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Mapping of Terrestrial Radioactivity Levels in Surface Soil. A Case Study of Damaturu L.G.A, Yobe State, Nigeria.

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Abstract *Preliminary measurement of the natural radioactivity levels due to terrestrial radionuclides in surface soil samples within Damaturu L.G.A in Yobe state was carried out. To estimate the radioactivity levels of unsampled locations, geostatistical analysis, using IDW interpolation method was used to plot maps for the spatial distribution of the radionuclides for the entire study area using ArcGIS software. Activity concentration of* ^{226}*Ra,* ^{232}*Th and* ^{40}*K were determined in 55 soil samples by gamma spectroscopy. The activity concentrations were calculated to range from 7 to 227 Bq* kg^{-1} *for* ^{226}*Ra, 21 to 463 Bq* kg^{-1} *for* ^{232}*Th and 20 to 1035 Bq* kg^{-1} *for* ^{40}*K. The mean values of* ^{226}*Ra,* ^{232}*Th, and* ^{40}*K were found to be 37.2, 45.3, and 185 Bq* kg^{-1}*, respectively. The results obtained are slightly higher than the worldwide average values (except for* ^{40}*K) recommended by UNSCEAR (2000). The result could be useful in evaluating gamma radiation exposure to the general public living in the area.*

Key Words: Damaturu, surface soil, terrestrial radionuclides, IDW interpolation, geostatistics.

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1.0 Introduction

Naturally occurring background gamma radiation in the environment is mainly contributed by the radioisotopes, ^{40}K and from the decay series of ^{232}Th and ^{238}U through which most of its decay products come from ^{226}Ra. These radioisotopes exist at trace amount in all rocks and soil formations with some part coming from cosmic source (Ravisankar *et al.*, 2015; Tzortzis *et al.*, 2004). Available literature reveal that these radionuclides are important for dose assessment in humans because we are constantly taking risk of accumulating radionuclides through direct exposure and ingestion of food and water (Fares, 2017). According to Kurnaz *et al.* (2007), radionuclides have ben idenfied in food, meat, water and even the air we breathe. The origin of radionuclides in food and food materials is through foliar absorption from the soil by plants (Al-Zahrani, 2017). The Rocks formations and soil types of a given region significantly determine background concentration of radionuclides materials on the earth. This implies that different regions may have different background concentration of radionuclides. However, in most cases, natural levels of radionuclides concentrations are within safe limits (except where there is extensive geological deposits (Baykara and Doğru, 2009). Therefore, increment that alters this background concentration could be anthropogenic, industrial or even natural transfer from regions to regions (Prakash *et al.*, 2017). Ravisankar, *et al.* (2015), stated that increasing urbanization and population growth, coupled with the use of some fertilizers have contributed significantly to increase soil radionuclides (especially uranium and thorium) in various regions.

Also, different rocks have different enrichment coefficient for different radionuclide. For example, igneous rocks of granitic origin have better enrichment capacity for U and Th compared to rocks of basaltic source (Gbenu *et al.*, 2016). Therefore, higher and lower concentrations of NORMs in any part of the world are linked with igneous and sedimentary rocks, respectively, with exception of certain shale and phosphate rocks (Baykara, 2005). Durusoy and Yildirim (2017) determined the activity concentrations of some radionuclides (^{238}U, ^{232}Th, ^{40}K and ^{137}Cs) in some soil sample around Turkey using gamma spectrophotometer and reported external hazard index in the range of 0.12 to 0.94. Onjefu *et al.* (2017) also reported concentrations of radionuclides in shore sediment samples around the North Dune beach in Namibia and used several radiological indices (as absorbed dose rates (ADR), radium equivalent (R_{eq}) annual effective dose equivalent (AEDE), the hazard indices (H_{ex} and H_{in}), and the excess lifetime cancer risk (ELCR)) to interpret their results. The average values of the radium equivalent and external hazard index were below the world allowable limits. However, they found that the mean absorbed dose rates, annual effective dose equivalent, internal hazard index) and excess lifetime cancer risk were above the permissible limits. Various types of radionuclides were identified in black sand and sediment samples from Lake Beach in Suez in Egypt. In Nigeria, most reported studies on determination of levels of radionuclides in different soils are concentrated in the Southern part of Nigeria (Gbadebo, 2011; Gbenu*, et al.*, 2016; Jibiri and Bankole, 2006; Ogezi, 1998; Olomo *et al.*, 1994) with few in the northern region of the country. To our knowledge, reference data on natural radionuclides level has not been established, neither has the sources been identified (Abba *et al.*, 2017). Knowledge of soil radioactivity distribution is important for understanding the level at which the population is exposed to background radiation which is associated with human health. The effective dose received by the global population annually from both natural and artificial sources is 2.8 mSv, about which 85% dose (2.4 mSv) comes from natural background radiation (Singh *et al.*, 2017). Therefore, this work seeks to determine the distribution of terrestrial radionuclides, namely, ^{226}Ra, ^{232}Th and ^{40}K in surface soils within Damaturu local government area (L.G.A), Yobe state. The preliminary study of the terrestrial radionuclides was carried out by means of High purity germanium (HPGe) gamma spectroscopic system. The results of the mapping suggest useful conclusion and allows dosimetry calculations to be made for the population of the area. The data will also serve as a baseline for checking background radioactivity level changes in the feature.

2.0 Material and Methods

2.1 The study area.

The study area, Damaturu, is the state capital of Yobe state and is situated between latitude $11^0 39^{'} 30^{"} - 11^0 47^{'} 00^{"}$ N and longitude $11^0 54^{'} 00^{"} - 12^0 02^{'} 00^{"}$ E in the North- Eastern region of Nigeria (see Fig. 1).The land size of Damaturu is 408 km^2 with estimated population of 69,952 in 2010 (NPC, 2006). Map of the study area is shown in Fig. 1.

2.1. 1 The geological setting of the area

The geology of the study which is that of Yobe state, basically comprises of crystalline and sedimentary rocks, underlain by basement complex rocks (Musa, 2011) The crystalline rocks are represented by older and younger granites found in pockets of places in the southern part of the study area (Musa, 2011).The older granite is of Pre Cambrian in origin consisting of metamorphic structures of gneiss and amphibolites. The younger granitic rocks are of Jurassic period, deposited between 195 and 135 million years ago. The sedimentary rocks that are found to be uncomfortably deposited on the basement crystalline rocks. However, the sedimentary formation is uncomfortably overlaid by a large expanse of Quaternary Chad formation that stretched into Jigawa and Borno States (Olayinka *et al.*, 1999; Raji and Alagbe, 2000).

2.2 Sample collection and preparation

Soil samples were collected at 55 random locations spread across the entire study area as shown in Fig. 2. Samples at proximity of buildings, roads, tree and other public obstructions were avoided in order to control interference from other sources rather than the background levels. For each sample of soil, an area of about 0.5 x 0.5 m was marked and cleared of debris to a depth of one centimetre. At least three soil samples were collected for each sampling location at different points, and thoroughly mixed together, in order to obtain a representative sample of that location. Samples were later cleared off pebbles, stones and organic materials, dried in an oven maintained at 85 °C for 3–5 hours to remove the moisture content, crushed and then passed through a fine mesh sieve (100 mm) to homogenize them. The prepared samples were weighted, sealed hermetically in plastic containers (5 cm height and 5 cm diameter). In order to limit escaping gas and for ^{226}Ra to attain secular equilibrium with its progenies, samples were stored for the period of 30 days before counting.

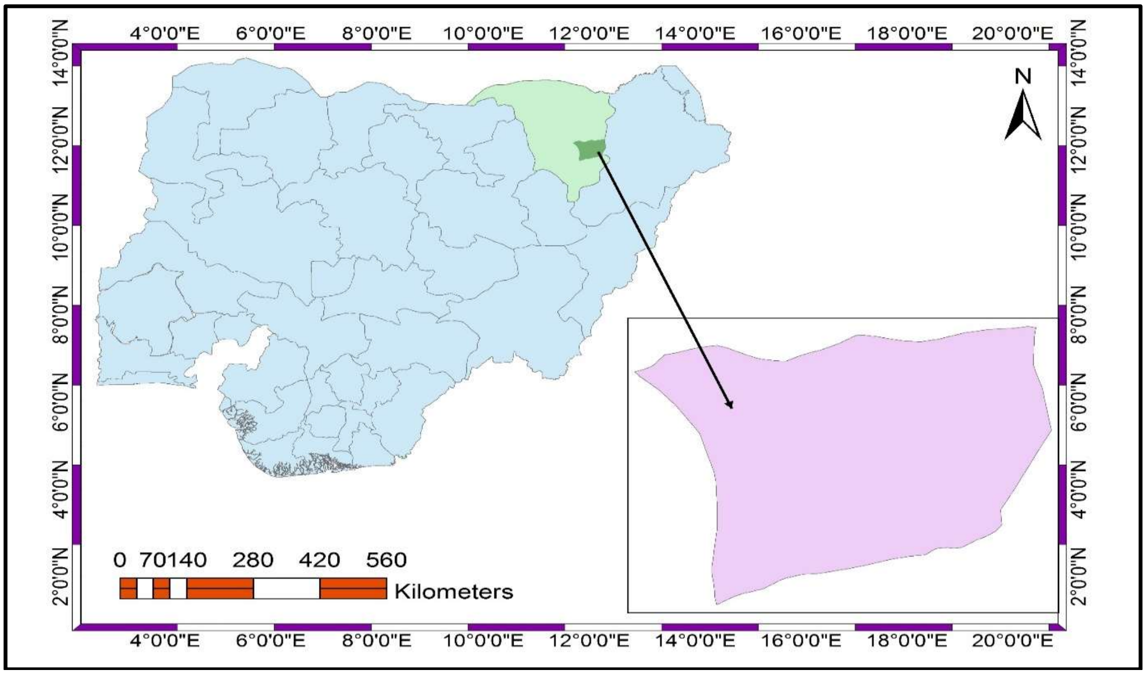

Fig. 1: Map showing Damaturu

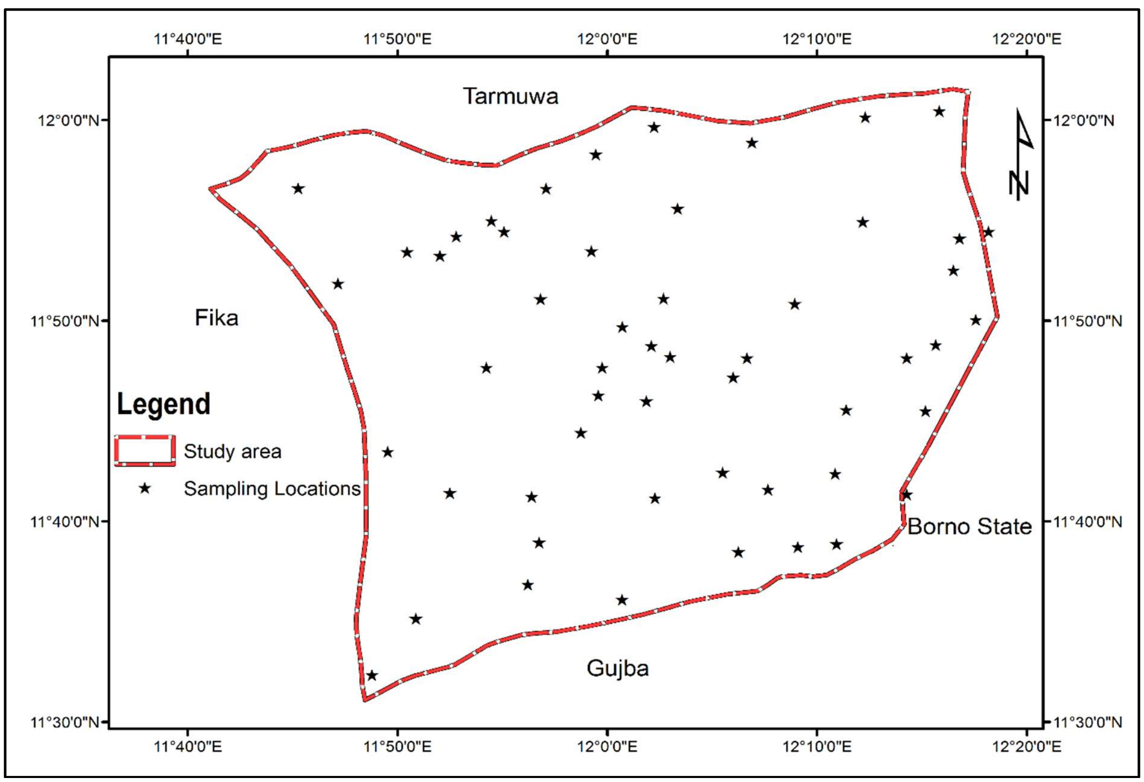

Fig. 2: Sampling Locations

2.3 Experimental Procedure

The concentration of the terrestrial radionuclides ^{226}Ra, ^{232}Th and ^{40}K in the soil samples were determined by gamma spectroscopy using high resolution Hyper pure germanium (HPGe) counting system with an efficiency of 50% relative to a $3^{''} X 3^{''}$ NaI(Tl) detector, and each sample was measured for counting time of 18 hours. Detailed information about calibration of the instrument, procedure followed and materials used for quality control can be found elsewhere (Abba *et al.*, 2018). The concentration of ^{226}Ra was derived from the weighted mean of the activities of two photopeaks of ^{214}Pb (295.2, 352.0 keV) and of three photopeaks of ^{214}Bi (609.3, 1120.3, 1764.5 keV). For ^{232}Th, two photopeaks of ^{228}A (338.4, 911.1 keV) and ^{208}Tl (583.1 keV) were used in the same way. Concentration of ^{40}K was obtained from the single photopeak of this isotope at 1460.8 keV.

2.4 Activity Concentration of ^{238}U, ^{232}Th and ^{40}K

From the gamma transition peaks of ^{226}Ra, ^{232}Th and ^{40}K, the activity concentrations were calculated according to equation1 (Gbenu*, et al.*, 2016).

$$A = \frac{c}{E} \qquad (1)$$

where A is the activity of the radionuclide in Bq Kg^{-1}; *E,* the detector efficiency for the gamma-ray line used and *c* the counts per second.

2.5 Geostatistical mapping

The measurement results obtained from the samples collected from a certain area are definite only at the sampled points. The interpolation values at the unsampled points need to be calculated to approximately determine the distribution of the random variable. These interpolation values were estimated by Inverse Distance Weighting (IDW), which is one of the geostatistical methods for interpolation (Mallet, 2002; Tolosana-Delgado *et al.*, 2011). The method is relatively fast, easy to compute and straightforward to interpret data. This has made IDW to be the most frequently used model for interpolation. Its general idea is based on the assumption that the attribute value of an unsampled point is the weighted average of known values within the neighbourhood, and the weights are inversely related to the distances between the prediction location and the sampled locations (Lu and Wong, 2008). In this study, IDW interpolation method using ArcGIS software was used to produce maps for the distribution of ^{226}Ra, ^{232}Th and ^{40}K.

3.0 Results and Discussion

3.1 Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K.

Table 1 presents mean values and corresponding ranges for the concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the surface soil samples from Damaturu. Worldwide data for ^{226}Ra, ^{232}Th and ^{40}K reported by UNSCEAR (2000) and IAEA (2003) are also presented in the Table. The activity concentrations of the terrestrial radionuclides in the soil samples from Damaturu are found to be higher than the global reference values of 30 Bq kg^{-1} for ^{226}Ra, 35 Bq kg^{-1} for ^{232}Th and 400 Bq kg^{-1} for ^{40}K. Hence, long-term health effects is associated with radiation exposure from soil.

Table 1: Specific activity concentration (Bq kg^{-1}) of terrestrial radionuclides in Damaturu surface soil

Radionuclide	Mean	Range		Worldwide Average
		Min.	Max.	
^{226}Ra	37.2	7	227	35
^{232}Th	45.3	21	463	30
^{40}K	185	20	1035	400

The results of this study are compared with similar studies from different regions in the world in Table 2. The results obtained for ^{226}Ra in Oguta Lake, Nigeria; Kedah, Malaysia; Turkey and Serbia are higher than the mean value obtained in this study. The mean activity concentration of ^{232}Th for studies conducted in Kedah, Malaysia and Oguta Lake are also higher than the present data indicating low level of radioactive risk. Geological setting of different regions which has direct relationship with the concentration of terrestrial radionuclides could explain the variation of the results of the different studies presented in Table 1. The result obtained for ^{40}K by Farai and Jibiri (2000) for some soils in Nigeria is found to be lower than the mean value calculated in this study. Regular and intensive use of agrochemicals (pesticides, herbicides and fertilizers) to improved crop yield in the area might have contributed to raise concentrations of radionuclides in the study area.

Table 2: Results of this study compared to studies from different countries/regions

Country/Region	Mean			Reference
	^{226}Ra	^{232}Th	^{40}K	
Nigeria	33.9	12.4	73.3	(Farai and Jibiri, 2000)
Oguta Lake, Nigeria	47.89	55.37	1023	(Isinkaye and Emelue, 2015)
Kedah, Malaysia	65.24	83.39	136.98	(Alzubaidi *et al.*, 2016)
Turkey	42.3	27.6	390.4	(Taşkın *et al.*, 2018)
Tamilnadu, India	2.1	14.3	360	(Ravisankar*, et al.*, 2015)
Setif, Algeria	47	43	329	(Boukhenfouf and Boucenna, 2011)
Kuwait	12	30	397	(Jallad, 2016)
Serbia	34.6	44.7	429	(Stajic *et al.*, 2016)
Damaturu, Nigeria	37.2	45.3	185	This Study

3.2 Mapping of ^{226}Ra, ^{232}Th and ^{40}K

In order to map out the distribution of the terrestrial radionuclides ^{226}Ra, ^{232}Th and ^{40}K based on activity concentration, IDW interpolation method was employed using ArcGIS software. Figs 3 to 5 are the maps created through the IDW interpolation method for Damaturu L.G.A. It is evident from the maps that the South Western zone, the Northern zone and the Central zone of Damaturu have higher activity concentration of ^{226}Ra than other parts. Concentration of ^{232}Th was observed to be higher in two spots around the South, East -Central and Central parts while ^{40}K displayed higher concentration in locations around the South West, Central and Northern parts of Damaturu.

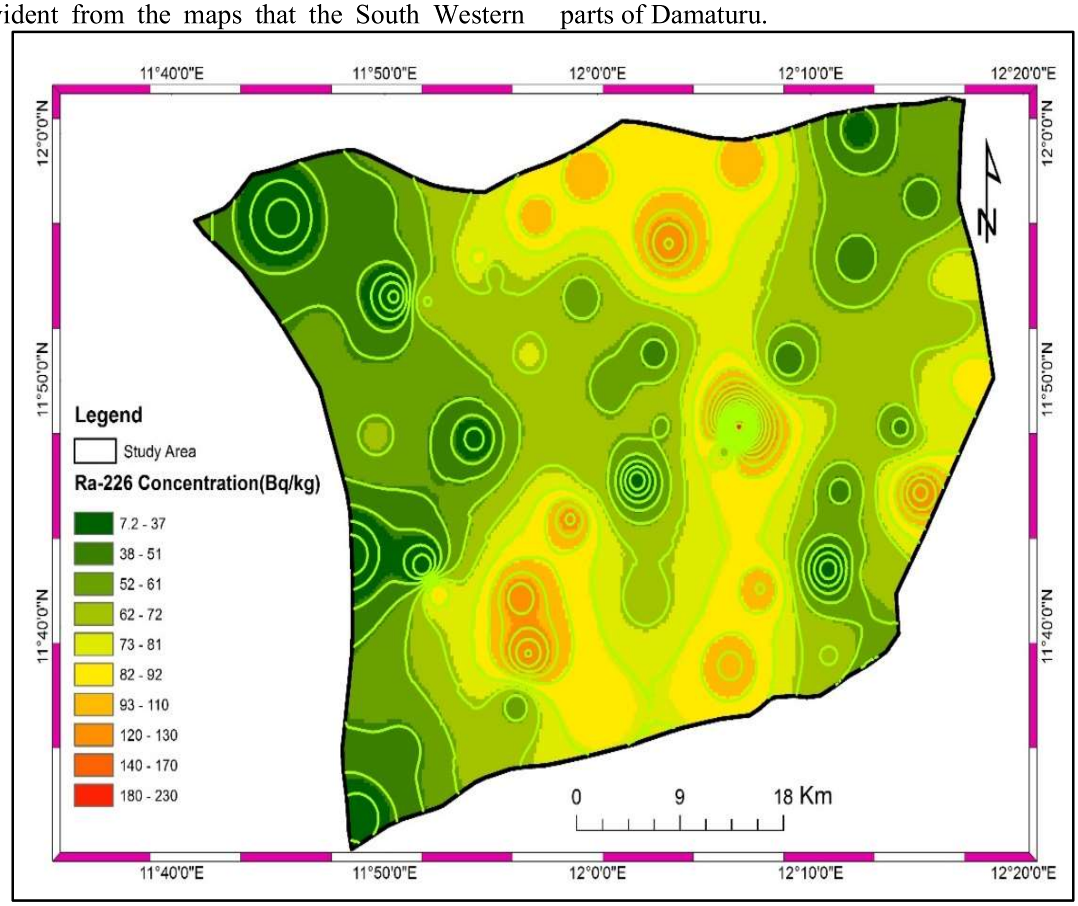

Fig. 3: Distribution Map for ^{226}Ra

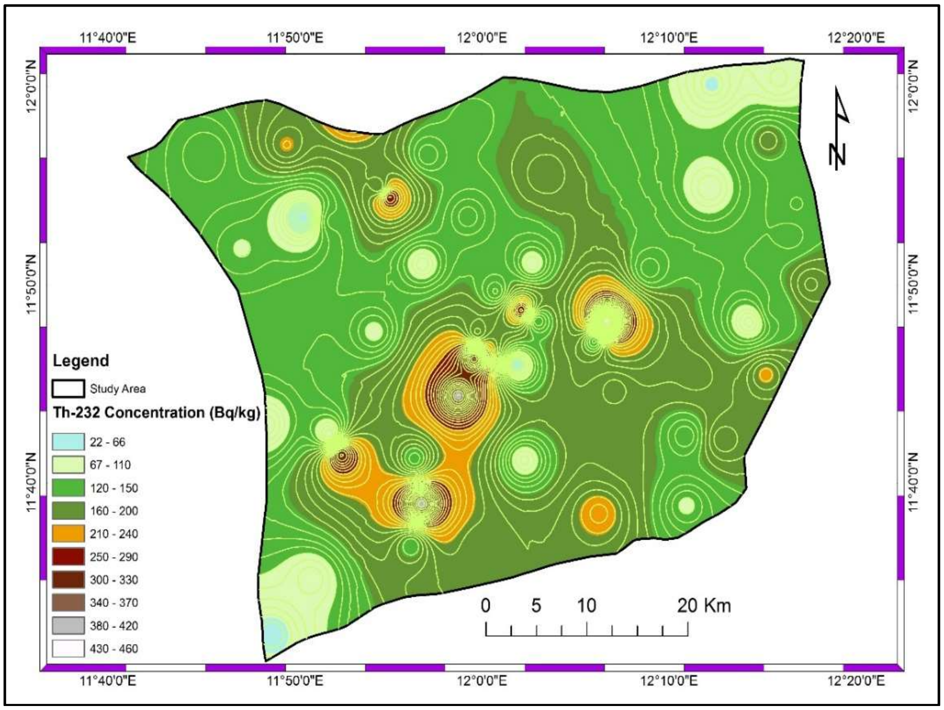

Fig. 4: Distribution Map for ^{232}Th

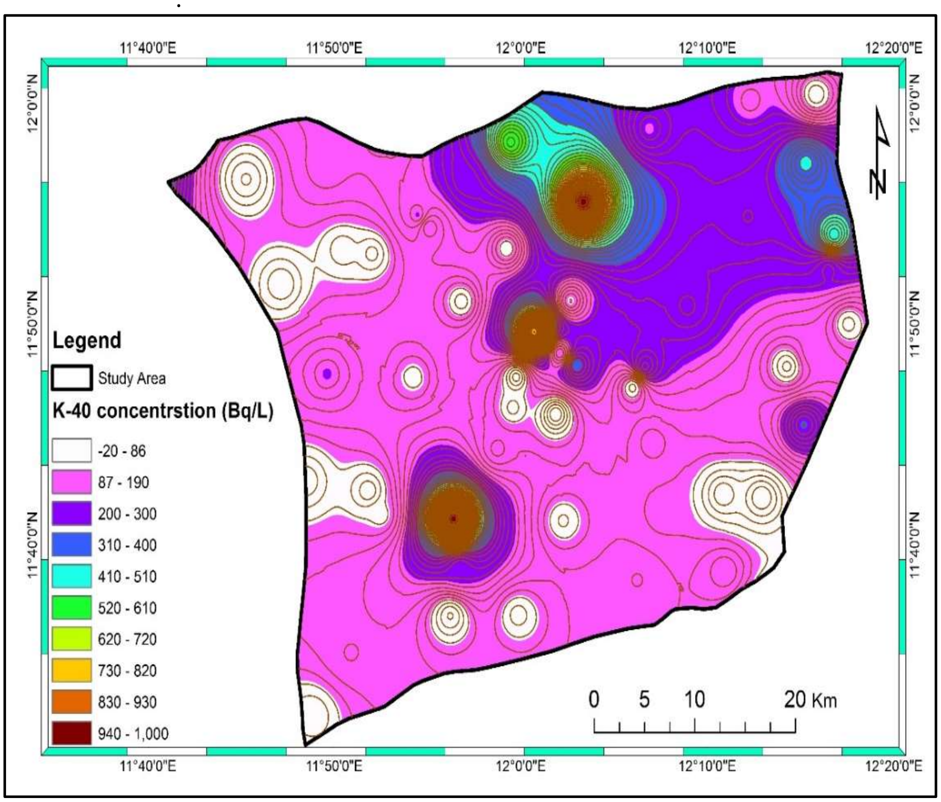

Fig. 5: Distribution Map for ^{40}K

4.0 Conclusion

This study was designed to measure the activity concentration of terrestrial radionuclides in 55 soil samples from Damaturu with the aim of obtaining the radiological maps for the study area. The results for the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K slightly exceed the worldwide average values set by UNSCEAR (2000) with the exception of ^{40}K. The higher concentration are attributed to regular and intensive use of agrochemicals (pesticides, herbicides and fertilizers) to improve crop yield. From the physical observation of the generated radiological maps, higher concentration of ^{226}Ra was noted in locations in the South-Western, Northern and Central parts of while ^{232}Th exhibited higher concentration in spots around the South, East and Central parts of Damaturu. Higher concentration of ^{40}K was found in the South-West, Central and Northern part of Damaturu. The result of this work can serve as a preliminary radiological data set for Damaturu L.G.A which could be used to identify areas with higher radioactivity levels. The results could also be useful in evaluating gamma radiation exposure for the general public living in the area.

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