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Activity Concentrations and Gamma Dose Rate Levels in Poultry Feeds and Manure used in Ibadan, Nigeria

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Abstract- Workers and dealers in poultry feeds, and commercial farmers may be exposed to elevated gamma radiation doses via internal and external exposure during handling of feeds and manure in farming operations. The measurement and evaluation of internal and external exposure to gamma radiation doses due to the distribution of activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in starter/grower poultry feeds, finisher poultry feeds and resulting poultry manure is therefore necessary from the radiation protection point of view. The measurement was done using Sodium Iodide activated with Thallium $\boldsymbol{NaI\ (Tl)}$ gamma–ray spectrometer. The mean activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in finisher poultry manure were 382.33±67.12 $\boldsymbol{Bq\,kg^{-1}}$ 8.92±3.48 $\boldsymbol{Bq\,kg^{-1}}$, 39.20±5.58 $\boldsymbol{Bq\,kg^{-1}}$ respectively, and in finisher poultry feeds were 284.31±27.46 $\boldsymbol{Bq\,kg^{-1}}$, 15.21±8.88 $\boldsymbol{Bq\,kg^{-1}}$, 38.43±4.08 $\boldsymbol{Bq\,kg^{-1}}$. The distribution of ^{226}Ra was more heterogeneous in all the samples than homogeneous distributions obtained in ^{40}K and ^{232}Th. The significant radiation exposure pathway to the farmers is from internal exposure due to inhalation of poultry and manure dust particles.

Keywords: *poultry feeds, poultry manure, primordial radionuclides, activity concentrations, effective radiation doses.*

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Activity Concentrations and Gamma Dose Rate Levels in Poultry Feeds and Manure used in Ibadan, Nigeria

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Abstract- Workers and dealers in poultry feeds, and commercial farmers may be exposed to elevated gamma radiation doses via internal and external exposure during handling of feeds and manure in farming operations. The measurement and evaluation of internal and external exposure to gamma radiation doses due to the distribution of activity concentrations of ^{40}K, ^{226}Ra and^{232}Th in starter/grower poultry feeds, finisher poultry feeds and resulting poultry manure is therefore necessary from the radiation protection point of view. The measurement was done using Sodium Iodide activated with Thallium $\boldsymbol{NaI(Tl)}$ gamma–ray spectrometer. The mean activity concentrations of ^{40}K, ^{226}Ra and^{232}Th in finisher poultry manure were 382.33±67.12 $\boldsymbol{Bq\,kg^{-1}}$, 8.92±3.48 $\boldsymbol{Bq\,kg^{-1}}$, 39.20±5.58 $\boldsymbol{Bq\,kg^{-1}}$ respectively, and in finisher poultry feeds were 284.31±27.46 $\boldsymbol{Bq\,kg^{-1}}$, 15.21±8.88 $\boldsymbol{Bq\,kg^{-1}}$, 38.43±4.08 $\boldsymbol{Bq\,kg^{-1}}$. The distribution of ^{226}Ra was more heterogeneous in all the samples than homogeneous distributions obtained in ^{40}K and ^{232}Th. The significant radiation exposure pathway to the farmers is from internal exposure due to inhalation of poultry and manure dust particles. The mean annual effective dose of 3.62±0.23 $\boldsymbol{\mu Sv\,y^{-1}}$, 3.73±0.38 $\boldsymbol{\mu Sv\,y^{-1}}$, 2.25±0.23 $\boldsymbol{\mu Sv\,y^{-1}}$ were obtained for starter/grower feeds, finisher feeds, and finisher poultry manure respectively. The total annual effective dose calculated from the three major pathways for finisher poultry manure (2.94±0.48 $\boldsymbol{\mu Sv\,y^{-1}}$) were lower than the results obtained for starter/grower (4.70±0.37 $\boldsymbol{\mu Sv\,y^{-1}}$) and finisher feeds (4.80±0.64 $\boldsymbol{\mu Sv\,y^{-1}}$). Lower values of internal and external dose rate ($\boldsymbol{\mu Sv\,y^{-1}}$) of the samples showed that workers, dealers in poultry feeds, and commercial farmers are not significantly exposed to elevated gamma doses. A very weak and negative linear relationships in the activity concentrations was found between finisher poultry manure and finisher poultry feed for ^{40}K and ^{40}K ($\boldsymbol{R = 0.16}$); ^{226}Ra and ^{226}Ra ($\boldsymbol{R = 0.19}$); and between ^{232}Th and ^{232}Th ($\boldsymbol{R = 0.29}$). This is an indication that the radionuclide contents in poultry feeds contributed but not significantly to the level of radionuclides in poultry manure.

Keywords: poultry feeds, poultry manure, primordial radionuclides, activity concentrations, effective radiation doses.

I. Introduction

Most farm crops such as maize, wheat, and beans mixed with some ingredients like crayfish, fishmeal and bone meal are importantly used in processing animal feeds. Organic manure and chemical fertilizers are applied to farm soil to replenish the lost nutrients which as a consequence boost the crop yield. Crops harvested from fertilized farm soil used in the manufacturing of poultry feeds may contain elevated doses of ionizing radiation due to the activity concentrations of natural radionuclides present in the materials. Dealers and users of the products, commercial farmers, as well as poultry workers may significantly be exposed to elevated doses of ionizing radiation. This has created undue anxiety among people especially those who are not in the field of environmental radioactivity. The possible pathways of exposure to radiation doses are internal exposure via inhalation and external exposure through handling, packing in bags, transportation, and application to farm soil. Sometimes, accidental internal exposure due to ingestion is likely possible from feeds and manure particles during handling.

Studies on environmental radioactivity have reported ^{40}K, ^{226}Ra and^{232}Th radionuclides in rocks, soil, farm soil and soil of quarry sites (Jankovic *et al.,* 2008; Jibiri *et al.,* 2009; Okeyede *et al.,* 2014; Feroz *et al.,* 2015; Faanu *et al.,* 2016), solid minerals (Ademola *et al.,* 2014; Kolo *et al.,* 2016), food crops and vegetables (Jibiri *et al.,* 2007; Ghosh *et al.,* 2011 Avwiri *et al.,* 2013; Tchokossa *et al.,* 2013), surface and ground water (Aziz *et al.,*2014; Aydan *et al.,* 2015; Ogundare and Adekoya, 2015) and agrochemicals for crop production (Saueia and Mazzilli, 2006; Ibeanu *et al.,* 2009; Tahir *et al.,* 2009; Jibiri and Fasae, 2012; Alharbi, 2013).

In other countries, Boukhenfouf and Boucenna (2011) for ^{226}Ra, ^{232}Th and ^{40}K radionuclides in NPK fertilizer one (1) and NPK fertilizer two (2) collected from Outlying Setif region Algeria, found 134.7±14.1 $Bq\,kg^{-1}$, 131.8±16.7 $Bq\,kg^{-1}$, 11644±550 $Bq\,kg^{-1}$ and 190.3±30 $Bq\,kg^{-1}$, 117.2±10.3 $Bq\,kg^{-1}$, 5321±249 $Bq\,kg^{-1}$ respectively. El –Taher and Althoyaib (2011) established that activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in natural fertilizers from cow, sheep, and chicken were lower than corresponding

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values in chemical fertilizers used in Kingdom of Saudi Arabia; also the range of Ra_{eq} in chemical fertilizers (100. 37 to 161.43 $Bq\,kg^{-1}$) and organic fertilizers (34 .07 to 102.19 $Bq\,kg^{-1}$) were lower than the standard limit of 370 $Bq\,kg^{-1}$ (Beretka and Mathew, 1985). Alharbi *et al.* (2013) in Saudi Arabia established mean activity of 31.6±1.6 $Bq\,kg^{-1}$, 6.3±0.3 $Bq\,kg^{-1}$, 277.3±12 $Bq\,kg^{-1}$ for ^{226}Ra, ^{232}Th and ^{40}K radionuclides and, absorbed dose rate and annual outdoor effective dose of 28.6 $\eta Gy\,h^{-1}$ and 0.03 $mSv\,y^{-1}$ for sheep fertilizer manure; corresponding result of 41.14±1.7 $Bq\,kg^{-1}$, 7.5±0.3 $Bq\,kg^{-1}$, 284.5±8 $Bq\,kg^{-1}$, 35.3 $\eta Gy\,h^{-1}$, 0.04 $mSv\,y^{-1}$ for cow fertilizer; and 54.2±1.3 $Bq\,kg^{-1}$, 16.9±3 $Bq\,kg^{-1}$, 410.7±14 $Bq\,kg^{-1}$, 51.0 $\eta Gy\,h^{-1}$, 0.06 $mSv\,y^{-1}$ respectively for natural organic.

In Nigeria, Ibeanu *et al.* (2009) reported high activity concentration of ^{40}K and ^{226}Ra in Nitrogen Phosphorus and potassium fertilizers (NPK 15 – 15 – 15, and NPK 16 – 16 – 16 – 16) than cow dropping and chicken droppings. Jibiri and Fasae (2012) recorded the high activity of concentrations of ^{40}K in NPK fertilizers comparable to the work of Ibeanu *et al.* (2009) in Zaria, Kaduna State. Njing *et al.* (2016) found gross alpha and gross beta activity concentrations of 0.262±0.052 $Bq\,kg^{-1}$ and 3.210±1.636 $Bq\,kg^{-1}$ in goat dung (manure) sold in Turaku area of Minna, Niger State, Nigeria. The scarcity of available data set and limited information on internal and external ionizing radiation doses received by dealers of poultry feeds, poultry workers, and farmers in the use of poultry manure for crop production necessitated the need for the study. Hence, it was carried out to fill in the gap in the existing knowledge on internal and external exposure to radiation doses emanating from the materials.

The study whose focus was on poultry feeds and poultry manure was aimed at providing the information on the concentrations of radionuclide ^{40}K, ^{226}Ra and^{232}Th in poultry feeds and poultry manure and to evaluate the associated internal and external exposure to the handlers. The objectives were (i) to evaluate if poultry workers, farmers, and dealers of these products are really exposed to high doses of ionizing radiation doses due to internal and external exposure; (ii) to determine whether the poultry manure collected in this study could be a less radionuclide content than other organic manure and chemical fertilizer reported in the literature; (iii) to provide the data and relevant radiometric information needed for future references and further studies in poultry manure management.

II. Materials and Method

a) Sample collection

In order to ensure that sampling relatively covers a good number of the poultry feeds, a pre–field survey was carried out to identify common poultry feed purchased by poultry farmers and major marketers for their poultry business. Twenty seven (27) samples comprising of nine (9) Starter/grower feeds, nine (9) finisher poultry feeds and consequent nine (9) finisher manures were randomly purchased and used for this study. The poultry feed were produced in Abeokuta, Ogun State; a high background radiation area in Southwestern Nigeria (Jibiri *et al.*, 2010; Okedeye *et al.*, 2014), and distributed to local marketers in Bodija Market in Ibadan, Oyo State. While finisher poultry manure were purchased from Student Research Farm at the University of Ibadan, Ibadan, Nigeria.

b) Sample preparation

The poultry feeds and manure samples were collected in nylon bags and properly labeled. They were then taken to the laboratory where they were dried in an oven at temperature of 90℃ for 2 hours each to maintain constant weight. The dried samples were pulverized, homogenized and allow to pass through ~ 1.5 mm mesh sieve, weighed about 200 g each and packed into empty plastic containers which was earlier certified to be non – radioactive. The sample containers were of uniform size 66 mm height by 62 mm diameter which fitted well in the detector holder. Thereafter the sample containers were hermetically sealed and kept in the laboratory for a period of about 30 days to enable the short–lived members of uranium and thorium series attain secular radioactive equilibrium prior to gamma counting.

c) Radioactivity measurements

A well calibrated, 7.60 cm × 7.60 cm $NaI(Tl)$ gamma–ray spectrometry detector enclosed in thick lead–shied to reduce the effects of laboratory background radiation was used as the set – up for radionuclide measurements. The detector was earlier used by Jibiri *et al.* (2010) in the measurement of radionuclides in water samples in high background radiation area of Abeokuta, Nigeria. It was coupled with a computer–based Multichannel Analyser (MCA) which was used for data acquisition and analysis of gamma spectra. The detector has a resolution of 8% at 0.665 MeV gamma line of ^{137}Cs, capable of distinguishing the gamma–ray energies of the radio nuclides of interest in this work.

To ensure that the radiation indices or parameters in the poultry feed and poultry manure samples could be expressed in physical radiometric units, two stages of calibration was done before the detector was used for analyses; these are energy calibration and efficiency calibration which was done using reference standard source materials. The energy calibration converts channel numbers to gamma–ray energy in MeV. This was carried out by placing different gamma sources of known energy or energies on the detector after a preset time of 900 seconds (15 minutes). The channel numbers of the various photopeaks corresponding to the gamma energies were identified and recorded. The reliability of the measuring instrument (detector) was determined from the regression plot ($R^2 = 0.99$) of channel number versus corresponding energies which gave correlation coefficient value of $R = 0.99$, considered very strong enough. The efficiency calibration was carried out to determine the gamma–ray counting efficiencies using a set of gamma sources of known radio nuclides supplied by the International Atomic Energy Agency (IAEA) Vienna, with well-defined energies (0.511 – 2.615 MeV) within the range of interest. This was carried out by converting the count per seconds (cps) under the photopeaks to activity concentrations in $Bq\,kg^{-1}$.

The counting time for accumulating the spectral for both background and samples was 36, 000 s which was good enough for the detector to analyze the spectrum with peaks of interest clearly shown and well distinguished (Jibiri *et al.,* 2010; Isinkaye and Emelue, 2015). Each of the empty containers as well as the containers that contained the samples was placed directly in the detector holder to determine the net count. The processes followed that; the background count was determined by counting an empty container of the same dimension as those containing the poultry feed and poultry manure samples. The gross count was also determined by counting the pulverized samples inside plus that of empty container. Thereafter, the net count was determined by subtracting the background count from the gross count. Both the background count and gross count were repeated at regular interval for quality control while each sample was counted for 36, 000 seconds to reduce the statistical uncertainty (Ademola *et al.,* 2014).

d) *Determination of Activity Concentrations of the Radionuclides*

The activity concentrations of ^{40}K in the individual poultry feeds and manure samples was determined by measuring the 1.460 MeV gamma–ray line of ^{40}K emitted during it decay, the activity of ^{226}Ra was estimated from 1.765 MeV gamma–ray line of ^{214}Bi while 2.165 MeV gamma–ray line of ^{208}Tl was used for the determination of activity concentration of ^{232}Th. The count rate under the photopeaks of each of the three radionuclides of interest is related to activity concentrations of the samples using equation 1 (Ademola *et al.,* 2014; Isinkaye and Emelue, 2015).

$$A_c = \frac{C_n}{P_\gamma\, M\, \varepsilon} \tag{1}$$

Where A_c, is the activity concentration of the radionuclide in each of the samples measured in $Bq\,kg^{-1}$, C_n is the net count rate under the corresponding peak, P_γ is absolute transition probability of the specific gamma ray, M is the mass of the sample (kg), and ε is the detector efficiency at specific gamma ray energy.

III. RESULTS

Table 1 presents the energy gamma line and minimum detection activity (MDA) for the radio nuclides of interest. Table 2 presents the dose coefficient and some risk parameters for radionuclide of interest adopted in this work. Descriptive statistical results for the activity concentrations of radio nuclides ^{40}K, ^{226}Ra, and ^{232}Th contained in starter/grower poultry feeds, finisher poultry feeds and finisher poultry manure were presented in Tables 3 to 5 respectively. Figures 1 to 3 represent the frequency distribution histogram of ^{40}K, ^{226}Ra, and ^{232}Th radio nuclides for starter/grower poultry feeds; Figure 4 to 6 represented the frequency distribution histogram ^{40}K, ^{226}Ra, and ^{232}Th radio nuclides for finisher poultry feeds, while Figure 7 to 9 represent the frequency distribution histogram ^{40}K, ^{226}Ra, and ^{232}Th radio nuclides for finisher poultry manure respectively. The frequency distribution histogram and curves were acquired from Software Package for Social Sciences (SPSS) version 20.0.

Table 1: Energy Gamma Line and Minimum Detection Activity (MDA) for Radio nuclides of interest

Radio nuclides of Interest	Energy (MeV)	Conversion Factor	Minimum Detection Activity, MDA ($Bq\,kg^{-1}$)
^{40}K	1.460	0.075	9.67
^{226}Ra	1.765	0.061	3.06
^{232}Th	2.615	0.029	3.00

a) *Estimation of Annual Effective Doses (Internal and external exposures)*

During handling, packing of materials in bags, transportation of poultry feeds and application of poultry manure to farm soil workers are exposed to ionizing radiation doses present in the material through three major pathways: external exposure to gamma–ray during the packing in bags and handling of the materials, internal exposure from inhalation of dust and contaminated air due to the practice and possible internal exposure from any accidental ingestion of the materials. These computed doses are summed up to get the total effective doses delivered by ^{40}K, ^{226}Ra and ^{232}Th radionuclides.

The ionizing radiation impacted on exposed workers, marketers and farmers through these exposure pathways were estimated from the activity concentrations of radionuclides ^{40}K, ^{226}Ra and ^{232}Th in different samples investigated. This was carried out by applying relevant conversion coefficient doses supply by the International Commission on Radiological Protection (ICRP). According to Kolo *et al.* (2016), the health risk of any adverse induced radiation exposure is dependent on the total effective dose. The dose from external exposure to gamma radiation is estimated from equation 2 (Mustapha *et al.*, 2007; Ademola and Oyema, 2014):

$$D_{Ext} = \sum_i A_i\, C_{Ext,\ i}\, T_{exp} \qquad (2)$$

Where A_i is the activity concentrations of nuclide, i $(Bq\, kg^{-1})$, $C_{Ext,\ i}$ is the effective dose coefficient for nuclides, i as presented in Table 2, T_{exp} is the duration of exposure in number in a year. For a poultry worker and markers who work for eight (8) hours per day in twenty (20) working days per month, the duration of exposure per year is therefore calculated as 20 × 8 × 12 which equals 1920 hours per year. In this study, we assume that for a farmer who works for 8 hours per day for three (3) days per a week which gives a total of twelve (12) days per month. The duration of exposure for such farmer per year is thus given as 12 × 8 × 12 which equals 1152 hours per year as presented in Table 2.

Internal exposure from inhalation of poultry/manure dust and contaminated air due to the practice was calculated using equation 3 (Mustapha *et al.*, 2007)

$$D_{Inh} = \sum_i A_i\, C_{Inh,\ i}\, \eta_{Inh} D_f\, T_{exp} \qquad (3)$$

Where A_i is the activity concentrations of nuclide, i $(Bq\, kg^{-1})$, T_{exp} is the duration of exposure in number of years (which for this study, has been corrected for 1920 for poultry feeds exposure and 1152 for poultry manure exposure), $C_{Inh,\ i}$ is the dose coefficient for inhalation of nuclide i measured in ${Sv}/{Bq}$, η_{Inh} is the breathing rate measured in ${m^3}/{h}$ with coefficient of 1.69 (Mustapha *et al.*, 2007) and D_f is the dust loading factor measured in ${g}/{m^{-3}}$ with coefficient of 1.0×10^{-3} (Degrand and Lepicard, 2005).

Internal dose from accidental ingestion of radionuclides was calculated from equation 4 (Kolo *et al.*, 2016)

$$D_{Ing} = \sum_i A_I C_{Ing,\ i}\, \eta_{ing}\, T_{exp} \qquad (4)$$

Where A_i is the activity concentrations of nuclide i $(Bq\, kg^{-1})$, $C_{Ing,\ i}$ is the dose coefficient for ingestion of nuclide, i, measured in ${Sv}/{Bq}$, η_{ing} is the ingestion rate for adults, measured in ${kg}/{h}$ whose value is 5.0×10^{-6} (Mustapha *et al.*, 2007) and T_{exp} is the duration of exposure in a years, which for this study has been corrected for 1920 for poultry feeds exposure and 1152 for poultry manure exposure.

Table 2: Dose coefficient and some risk parameters for radionuclide of interest adopted in this work

Dose coefficient parameters	^{40}K $(Bq\, kg^{-1})$	^{226}Ra $(Bq\, kg^{-1})$	^{232}Th $(Bq\, kg^{-1})$	T$_{exp}$ $(h\, y^{-1})$	References
Effective dose coefficient, C$_{ext}$ $(\eta Sv\, h^{-1}/Bq\, kg^{-1})$	1.175	9.929	0.003		Mustapha *et al.* (2007)
Dose coefficient for inhalation, C$_{Inh}$ $(Sv\, Bq^{-1})$	3.0 E-09	2.2 E-06	2.9 E-05		1CRP, 119 (2012)
Dose coefficient for ingestion C$_{Ing}$ $(Sv\, Bq^{-1})$	6.2 E-09	2.8 E-07	2.2 E-07		1CRP, 119 (2012)
Duration of exposure for poultry workers				1920*	
Duration of exposure for commercial farmers				1152**	

Source: Kolo et al. (2016), except for 1920 and 1152** which were computed for this study*

Table 3: Some descriptive statistics of radionuclides and dose rates for starter/grower poultry feeds

Statistics	Minimum value	Maximum value	Mean	Standard Deviation	Coefficient of variation (CV)
^{40}K ($Bq\,kg^{-1}$)	339.29±17.27	388.35±19.76	362.87	16.28	0.04
^{226}Ra ($Bq\,kg^{-1}$)	3.28±6.88	14.62±4.02	7.15	4.13	0.58
^{232}Th ($Bq\,kg^{-1}$)	33.33±0.53	41.18±0.55	37.92	2.28	0.06
$D_{Ext.}$ ($\mu Sv\,y^{-1}$)	0.83	1.16	0.96	0.12	0.13
$D_{Inh.}$ ($\mu Sv\,y^{-1}$)	3.16	3.98	3.62	0.23	0.06
$D_{Ing.}$ ($\mu Sv\,y^{-1}$)	0.09	0.15	0.12	0.02	0.17
Total annual effective dose ($\mu Sv\,y^{-1}$)	**4.08**	**5.29**	**4.70**	**0.37**	**0.08**

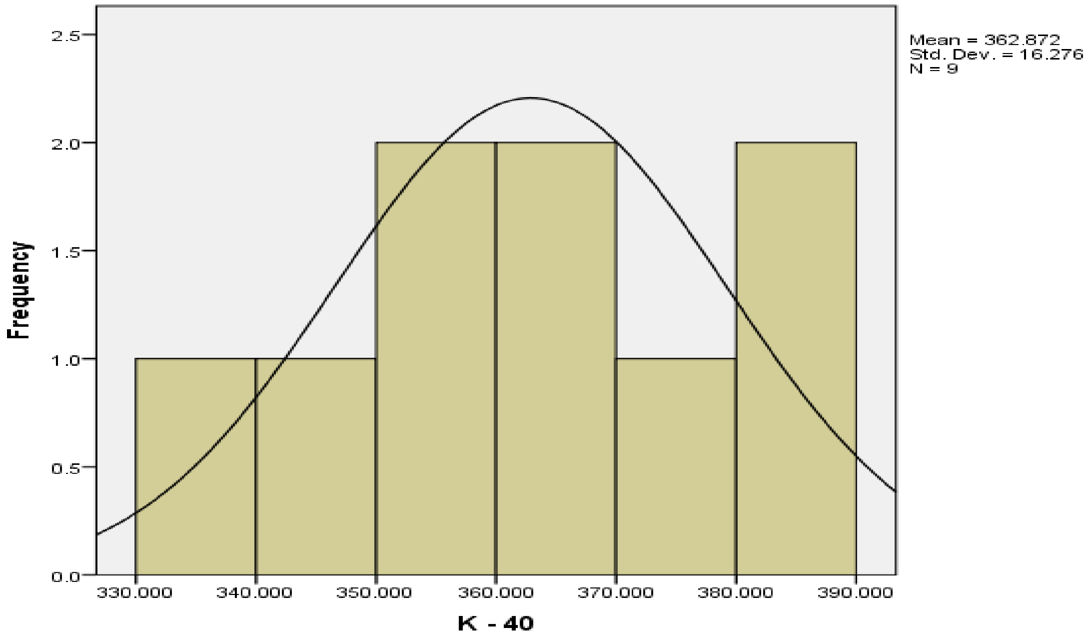

Figure 1: Frequency distribution histogram for activity concentration of ^{40}K in $Bq\,kg^{-1}$ for starter/grower poultry feeds

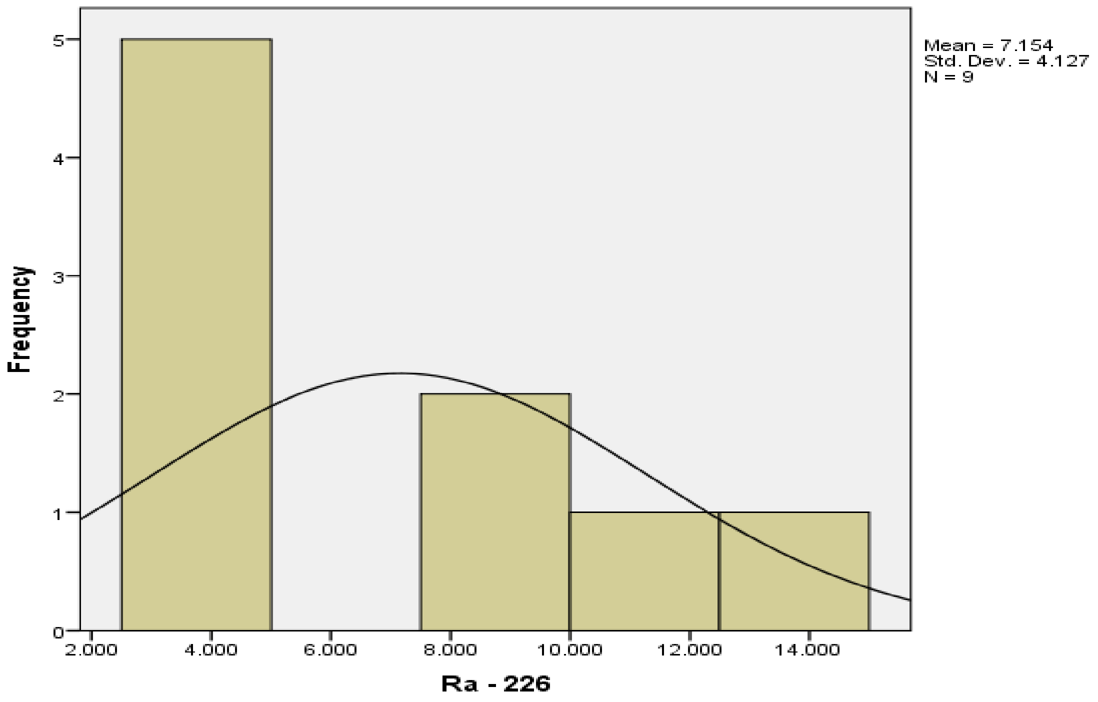

Figure 2: Frequency distribution histogram for activity concentration of ^{226}Ra in $Bq\ kg^{-1}$ for starter/grower poultry feeds

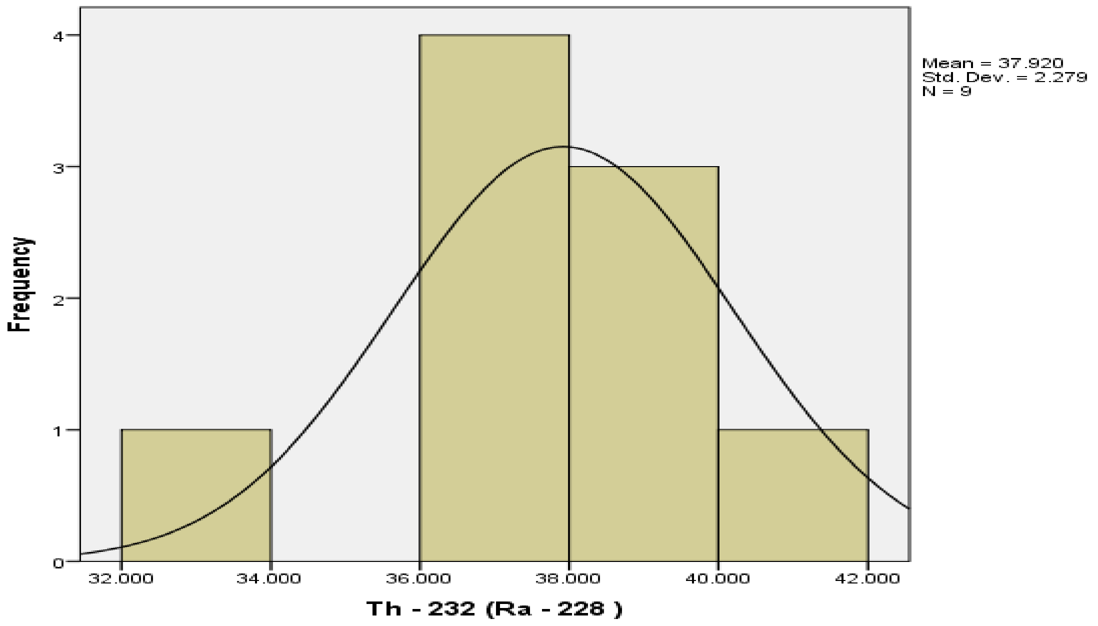

Figure 3: Frequency distribution histogram for activity concentration of ^{232}Th (^{228}Ra) in $Bq\ kg^{-1}$ for starter/grower poultry feeds

Table 4: Some descriptive statistics of radio nuclides and dose rates for finisher poultry feeds

Statistics	Minimum value	Maximum value	Mean	Standard Deviation	Coefficient of variation (CV)
^{40}K ($Bq\,kg^{-1}$)	269.66±13.73	353.24±17.98	284.31	27.46	0.01
^{226}Ra ($Bq\,kg^{-1}$)	3.82±11.06	29.42±3.24	15.21	8.88	0.58
^{232}Th ($Bq\,kg^{-1}$)	33.33±0.53	44.59±0.57	38.43	4.08	0.11
$D_{Ext.}$ ($\mu Sv\,y^{-1}$)	0.68	1.36	0.93	0.23	0.25
$D_{Inh.}$ ($\mu Sv\,y^{-1}$)	3.17	4.41	3.73	0.38	0.10
$D_{Ing.}$($\mu Sv\,y^{-1}$)	0.10	0.19	0.14	0.03	0.21
Total annual effective dose ($\mu Sv\,y^{-1}$)	3.95	5.96	4.80	0.64	0.56

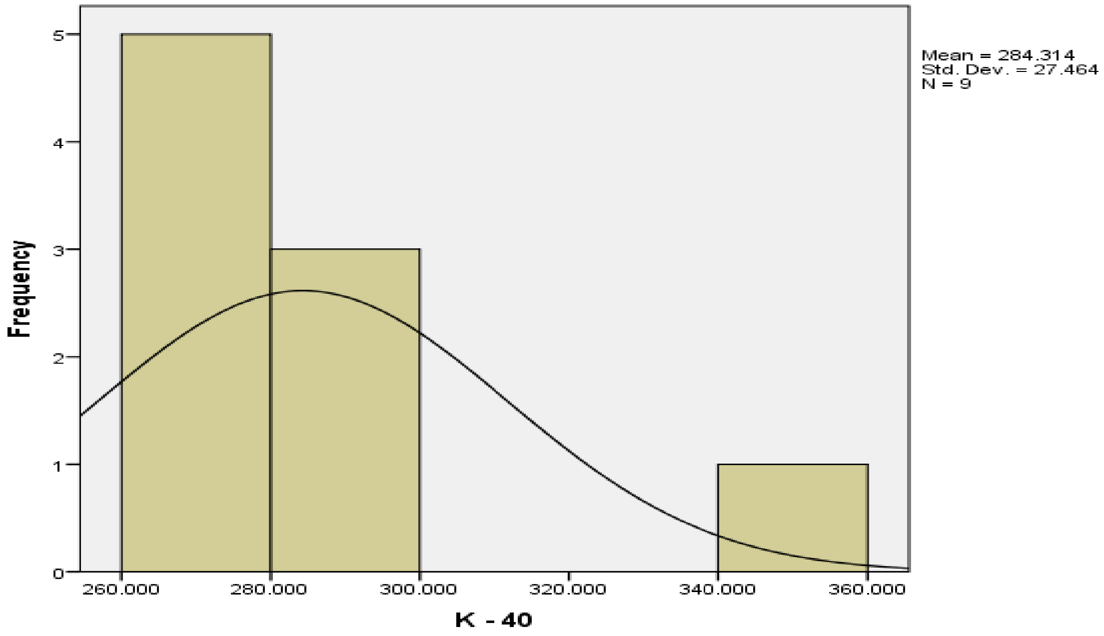

Figure 4: Frequency distribution histogram for activity concentration of ^{40}K in $Bq\,kg^{-1}$ for finisher poultry feeds

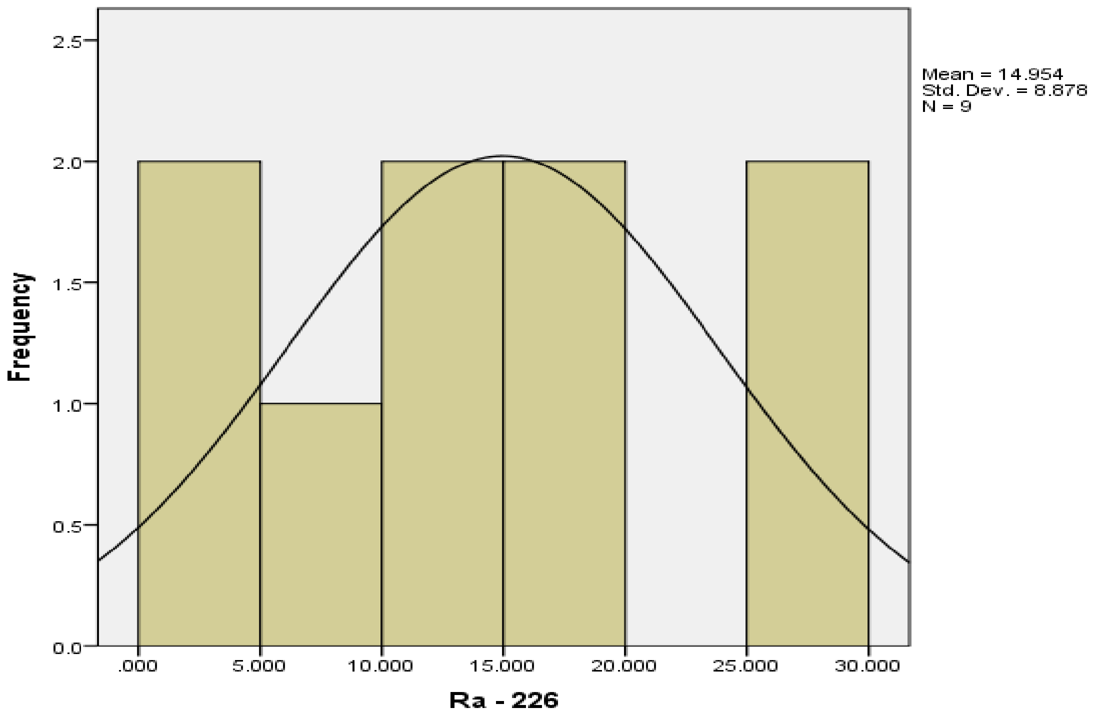

Figure 5: Frequency distribution histogram for activity concentration of ^{226}Ra in $Bq\,kg^{-1}$ for finisher poultry feeds

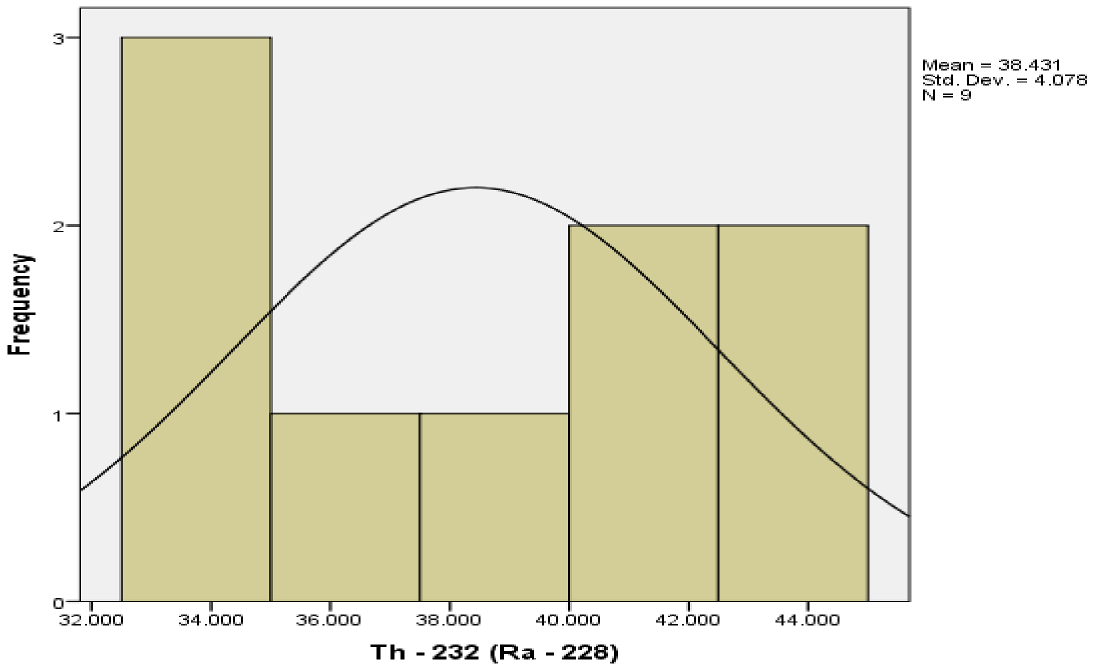

Figure 6: Frequency distribution histogram for activity concentration of ^{232}Th (^{228}Ra) in $Bq\,kg^{-1}$ fo finisher poultry feeds

Table 5: Some descriptive statistics of radionuclides and dose rates for finisher poultry manure

Statistics	Minimum value	Maximum value	Mean	Standard Deviation	Coefficient of variation (CV)
^{40}K $(Bq\,kg^{-1})$	288.04±14.64	509.68±25.93	382.33	67.12	0.18
^{226}Ra $(Bq\,kg^{-1})$	4.43±6.39	14.74±6.14	8.92	3.48	0.39
^{232}Th $(Bq\,kg^{-1})$	28.83±0.54	46.14±0.63	39.20	5.58	0.14
$D_{Ext.}$ $(\mu Sv\,y^{-1})$	0.44	0.86	0.61	0.13	0.21
$D_{Inh.}$ $(\mu Sv\,y^{-1})$	1.65	2.67	2.25	0.33	0.15
$D_{Ing.}$ $(\mu Sv\,y^{-1})$	0.05	0.10	0.08	0.02	0.25
Total annual effective dose $(\mu Sv\,y^{-1})$	2.14	3.63	2.94	0.48	0.16

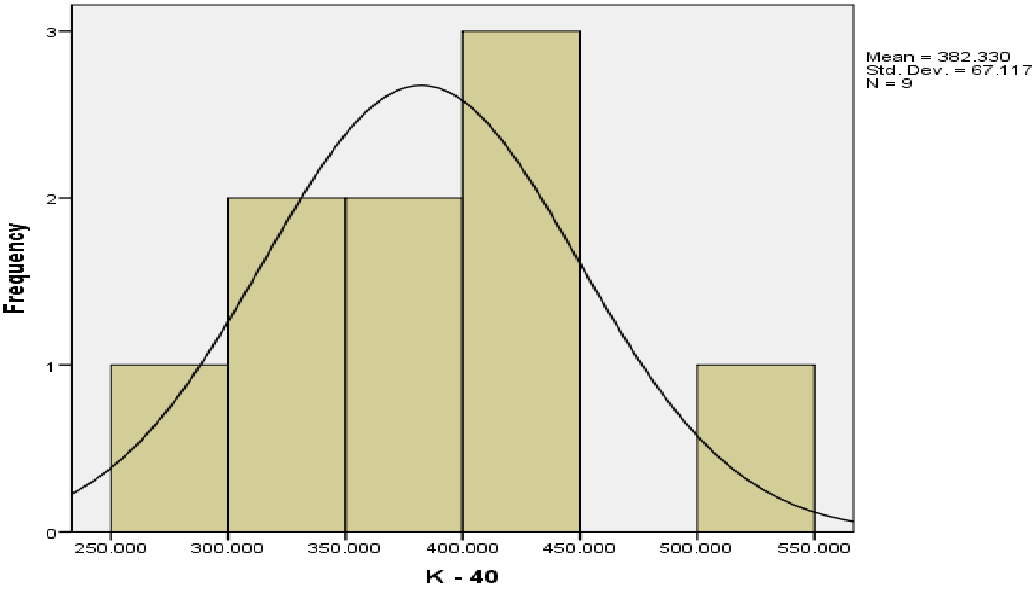

Figure 7: Frequency distribution histogram for activity concentration of ^{40}K in $Bq\,kg^{-1}$ fo finisher poultry manure

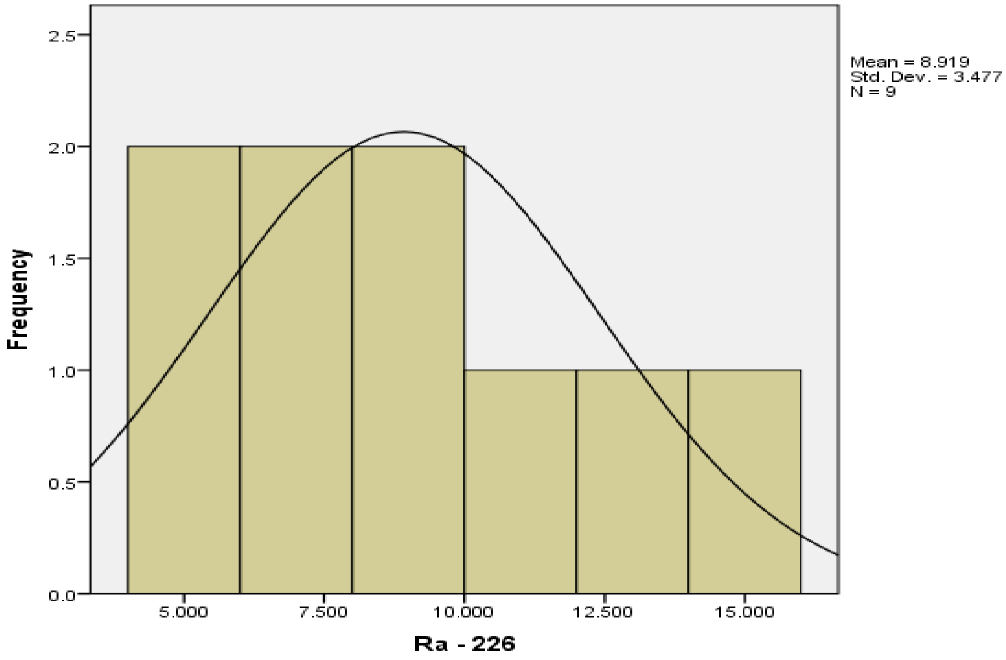

Figure 8: Frequency distribution histogram for activity concentration of ^{226}Ra in $Bq\,kg^{-1}$ fo finisher poultry manure

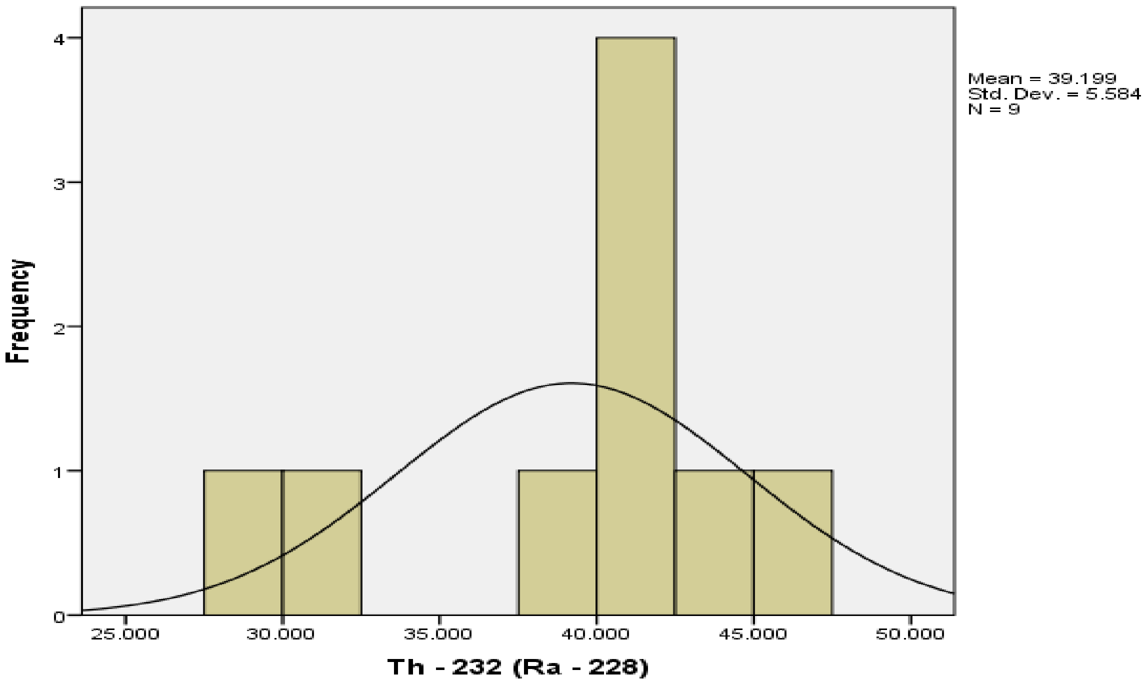

Figure 9: Frequency distribution histogram for activity concentration of ^{232}Th (^{228}Ra) in $Bq\ kg^{-1}$ fo finisher poultry manure

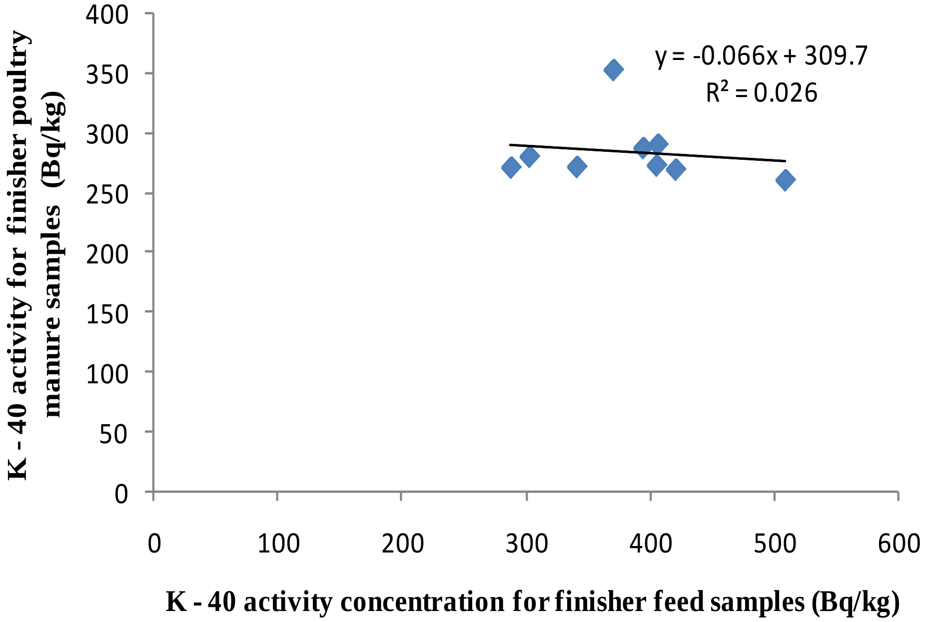

Figure 10: Regression plot to determine correlation coefficient between ^{40}K and ^{40}K for poultry manure and poultry feeds

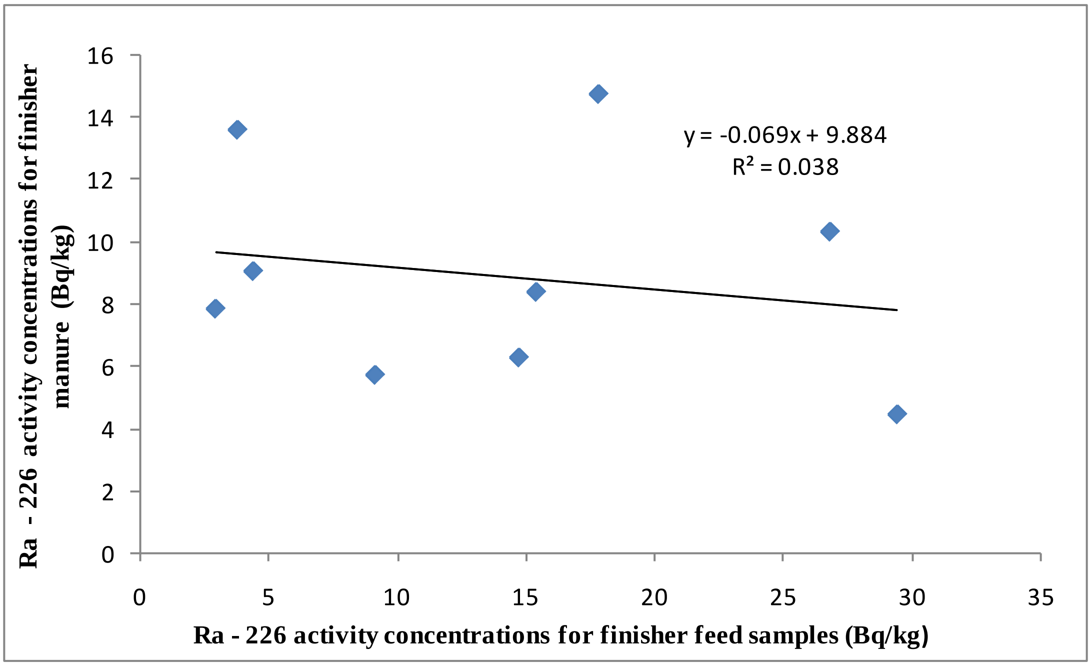

Figure 11: Regression plot to determine correlation coefficient between ^{226}Ra and ^{226}Ra for poultry manure and poultry feeds

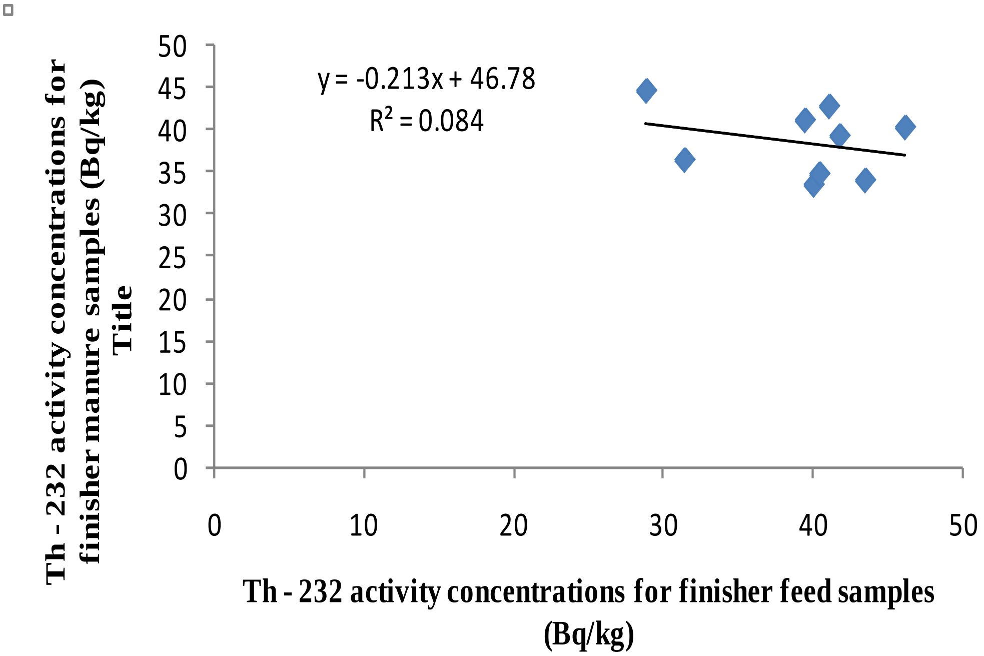

Figure 12: Regression plot to determine correlation coefficient between ^{232}Th and ^{232}Th for poultry manure and poultry feeds

IV. DISCUSSION

a) *Range, mean, standard deviations and coefficient of variation for Radionuclides*

The range of activity concentrations obtained in starter/grower feed samples for ^{40}K, ^{226}Ra, and ^{232}Th radionuclides respectively presented in Table 3 were from 339.29 to 388.35 $Bq\ kg^{-1}$; 3.28 to 14.63 $Bq\ kg^{-1}$; 33.33 to 41.18 $Bq\ kg^{-1}$, with mean and standard deviation of 362.87±16.28 $Bq\ kg^{-1}$; 7.15±4.13 $Bq\ kg^{-1}$; and 37.92±2.28 $Bq\ kg^{-1}$ respectively. The distribution of ^{226}Ra (CV = 0.58) was observed to be more varied than ^{40}K (CV = 0.04) and ^{232}Th (CV = 0.06) radionuclides in the starter/grower feed samples.

As Observed from Table 4, the activity concentrations obtained in finisher feed samples for ^{40}K, ^{226}Ra, and ^{232}Th radionuclides respectively ranged from 269.66 to 353.25 $Bq\,kg^{-1}$; 3.82 to 29.42 $Bq\,kg^{-1}$; 33.33 to 44.59$Bq\,kg^{-1}$, with mean and standard deviation of 284.31±27.46 $Bq\,kg^{-1}$; 15.21±8.88 $Bq\,kg^{-1}$; and 38.43±4.08 $Bq\,kg^{-1}$ respectively. The distribution of ^{226}Ra (CV = 0.59) was observed to be more dispersed than ^{40}K (CV = 0.01) and^{232}Th (CV = 0.11) radionuclides in the finisher feed samples.

As shown in Table 5, the activity concentrations obtained in finisher poultry manure samples for ^{40}K, ^{226}Ra, and ^{232}Th radionuclides respectively ranged from 288.04 to 509.68 $Bq\,kg^{-1}$; 4.43 to 14.74 $Bq\,kg^{-1}$; 28.83 to 46.14 $Bq\,kg^{-1}$, with mean and standard deviation of 382.33±67.12 $Bq\,kg^{-1}$; 8.92±3.48 $Bq\,kg^{-1}$; and 39.20±5.58 $Bq\,kg^{-1}$ respectively. Observation from the table showed the distribution of ^{226}Ra (CV = 0.39) was widely spread than ^{40}K and ^{232}Th radionuclides in the finisher feed samples.

Observation from Tables 3, 4 and 5 revealed finisher poultry manure contained the highest ^{40}K activity (382.33±67.12 $Bq\,kg^{-1}$) while the lowest was found in finisher poultry feeds (284.31±27.46 $Bq\,kg^{-1}$). Also, finisher poultry feeds recorded the highest ^{226}Ra activity concentrations (15.21±8.88 $Bq\,kg^{-1}$) among the three materials investigated while the lowest was found in starter/grower feeds (7.15±4.13 $Bq\,kg^{-1}$). While the activity concentrations of ^{232}Th radionuclides in the three materials were highest in finisher poultry manure (39.20±5.58 $Bq\,kg^{-1}$) with the lowest result obtained in starter/grower feed samples (37.92±2.28 $Bq\,kg^{-1}$). Radionuclide content of ingredient used in processing the feeds, the lithology and geochemical composition of agricultural farm soil from where the materials were sourced could likely be a major contributor to radionuclides found in the materials.

The mean result for ^{40}K contained in finisher poultry manure was found higher than 277.3±12 $Bq\,kg^{-1}$, and 284.5±8 $Bq\,kg^{-1}$ reported in Sheep and Cow fertilizers in Saudi Arabia (Alharbi, 2013); BDL and 336.3±13.9 $Bq\,kg^{-1}$ established in Chicken droppings and Cow droppings collected from Zaria, Kaduna State (Ibeanu *et al.,* 2009). However, the mean activity concentrations of ^{226}Ra found in the poultry manure were lower than the corresponding 31.6±1.6 $Bq\,kg^{-1}$ and41.1±1.7 $Bq\,kg^{-1}$ recorded in Sheep and Cow fertilizer in Saudi Arabia (Alharbi, 2013), and 134.7±24.1 $Bq\,kg^{-1}$ and 190.3±30 $Bq\,kg^{-1}$ contained in Chicken droppings and Cow droppings obtained in Zaria, Kaduna State, Nigeria (Ibeanu *et al.,* 2009). Though the poultry manure contains some levels of ^{40}K, ^{226}Ra and ^{232}Th radionuclides, its application to farm soil may not significantly increase the radioactivity levels.

b) Total mean annual effective dose

The levels of total mean annual effective doses were directly associated with the activity concentrations of radionuclides in the poultry feeds and poultry manure samples. The calculated effective dose due to external exposure to the two poultry feeds ranged from 0.68 $\mu Sv\,y^{-1}$ (finisher poultry feeds) to 1.36 $\mu Sv\,y^{-1}$ (finisher poultry feeds) with the mean and standard deviation of 0.93±0.23 $\mu Sv\,y^{-1}$; while for finisher poultry manure it ranged from 0.44 $\mu Sv\,y^{-1}$ to 0.86 $\mu Sv\,y^{-1}$ with the mean and standard deviation of 0.61±0.13 $\mu Sv\,y^{-1}$. The effective dose delivered to the workers, dealers of the two poultry feeds via inhalation pathway ranged from 3.16 $\mu Sv\,y^{-1}$ (starter poultry feeds) to 4.41 $\mu Sv\,y^{-1}$ (finisher poultry feeds) with the mean of 3.68±0.31 $\mu Sv\,y^{-1}$; while for finisher poultry manure, it ranged from 1.65 $\mu Sv\,y^{-1}$ to 2.67 $\mu Sv\,y^{-1}$ with the mean and standard deviation of 0.08±0.02 $\mu Sv\,y^{-1}$. Mean effective doses from accidental ingestion for starter/grower poultry feeds (0.12±0.02 $\mu Sv\,y^{-1}$), finisher poultry feeds (0.14±0.03 $\mu Sv\,y^{-1}$) and finisher poultry manure (0.08±0.02 $\mu Sv\,y^{-1}$) were considered to be in good agreement. The most significant radiation exposure pathway in all the three materials investigated as observed in Tables 3, 4, and 5 was the internal exposure from inhalation of poultry feeds dust particles associated with air. Considering the distribution of the total mean annual effective dose due to internal and external exposures, workers in poultry environment and dealers of poultry feeds are more exposed to radiation risk than farmers in farm soil environment. Relatively lower values of internal and external doses rate ($\mu Sv\,y^{-1}$) of the samples investigated showed that workers, dealers in poultry feeds, and commercial farmers are not significantly exposed to elevated gamma doses.

c) Frequency histogram distribution, skewness, and kurtosis

Figures 1 to 9 showed the distributions of frequency histogram of activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th radionuclides respectively in starter/grower poultry feeds, finisher poultry feeds and finisher poultry manure. Skewness is a measure of asymmetry or departure from the symmetry of distribution while kurtosis measures the tailedness (outliers) of the probability distribution. Close observation showed that about 77.8% of the distributions was moderately symmetric (bell–shape) while 22.2% was asymmetric about the mean. Few of the frequency distribution curves were heavy–tailed, while others were light – tailed.

d) Regression and correlation analysis

To find out the strength and degree of associations between the pair of radionuclides for poultry feeds and poultry manure, correlation studies were carried out between each pair of radionuclides.

The regression analyses were between ^{40}K and ^{40}K; ^{226}Ra and ^{226}Ra; and ^{232}Th and ^{232}Th activity concentrations of finisher poultry manure and feed respectively. The scatter plots from the regression analyses are shown in Figures 10, 11 and 12 respectively. Close observation from plots revealed very weak and negative linear association/relationship existed between the activity concentrations for finisher poultry manure and finisher poultry feed for ^{40}K and ^{40}K $(R = 0.16)$; ^{226}Ra and ^{226}Ra $(R = 0.19)$; and between^{232}Th and ^{232}Th $(R = 0.29)$ respectively which shows that data set move in opposite directions for each pair of radionuclides; in other words, for every positive increase in data set for finisher feed there is a corresponding decrease in finisher manure for the pairs of radionuclides investigated which signify that the radionuclide contents of poultry feeds did not contribute significantly to the level of radionuclides in poultry manure. It could be from other sources such as the water they drink, and other food supplements were given to the poultry bird.

V. CONCLUSION

Measurement and evaluation of internal and external exposure to ionizing radiation doses due to the distribution of activity concentrations of radionuclide ^{40}K, ^{226}Ra and^{232}Th in starter/grower poultry feed, finisher poultry feed and resulting poultry manure was carried out. The ^{40}K concentration, in all the samples, investigated recorded the highest mean activity concentration than ^{226}Ra and ^{232}Th. The distribution of ^{226}Ra was more heterogeneous in all the samples than homogeneous distributions obtained in ^{40}K and ^{232}Th. Activity concentrations of ^{40}K in poultry manure were found higher than reported works for animal manure in Saudi Arabia and Zaria (Nigeria). In all, about 77.8% of the distribution was moderately symmetric while 22.2% were asymmetric about the mean. Most significant exposure pathway in all the three materials investigated was the internal exposure from inhalation of poultry and manure dust particles. Considering the distribution of the total mean annual effective dose due to internal and external exposures, workers in poultry environment and dealers of poultry feeds are more exposed to ionizing radiation risk than farmers in farm soil environment. A very weak and negative linear relationship found between the activity concentrations of pairs of radionuclide recorded in finisher poultry manure and finisher poultry feed could suggest radionuclide contents in poultry feeds contributed but not significantly to the level of radionuclides in poultry manure. The radiometric information from this study could serve as baseline in the study area and as a reference material for similar studies in the future within the country and beyond in situations of environmental radioactivity contaminations from uncontrolled releases of radiation sources into the environment.

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