, 2013
Thailand	230.00	7.00 - 712.00	43.00	11.00 – 78.00	51.00	7.00 – 120.00	UNSCEAR, (2000)
Malaysia	310.00	170.00 – 430.00	66.00	49.00 – 86.00	82.00	63.00 – 110.00	UNSCEAR, (2000)
Greece	305.00	222.00 – 376.00	16.00	12.00 – 26.00	55.00	39.00 – 72.00	Ioannides *et. al*., (1997)
Malaysia/Kedah	325.87	202.20 – 529.17	102.08	58.93 – 166.55	133.96	87.98 – 180.45	Alzubaidi *et. al*., (2016)
Nigeria/Kano	509.51	249.01 – 1098.91	25.46	0.97 – 59.92	12.26	3.28 – 24.13	Present Study

4. Conslussion

Activity concentrations of ^{40}K and ^{238}U were found to be higher in uncultivated soils than those recorded in agricultural soils in majority (4 out of 6) of the study areas, while the concentrations of ^{232}Th uncultivated soils in five study locations, out of six, were less than values recorded in the farm (or agricultural) soils. All the estimated values of hazard indices indicators: H_{ex}; $H_{in.}$; I_{γ}; and AUI in all the sample locations for both the uncultivated soils and the agricultural soils are less than Unity, which is the maximum permissible limit for each of the parameters (UNSCEAR, 2000). However, slightly higher values of H_{ex}, $H_{in.}$, I_{γ}, and AUI were obtained in uncultivated soils in all the study areas than the ones obtained in agricultural soils. The average values of D, AGED, AEDE and ECLR in uncultivated soils (42.73 nGy.h^{-1}, 306.20 mSv.y^{-1}, 0.0524 mSv.y^{-1} and 0.119 x 10^{-3}) were equally slightly higher than those recorded in agricultural soils

(40.741 nGy.h^{-1}, 289.90 mSv.y^{-1}, 0.0500 mSv.y^{-1} and 0.113 x 10^{-3}), and they are all lower than their corresponding world average values of: 59.0 nGy.h^{-1}; 300 mSv.y^{-1}; 0.07 mSv.y^{-1} and 0.29 x 10^{-3} (UNSCEAR, 2000) with the exception of AGED values recorded in Bagwai and Wudil LGAs.

Conflict of Interest

The authors declare no conflict of interest.

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