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An Assessment of Absorbed Dose Rate, Radiation Hazard Index and Excess Lifetime Cancer Risk from Natural Radioactivity and Their Implications on Human Health

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ABSTRACT

Naturally occurring radionuclides such as ^{40}K, ^{238}U and ^{232}Th which through their decay processes emit gamma radiation that are very dangerous and affect human health. The study areas were chosen due to their geographical formation such as flat land catchments, revering, slope and agricultural rich farming land**,** factories, , gullies and water eroded areas, and soil deposits very close to flowing waters from rocks, due to environmental concerns arising from human activities in this region, which was the major reason for selecting the study areas. Soil samples were collected manually and the sampling positions were determined using a Global Positioning System (GPS). The amount of radioactivity concentration of these radionuclides is the major factor in assessing the harmful effect of the radionuclides on human health. In this study, the radioactivity concentration levels were measured using gamma spectrometry using Sodium Iodide Thallium doped NaI (TI) detector coupled with a pre-amplifier base to a multiple channel analyzer (MCA) and the surface doses rate measurements were done using dose rate meter in the laboratory. Highest radioactivity concentrations of ^{40}K, and ^{232}Th were obtained from Awka North soil samples with a mean value of 3.534 ± 0.366, 2.162 ± 0.372 and 1.116 ± 0.11. The total mean values of absorbed dose rate, External and Internal hazard index and Excess Life cancer Risk for soil samples in Awka North are 1.81393 $nGyh^{-1}$; 0.01089 $nGyh^{-1}$, 0.01673 $nGyh^{-1}$ and 0.03704 respectively. The obtained values were below the safe limit values set by the United Nations Scientific Committee on the Effects of Atomic Radiation set for Absorbed dose rate and hazard index 59.0 nGyh□ □, and 1.0 mSv. According to the findings, the regions under study are reasonably safe for human outdoor activities such as agriculture, construction, and factory operations. The results show a reasonably low radiation absorb dose and radiation hazard index, which is a good indication for the farmers to work in the area.

I. INTRODUCTION

Radionuclides are found naturally in air, rocks, soil that makes up our planet, in water, streams and oceans, and in our building materials and homes. They are even found in human body, since they are products of our environment. In our daily activities, we ingest and inhale radionuclides in the air we breathe, the food we eat and the water we drink. There is nowhere on Earth that we cannot find radionuclides (Shams, Issa Uosif, Hefni, El-Kamel and Nesreen, 2012). Radioactive isotopes concentration in soil is an indicator of radioactive accumulation in the environment, which affects humans, plants and animals. Naturally occurring radioactive materials generally contain terrestrial origin radionuclides primordial. The natural radioactivity in soil is derived mainly from the ^{238}U and ^{232}Th parent series and natural ^{40}K (Charles, 2021). Natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical

conditions. The sources of radioactivity in soils other than those of natural origin are mainly due to extensive use of fertilizers rich in phosphates for agricultural purposes (UNSCEAR, 2000). Study of soil radioactivity can provide reference data in observing possible future anthropomorphic impact and associated radiological risk to human health. The activity concentrations of radionuclides in the 238U and 232Th decay chains and from 40K were determined through gamma-rays spectrometry in a low background configuration (3).

The natural terrestrial component is due to the radioactivity of members of the decay series of ^{238}U and ^{232}Th and the non-series ^{40}K that are present in environmental materials such as different types of water, rock, soil and the building materials composed of them. Activity concentrations in soil and water give rise to radionuclide loading in food and fodder crops, which in turn gives rise to internal exposure of humans. The man-made terrestrial component is due to the deposition of radioactive fallout ^{137}Cs, ^{237}U, ^{239}Np, and others at any location. This deposition is dependent on latitude, precipitation and topography (Jibiri et al., 2008; Krstic et al., 2004).

Estimated exposure to natural radiation from naturally occurring radionuclides has become environmental concern to the public and national authorities of many countries because of its deleterious effects on human health (Kitto et al., 2006). Therefore tremendous efforts are being made to locate and control the sources of natural radiation where economical interest exists and on which legislation must be applied. It has been reported that natural sources contribute almost 90% of the collective radiation exposure of the world's population (UNSCEAR, 2013). Knowledge of the distribution pattern of both anthropogenic and natural radionuclides is essential in maintaining some sense of control of prevailing radiation levels.

Radionuclides have been essentially present in the environment since the creation of the earth. Only nuclides with half-lives comparable to the age of the earth or their corresponding decay products such as ^{40}K, and the radionuclides from the ^{238}U and ^{232}Th series can still be found on earth (Abu, 2012). Human beings are primarily exposed to ionizing radiations emitted from naturally occurring radioactive materials found in earth's crust, as well as from man-made sources (Tabassum, 2012).

The radioactivity level from the natural radionuclides is termed as background radiation which depend on the amount of the radioactive materials in the environment. The background radiation can be high if the environment is polluted either from man-made or natural activities. It can also be high in regions with deposit of mineral resources such as uranium ores and phosphate (Oyedele, 2006). Materials from the deposit may be brought to the surface soil through processes such as weathering of rocks and soil formation. They can also leach into the surface water, contaminate it, and lead to pollution far away from the source.

The radioactivity concentrations in soil and water give information on both natural and man-made sources which is important in radiological monitoring and assessment of radiation dose for public (EPA, 2007). Measurement of natural radioactivity in soil and water is very important to determine the amount of change of the natural background activity with time as a result of radioactivity release. Studies of natural radioactivity are necessary not only for their radiological impact but also for their ability to act as excellent biochemical and geochemical traces in the environment (Bashiru, 2018). Though natural radioactivity is found in rocks, soils and water throughout the earth, the accession in specific areas varies relatively within narrow limits (Surinder, 2003). Therefore, great interest has been expressed worldwide for the study of naturally occurring radiation sources as well as environmental radioactivity has led to the interest in extensive surveys in many countries.

Exposure to low-levels of radiation does not cause immediate health effects, but can cause a small increase in the risk of cancer over a lifetime. The effects of radiation at high doses and dose rates are reasonably well documented. A very large dose delivered to the whole body over a short time will result in the death of the exposed person within days. However, at low doses of radiation, there is still considerable uncertainty about the overall effects (Bashiru, 2018). It is presumed that exposure to radiation, even at the levels of natural background, may involve some additional risk of cancer. Sunlight feels warm because our body absorbs the infra-red rays it contains. But, infra-red rays do not produce ionization in body tissue. In contrast, ionizing radiation can impair the normal functioning of the cells or even kill them. The amount of energy necessary to cause significant biological effects through ionization is so small that our bodies cannot

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feel this energy as in the case of infra-red rays which produce heat.

A very high level of radiation exposure delivered over a short period of time can cause symptoms such as nausea and vomiting within hours and can sometimes result in death over the following days or weeks. This is known as acute radiation syndrome, commonly known as "radiation sickness."

Pollutants from residential and hospital wastes, as well as from fertilizers on farmlands from rainwater and the naturally occurring radioactive materials (NORMS) in a particular area affect the quality of water and soil in the area. Some of these pollutants are radioactive and their deposition into the human body through drinking of contaminated water, living in buildings, offices, shops and schools built from soil contaminated with radionuclides, utilization of phosphate fertilizer, burning of fossil fuels (crude oil and coal), mining and milling operations, and building materials can be hazardous to human health. Ingesting and inhaling high levels of radionuclides contribute significantly to the radiation dose that people receive. The use of agrochemicals such as fertilizers, pesticides and herbicides by farmers on the farmland and in the river, dumping of refuse and domestic wastes on the land and near the river bank as well as domestic sewage into the river are main sources of contaminants in the soil and river (Bashiru, 2018). The specific objectives of the research include; to determine the radionuclide's content of surface soils, absorbed dose rate in air, external/internal hazard index and excess lifetime cancer risk dose using spectrometry system, to establish the distribution pattern of environmental radioactivity measured in the areas in order to identify areas of elevated activity or areas prone to high radiological risk, to determine the correlation between the effects of water and soils use in the selected areas and how it affects the health of the people (Bashiru, 2018).

Till date, there is no known literature on the radioactivity levels at Awka North Local Government Areas nor the population risk of the local people within the vicinity of the study areas due to continuous exposure. The present research assesses the environmental radioactivity of surface water sources and surface soils in the environment of the study areas.

II. MATERIALS AND METHODS

Materials

The detection and measurement of radionuclides in the samples were carried out using the following materials: Five (5) samples of surface soils, Gamma spectrometry system NaI (TI) detector with multiple channel analyzer (MCA) (Model: 802), Sampling plastic container of about 1-2 volume, Polyethylene bags, Masking tape, Mesh of 2mm, Geographical Positioning System (GPS) for measuring the geographical co-ordinates, thermometer and dose rate meter.

Methods

Sampling Sites

Table 1: Sampling locations and their coordinate (Otukpo LGA)

S/N	LOCATION	LATITUDE	LONGITUDE
1	AMANSEA	6.3333°6° 20'	7^0 94' 92" E
2	ACHALLA	6° 19' 48"N	6° 58' 48"E
3	ISU-ANIOCHA	6° 21' 11" N	6° 55' 14" E
4	AWBA-OFEMILI	6° 16' 16" N	7° 3' 28" E
5	AMANUKE	6° 18' 14" N	7° 2' 18 E

Sample Selection

The stratified random sampling (Williams, 1977) was used to select sample site. Five (5) Soil samples were collected with a distance of about 500m between one sampling point and the other.

Surface Soil Samples Collection and Preservation

The soil samples were collected in a labeled polythene bags for analysis purpose. The samples was sundried to a constant weight, ground and sieved using 2mm mesh to obtain a fine - powder texture that would give an equilibrium level to the detector. About 200g of each sieved sample will packed in a plastic container and sealed for at least 30 days before analysis. This is to allowed time for the daughters to reunite with their parent radionuclides.

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Identification of Radionuclides present in the Samples.

The Gamma Spectrometry System identifier was used to identify the radionuclides in each of the 5 samples collected. The radionuclides that were identified in the samples are ^{238}U, ^{232}Th, ^{40}K and unidentified radionuclides, which are the radionuclides that are not in the library of the identifier. The energy peak of the various radionuclides was obtained from the Gamma Spectrometer.

Calibration and Efficiency of Materials

The detector efficiency and calibration of the detector was performed using a reference standard source (IAEA - 444) prepared from the Radiochemical Centre, Vienna, England. The efficiency for each radionuclide was calculated and used to estimate the activity concentration of each of the radionuclides in the samples.

Radiometric Analysis and Assessment

Activity Concentration Determination

All samples were subjected to gamma spectral analysis with a counting time of 10hrs (i.e. 36000 secs). An 8.5cm x 6.5cm NaI (TI) detector model 802 was used and the detector was shielded in a 10cm thick and cylindrical in shape Canberra leads to reduce gamma ray background (Ajibode et al., 2013; Ravisankar et al., 2014).

The activity concentration (A) of each radionuclide in the samples was determined by using the net count (cps) (found by subtracting the background counts from the gross counts with same counting time under the selected photo peaks), weight of the sample, the photo-peak efficiency and the gamma intensity at a specific energy

$$A = \frac{cps}{E \times I \times W}$$

Where, A = activity concentration of the sample in $Bqkg^{-1}$ or BqL^{-1}

cps = the net count per second

E = the counting efficiency of the gamma energy

I = Absolute intensity of the gamma ray and

W = net weight of the sample (in kilogram, kg or litre, L).

The errors in the measurement were expressed in term of standard deviation ($\pm 2\sigma$) where σ is expressed as (UNSCEAR, 2000).

$$\sigma = \left[\frac{N_s}{T_s^2} + \frac{N_b}{T_h^s}\right]^{1/2}$$

Where, N_s is the sample counts measured in time T_S and N_b is the background counts measured in time T_b. The standard deviation $\pm 2\sigma$ in cps was converted into activity in $Bqkg^{-1}$.

Dose Calculations

Radium equivalent activity

The radium equivalent activity, Ra_{eq}, measured in Bq kg^{-1}, was introduced to identify the uniformity to radiation exposure. The calculated values of Raeq are generally used to compare the specific activity of materials containing different amounts of ^{238}U, ^{232}Th, and ^{40}K. Besides, Ra_{eq} data can be used to assess the health hazard effects produced from the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K radionuclides in soil and water samples . The measured values of Ra_{eq} were obtained by making use of the following equation (Huy, 2005 & Alharbi, 2011).

$$Raeq\ (Bqkg^{-1}) = A_U + 1.43A_{Th} + 0.077A_k$$

Absorbed dose rate in air

The effects of gamma radiation originating from radioactive sources in the environment are generally expressed in terms of the total gamma radiation absorbed dose rate in air, D_r. The values of D_r in air and 1 m above the ground level are calculated from the measured activity concentrations of ^{238}U, ^{232}Th, and ^{40}K radionuclides using the following semiempirical formula (El-Shershaby, 2016 & Fatima, 2008).

$$D_r\ (nGyh^{-1}) = 0.427A_U + 0.662A_{Th} + 0.043A_K$$

Radiological Hazard Indices

External and internal radiation hazard indices

$$\mathbf{H_{ex}} = \frac{\mathbf{A_U}}{\mathbf{370Bqkg^{-1}}} + \frac{\mathbf{A_{Th}}}{\mathbf{259Bqkg^{-1}}} + \frac{\mathbf{A_K}}{\mathbf{4810Bqkg^{-1}}}$$

The external radiation hazard index, H_{ex} , corresponding to ^{238}U, ^{232}Th, and ^{40}K natural radionuclides, was calculated using the following equation (Shams, 2013).

$$\mathbf{H_{in}} = \frac{\mathbf{A_U}}{\mathbf{185Bqkg^{-1}}} + \frac{\mathbf{A_{Th}}}{\mathbf{259Bqkg^{-1}}} + \frac{\mathbf{A_K}}{\mathbf{4810Bqkg^{-1}}}$$

The measured values of H_{in} should also be less than or equal to unity, i.e. $H_{in} < 1$ (UNSCEAR, 2000).

Excess lifetime cancer risk

The excess lifetime cancer risk (ELCR) values are calculated using the below equation (Ramasamy, 2009).

$$ELCR = D_{tot} \times D_L \times R_F$$

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Here D_L is the duration of life (approximately 70 years), and R_F is the risk factor ($0.05Sv^{-1}$), which reflects the fatal cancer risk per sievert. For stochastic effects, ICRP 60 uses values of 0.05 for the public (Taskin, et al., 2009).

III. RESULTS

Activity concentration results

The results of the present study on the two types of samples are summarized in following sections.

Table 2: Activity Concentration ($Bqkg^{-1}$) in different Soil Samples in Awka North LGA

SAMPLE CODE	K-40	U-238	Th-232
AMANSEA	262.37±23.76	27.55±6.64	41.87±3.63
ACHALLA	288.33±34.45	31.97±7.18	95.35±11.37
ISU-ANIOCHA	73.71±8.39	21.24±4.87	32.06±3.68
AWBA OFEMILI	145.25±16.30	21.02±4.61	15.62±2.02
AMANUKE	114.30±10.26	25.79±5.56	27.82±2.61
Mean	**176.792±18.632**	**25.514±5.772**	**42.544±4.662**

Table 3: The absorbed dose Rate (D), (external, Hex and internal, Hin) and Excess Life cancer Risk (ELCR) and for Soil Sample in Awka North LGA

Sample Code	Absorbed dose ($nGyh^{-1}$)	External hazard Index (H_{in})	Internal hazard Index (H_{in})	ELCR x 10^{-3}
AMANSEA	50.76365	0.29067	0.36513	0.1777
ACHALLA	89.17108	0.51451	0.60090	0.3121
ISU-ANIOCHA	33.46273	0.19651	0.25392	0.1171
AWBA OFEMILI	25.56173	0.14732	0.20413	0.0895
AMANUKE	34.34407	0.20080	0.27058	0.1202
MEAN	**46.66065**	**0.26996**	**0.33893**	**0.1633**

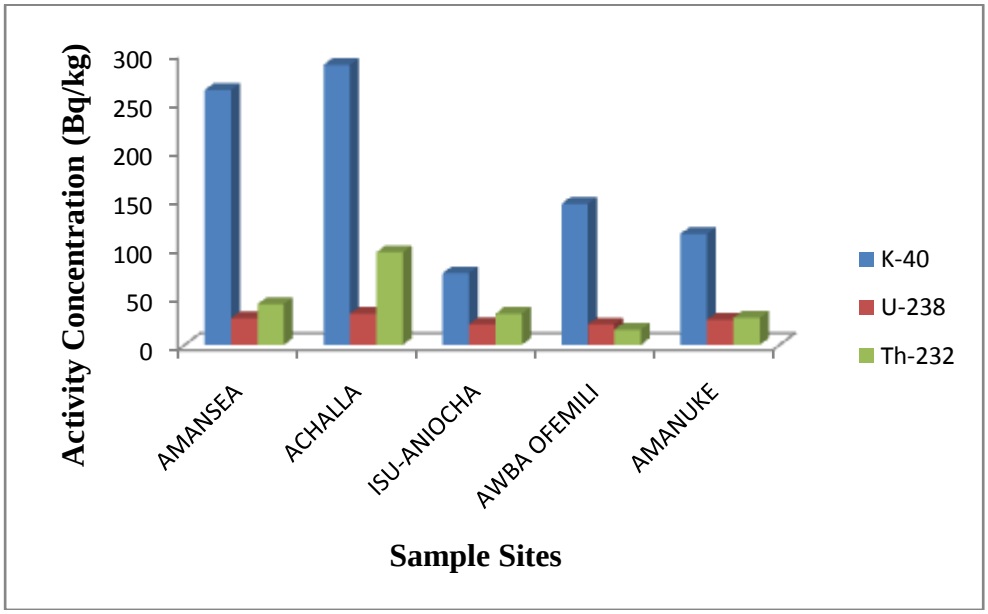

Fig 1: Showing Activity Concentration (Bq/kg) in different Soil Samples in

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Awka North LGA

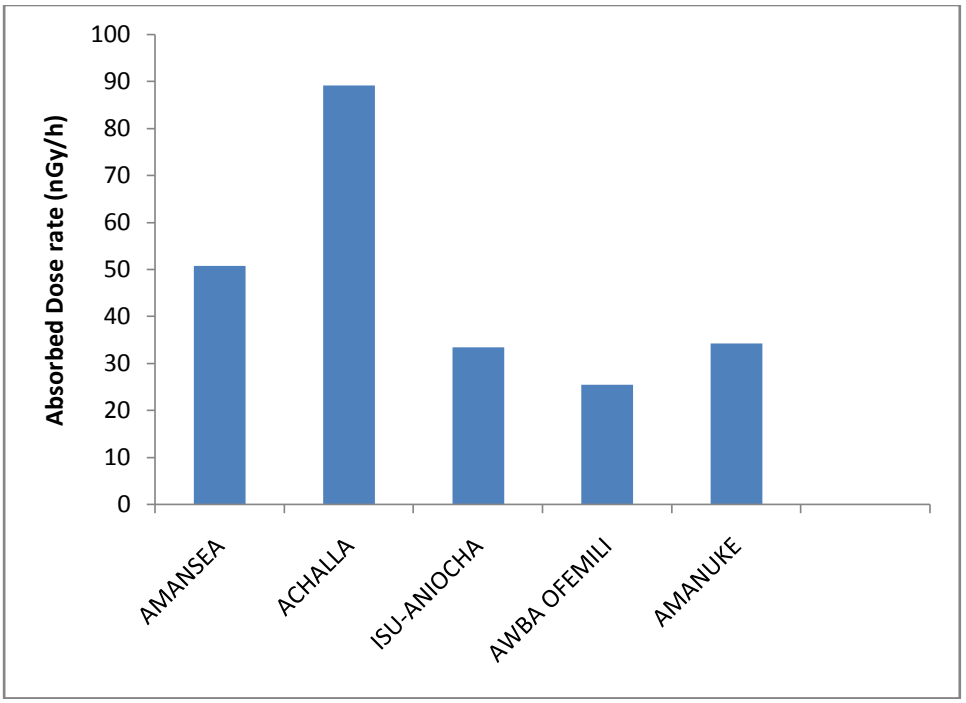

Fig. 2: Mean Absorbed Dose rate (nGy/h) in Soil Samples Vs Study Areas

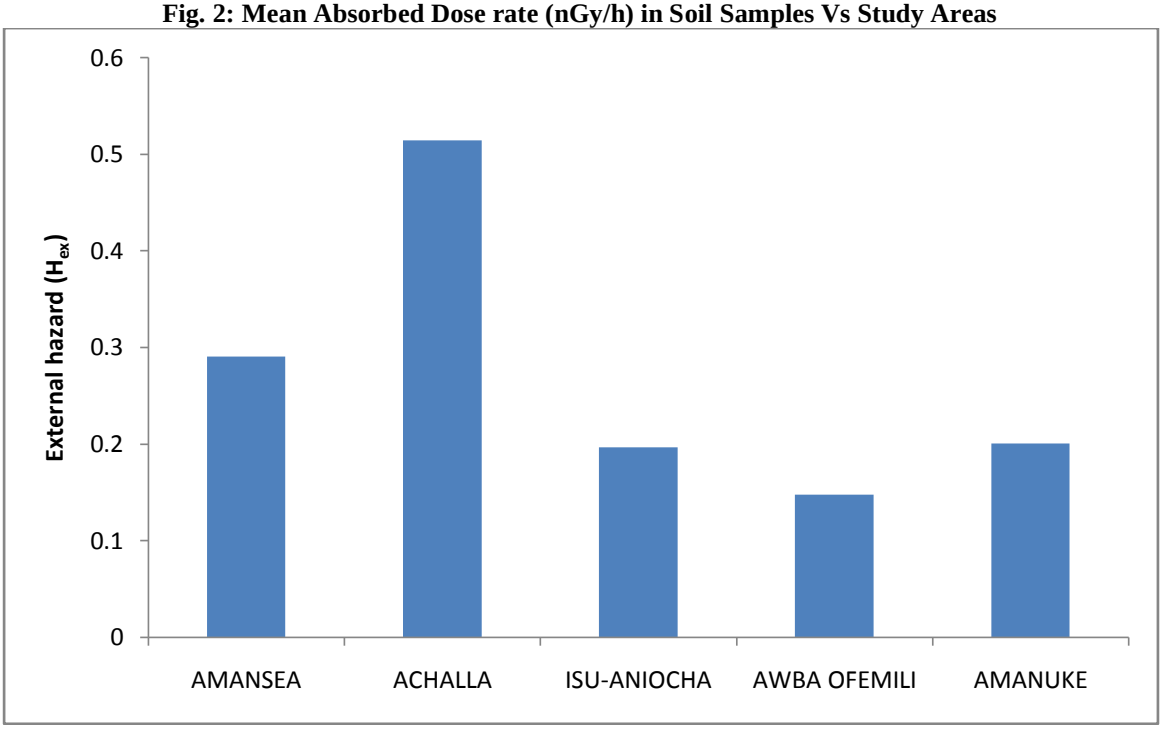

Fig. 3: Mean External Hazard (H_{ex}) in Soil Samples Vs Study Areas

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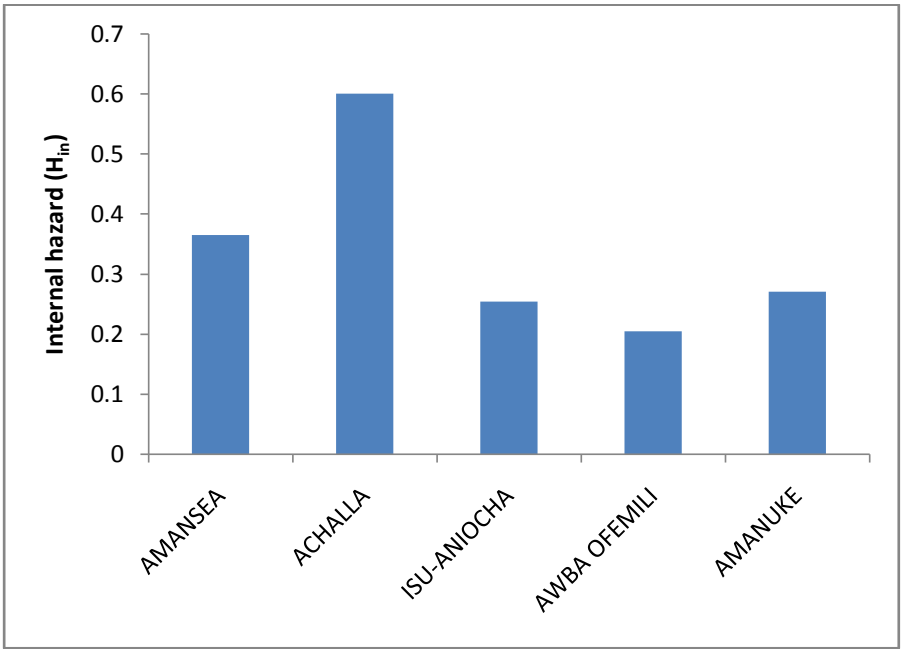

Fig. 4: Mean Internal Hazard (H_{in}) in Soil Samples Vs Study Areas

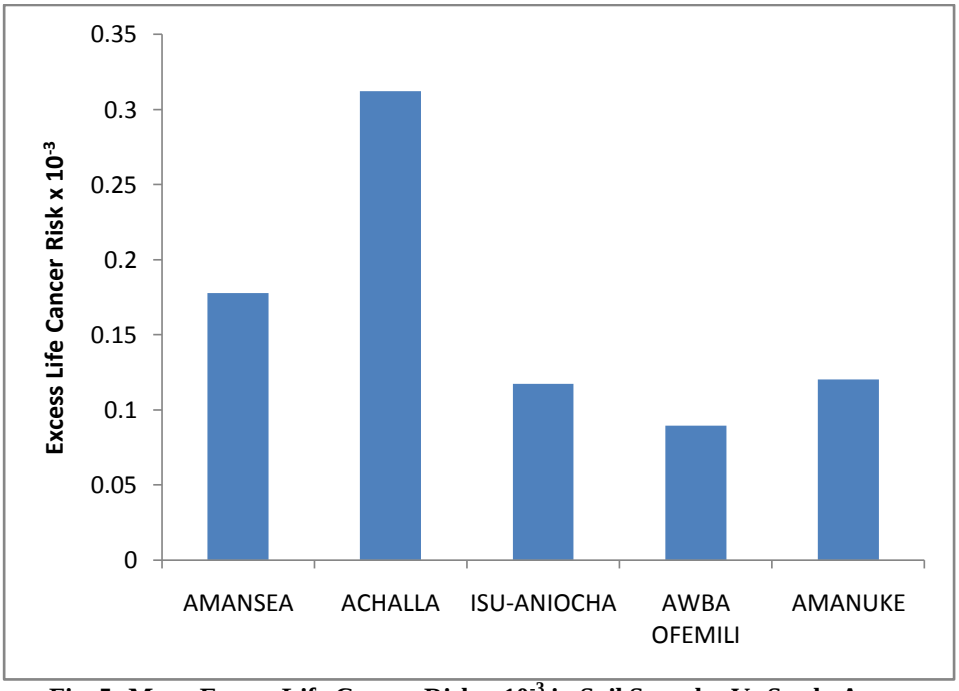

Fig. 5: Mean Excess Life Cancer Risk x 10^{-3} in Soil Samples Vs Study Areas

IV. DISCUSSION

Radioactivity assessment in soil in many parts of the world has been on increase in the past two decades because of hazard on the health of the populace (Belivermis et al., 2009).

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Concentrations of ^{40}K, ^{238}U and ^{232}Th in Surface Soils of the Study Areas

Tables 2, presents the activity concentration of ^{40}K, ^{238}U and ^{232}Th as obtained during the spectrometry of soil samples collected from the five (5) sample sites. It is observed that potassium-40 have higher concentration ranging from a mean value of 73.71 ± 8.3 Bq kg^{-1} - 288.33 ± 34.45 Bq kg^{-1} in all the five sites with the highest mean concentration in Achalla Village of 288.33 ± 34.45 Bq kg^{-1} followed by Thorium-232 ranging from 15.62 ± 2.02 Bq kg^{-1} - 95.35 ± 11.37 Bq kg^{-1} with highest mean concentration of 42.544 ± 4.662 Bq kg^{-1} . Thorium-232 is the one having the least concentration ranging from 21.02 ± 4.61 Bq kg^{-1} – 31.7 ± 7.18 Bq kg^{-1} with highest mean value of 25.514 ± 5.772 Bq kg^{-1} all in Awka North LGA. For the entire areas, activity concentration of ^{40}K in Achalla is higher when compared to those of ^{238}U and ^{232}Th respectively. The elevated concentration of potassium-40 and Uranium-238 in Awka North LGA could be attributed to the use of agrochemicals such as NPK fertilizer for agricultural practice and also due to uranium occurring as a natural constituent in soil, originating from rocks in the earth's mantle. (ATSDR et al., 2004).

Absorbed dose rate, External and Internal hazard Indices of Soil Samples for the Study Areas

Absorbed dose rate is the measure of the amount of energy (radionuclides) deposited by ionization radiation in the human body for a given period (Avwiri and Ononugbo, 2013).The absorbed dose rates due to gamma rays in air at 1 m above ground surface for the activity concentration of ^{40}K, ^{238}U and ^{232}Th in the soil samples were obtained and calculated based on guidelines provided by (UNSCEAR, 2000) using equation above.

Table 3, presents the Absorbed dose rate, external and internal hazard indexes for soils in Awka South LGA. The absorbed dose values ranges from 25.56173 nGyh^{-1} - 89.17108 nGyh^{-1} with a mean value of 46.66065 nGyh^{-1}. The external (H_{ex}) and internal (H_{in}) hazard indexes, has a (Minimum. of 0.14732, Maximum. 0.51451 with an overall average value of 0.26996) and (Minimum. of 0.20413, Maximum. of 0.60090 and average of 0.33893) for the external and internal hazard indices respectively. Mean external and internal hazard index is lower than unity (permissible level) recommended by (UNSCEAR, 2000).

Excess lifetime cancer risk (ECLR)

The probability of developing an extra cancer in a population within a life time after exposure to radionuclides can be estimated in terms of excess lifetime cancer risk (Taskin et al., 2009). The mean value of the excess lifetime cancer risk (ELCR) calculated for all the samples from the study area is lower than the world mean value of 0.29 x 10^{-3} recommended by (UNSCEAR, 2000) except from the mean value of soil samples obtained in Oju LGA

V. CONCLUSION AND RECOMMENDATIONS

Conclusion

The study considered public exposure in the environment due to exposure pathways; namely direct external exposure from natural radioactivity concentrations in soil radioactivity due to ^{238}U, ^{232}Th and ^{40}K and internal exposure due to natural radioactivity by accessing the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in water samples from surface water used in the surrounding communities of the study areas.

The little values of the background ionizations radiation and absorbed dose rate obtained in the sample areas may be as a result of metamorphic rock underlying the territory, mining, use of phosphate fertilizer by farmers in the areas, brown earth volcanic formation of material (salt spring) and other hazardous materials in the areas. Therefore, continuous absorption of the radiation dose may result to health problems such as cancer of the lungs, mutation, heart disease, chronic kidney disease, hypokalemia and antibiotics, erythema, low and high blood pressure etc. This calls for medical investigation of the radiological level of the surface soils Awka North local government area of Anambra State, Nigeria.

In general the results in this study are comparable to similar studies carried out previously at the farming sites and in other areas in Nigeria (Darko et al., 2010; Faanu et al., 2010, 2013, 2014) as well as in other countries (UNSCEAR , 2000; Huang et al., 2014). It also indicates significant levels of the natural radionuclides in the study area and therefore radiation exposure to farmers as well as members of the public may pose significant hazard and high level risk is considered generally significant. Finally it also implies that previous farming, fishing and construction activities had imparted negatively in terms of radiological hazard to

the communities in this area.

Recommendations

The following recommendations are made in line with the findings of this study:

i. There is need for seasonal study of the radioactivity of the river in the mentioned zones to check seasonal variations in the radioactivity of surface soils and surface water sources in the entire state.
ii. Different types of crops (such as roots and tubers, fruits, legumes, vegetables and cereals) and weeds grown in the area of study should be collected and analyzed.
iii. There needs to enforce existing public health law, to safeguard the lives of the inhabitants and aquatic lives.
iv. There is also need for constant environmental monitoring by the regulated agency to prevent people from radiation health hazards.
v. Other alternative should be used by improving the soil fertility than to depend on fertilizer hence it add reasonable amount of heavy metals in the soil.
vi. Adequate information should be sought from the environmental scientist before construction of any building in order to assess the level of background ionization radiation.

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