# ENVIRONMENTAL FACTORS AND CANCER PREVALENCE IN ONDO STATE, SW-NIGERIA: IMPACT OF RADIOACTIVITY IN SOIL AND IN AIR

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## ABSTRACT

Association has been investigated between prevalence of cancer and radioactivity levels in soil and in air at five geographically-contiguous and culturally-identical Local Government Areas (LGAs) in Ondo State, Southwest Nigeria. To choose the sites, the Southwestern region of Nigeria was classified into five class-intervals of registry-reported prevalence of cancer using geo-spatial technique on data from 830 patients obtained from the Ife-Ijesha Cancer Registry, Obafemi Awolowo University Teaching Hospital, Ile-Ife. For sample collection, five towns conveniently accessible on the road network were chosen from each of these LGAs. At each town, five soil samples were randomly collected and taken to the laboratory for evaluation of gamma radioactivity using a CsI-based spectrometer. Furthermore, a survey meter was used at each sample collection point to determine *in situ* the gamma dose rate in air. There was a good correlation between results obtained *in situ* by survey meter and laboratory gamma spectrometry. No statistically significant relationship was observed between Cancer prevalence and the levels of gamma radioactivity measured in the study area in general. However, wide disparity in cancer prevalence was observed between the two LGAs (Ondo East and Ondo West) into which the city of Ondo is divided. Ondo East had a prevalence of 54 cancer cases per million while the prevalence for Ondo West in the same period was 187 cases per million. The activity concentrations of all three families of naturally-occurring radioactivity were also found to be significantly higher in soil samples from Ondo West. The p-levels of the differences were respectively (p=0.025 for $^{40}$K, 0.066 for $^{238}$U, and 0.081 for $^{232}$Th. The study concludes that environmental radioactivity is associated with cancer prevalence in the city of Ondo, although the picture in the entire Southwest Nigeria is not conclusive given the limited size of data in the study.

**KEYWORDS:** Radioactivity, Background Radiation, Cancer Prevalence. Gamma Spectrometry

## INTRODUCTION

According to the World Cancer Report (2003), approximately 10 million people are diagnosed with cancer annually and more than 6 million die of the disease every year. Even though cancer is a major disease burden worldwide, marked geographical variations in its overall incidence have been observed. In Nigeria, as in several other countries it is required that every diagnosed case of cancer or other malignant disease be processed and reported to a Cancer Registry. The Registries therefore contain vital information, including the spatial and temporal distribution of the cancer cases, which could help in identifying factors associated with the development of cancer, and ultimately help in preventing the disease.

One of the physical variables that has been associated with carcinogenesis is environmental radioactivity (Avwiri *et al.*, 2014a; Akinloye 1999; Akinloye *et al.,* 1999 and Hess *et al.*, 1983). Background radiation levels are from a combination of terrestrial (from $^{40}$K, and from $^{232}$Th, $^{226}$Ra and their progenies) and cosmic radiation (photons, muons, heavy charged particles, *etc*.). According to Nussbaum and Kohnlein (1995), records of measurements of terrestrial gamma ray dose rates by British Government Agencies show that the doses vary by as much as a factor of five across the British Isles. Using the very large data base of the Oxford Survey of Childhood Cancer (containing detailed records of more than 22,000 childhood cancer deaths, and an equal number of matched controls in Great Britain from 1950-1979), Knox *et al.* (1988) were able to correlate the geographic distribution of childhood cancers with the gamma ray dose rates in Great Britain. The authors concluded that prenatal exposure to background radiation may contribute a major fraction of all "normal" childhood cancers. Similarly, it is expected that a significant fraction of adult cancers is radiogenic. According to estimates made by Gofman (1990), as much as 25% of adult cancers could be due to background radiation.

There are only few published works that attempted to link cancer incidence or prevalence with data available at Cancer registries in Nigeria. One of the serious efforts involved an attempt to correlate soil radioactivity and incidence of cancer in 6 geo-political zones of Nigeria (Farai *et al.*, 2006). Though a good pioneering work, the use of geo-political zones was rather nebulous with so many factors capable of confounding the results embedded. It is extremely difficult to connect the cancer patients represented by the incidence data with the soil radioactivity measured; and the null result obtained in the work is therefore not surprising. In this study, association is sought between environmental radioactivity and cancer prevalence in geographical locations of cancer patients using data available at both the Ife-Ijesha Cancer Registry and the Medical Records Department at the Obafemi Awolowo University Teaching Hospital Complex (OAUTHC) Ile-Ife.

## MATERIALS AND METHODS

## The Study Area

The study area, in principle, comprised of the entire Southwest region of Nigeria. The region was classified into five class-intervals of cancer prevalence using geo-spatial technique on data from the Ife-Ijesha Cancer Registry at the Obafemi Awolowo University Teaching Hospital, Ile-Ife. Five geographically-contiguous and culturally-identical Local Government Areas (LGAs), with cancer prevalence spanning the five class intervals were then identified. All these LGAs were purposively chosen to fall within Ondo State. Such restriction ensured that the inevitable bias introduced into the prevalence data by the distance to the Cancer registry under consideration could be minimized. The use of a Hospital-based, and not population-based data made this bias, inevitable. For instance, a great percentage of the cancer cases reported from SW Nigeria at the Ife-Ijesha Registry were observed to be from Local Government areas close to Ile-Ife. Patients from Ondo State however have similar likelihood of presenting at Ife-Ijesha Registry than going elsewhere. The selected LGAs, which thus formed the core study area for this work, were Ondo West, Ondo East, Idanre, Akure South, and Ifedore. The study area is shown in Figure 1 while the cancer prevalence from the selected LGAs is shown in Table 1. The cancer prevalence for each LGA was computed by dividing the number of cancer cases reported at the Registry, by the 2006 population census data for the LGA as supplied by the National Population Commission. For sample collection, five cities/villages conveniently accessible on the road network (for ease of sample collection), were chosen from each of these LGAs. These sites and their exact GPS locations are included in the results in Table 2.

## Sampling Method

Five soil samples were collected from different parts of each of the sites selected as described above. Hence a total of twenty five (25) samples were collected from five selected Local Government Areas in Ondo State. A survey meter was employed in recording *in-situ* the radioactivity measurement at the point of each sample collection to determine the exposure rate due to background radiation. At the point of collection, the samples were properly labeled to avoid any mix up, and the GPS coordinates of the locations were recorded. The samples so collected were then transported to the laboratory for further processing.

## Sample Preparation

The soil samples collected were air-dried at laboratory temperature until constant weight was achieved. The dried samples were crushed, homogenized and made to pass through a 2 mm mesh sieve. The processed soil samples were kept in air-tight plastic containers which had been washed thoroughly with dilute $HNO_3$ and rinsed with distilled water. Each of the pulverized samples was weighed using an electronic balance and placed in a labeled and pre-weighed container. Each sample was sealed for a period of at least 28 days to ensure secular equilibrium between the various radioactive daughters involved.

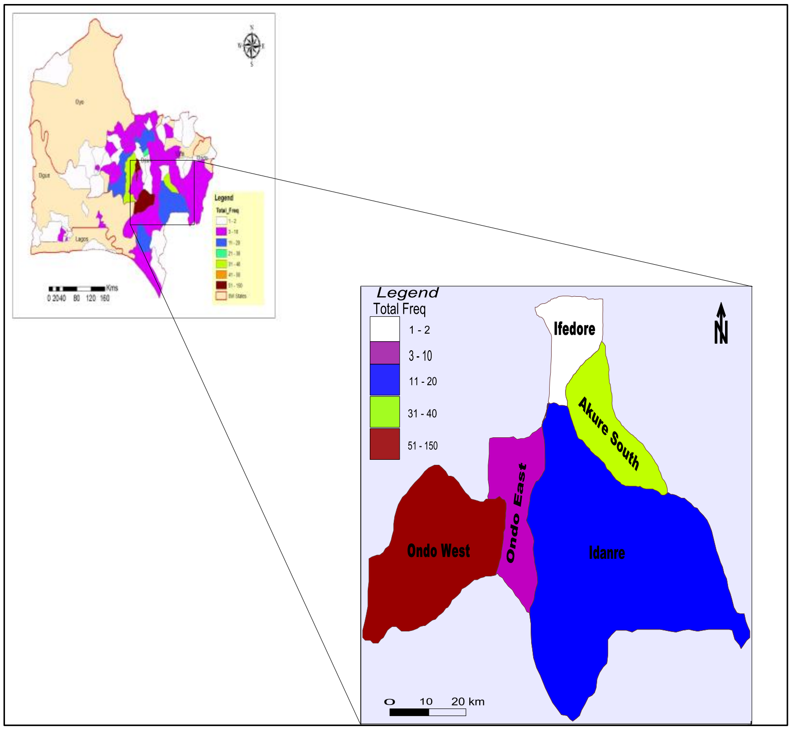



**Figure 1:** Geo-spatial distribution of cancer prevalence from 2010 to 2014 in South-Western Nigeria and selected Local Government Areas (from Ondo State) for this study

**Table 1:** Cancer Prevalence in Ondo State based on cases reported at Ife-Ijesha Cancer Registry and Population Census Data for 2006 by National Population Commission of Nigeria (https://en.wikipedia.org/wiki/Ondo_State)

| Local Governments | Number of Cancer Cases Observed | Population Census Data | Prevalence Per million |
|---|---|---|---|
| Akure South | 36 | 353, 211 | 102.9 |
| Idanre | 12 | 129,024 | 93.0 |
| Ifedore | 1 | 176,327 | 5.7 |
| Ondo East | 4 | 74,758 | 53.5 |
| Ondo West | 53 | 283,672 | 186.8 |
| Other LGAs in SW | 724 | | |
| Total | 830 | | |

**Gamma Spectrometry and Determination of Activity Concentration**

A gamma spectrometry system comprising of a well-calibrated CsI(Tl) detector, a URSA II Multichannel Analyser, and a custom-made Pb-shielding array located at the Nutrition and Health-Related Environmental Research Laboratory of the Department of Physics and Engineering Physics in Obafemi Awolowo University, Ile-Ife, Nigeria, was employed in determining the activity concentrations of the radionuclides in the samples. All the samples were counted for 36,000 seconds (10 hours) and the peak areas corresponding to 1460 keV for $^{40}K$, 352 keV ($^{214}Pb$) for $^{238}U$, and 583 keV ($^{208}Tl$) for $^{232}Th$ were considered for the estimation of natural radionuclides in all the samples. The integrated counts recorded under the chosen energy peaks were noted for each spectrum. The specific activity concentration of each radionuclide in the samples was obtained using the comparative method of analysis. In this method, the activity concentration of the sample is determined by comparing the relevant peak area in the sample with area of similar photopeak in a reference standard with already known activity concentration. Equation 1 gives the Activity Concentration $A_c$ in a sample counted on a detector with a given efficiency $\varepsilon_\gamma$ for the gamma line of interest:

$$A_c = \frac{A_N}{P_\gamma M_s \varepsilon_\gamma t} \qquad (1)$$

In the equation, $A_N$ = net area of photopeak (after subtracting appropriate background counts).
$M_s$ = Sample mass, t = total counting time and $P_\gamma$= is the fractional abundance of the γ-line of interest.
Comparing the unknown activity concentration in the sample ($A_c$*) with the known activity concentration in the standard ($A_c^S$), equation (1) thus becomes

$$A_c^* = A_N^* A_c^S M_s^S / A_N^S M_s^* \qquad (2)$$

since the counting geometry and detector efficiency, gamma fractional abundance, and the counting time are the same for both the standard and the sample . In equation (2), the superscript * applies to variables in the sample while the superscript S applies to those in the standard.
The reference standard used for the comparison in this work was IAEA S-357 soil standard.

## RESULTS AND DISCUSSION

**Exposure Rate by Survey Meter**

The results of the *in-situ* measurement in air using a radiation survey meter, together with the activity concentrations in soil (for easy comparison) are shown in Table 2. The average exposure rates in air at the 5 LGAs ranged between 0.17 to 0.63 µSv/hr (1.53 to 5.48 mSv/y) with a mean of 0.35 µSv/hr (3.12 mSv/y). The lowest exposure rate was in Ireje (Ondo East Local Government) and Ayedun (Akure South Local Government) while the highest was in Alade 2 (Idanre Local Government).

Idanre Local Government had the highest mean exposure rate of 0.44 µSv/hr (3.84 mSv/y) while Akure South Local Government had the lowest mean value of 0.26 µSv/hr (2.59 mSv/y). These results do not correlate with the order of cancer prevalence as Ondo West and Ifedore Local Government Areas were expected to have the highest and the lowest mean values respectively.

UNSCEAR (2000) recommended a limit of 20 mSv/y (2.28 μSv/hr) for occupational exposure and 1 mSv/y (0.11 μSv/ hr) for general exposure. However, the results in this work, although higher than the mean background radiation levels reported by Jwanbot *et al.*, (2013) for Jos and environs, are low compared with values of 30 μSv/hr (262 mSv/y) obtained in high background radiation areas in China, Brazil and India (Larmash, 1983).

## Activity Concentrations

Typical spectra for soil samples with high and low activity levels, and from IAEA Soil-357 used as reference standard are shown in Figures 2a-c. The result of the gamma ray spectrometry of the soil samples is presented as bar charts in Figure 3. The radionuclide observed with reliable regularity belonged to the decay series chain headed by $^{238}$U and $^{232}$Th as well as the non- series $^{40}$K. The $^{40}$K activity concentration dominated over the $^{238}$U and $^{232}$Th elemental activities as expected. The activity concentration of $^{40}$K ranged from 89.1 ± 2.9 to 561.9 ± 18.6 Bq/kg. Similar results for $^{238}$U are 20.3 ± 2.1 to 344.3 ±35.5 Bq/kg. For $^{232}$Th, gamma activity ranged from 3.3 ± 0.6 to 83.4 ± 14.2 Bq/kg. From Figure 3, it could be seen that Idanre Local Government Area had the highest mean values of 117.4, 28.2 and 272.8 Bq/kq for $^{238}$U, $^{232}$Th and $^{40}$K respectively compared with Ondo East that had the lowest mean value of 25.8, 4.8 and 134.9 Bq/kg for $^{238}$U, $^{232}$Th and $^{40}$K respectively. These results do not correlate with the order of cancer prevalence as Ondo West and Ifedore were expected to have the highest and the lowest mean values respectively.

**Table 2:** Exposure Rates in Air and Activity Concentrations in Soil across selected LGAs in Ondo State

| S/N | Local Govt | Stations | GPS Location | | Exposure Rate in air (Arbitrary units) | Activity Concentration (Bq/kg) | | | Absorbed Dose (nGy/hr) | Annual Effective Dose (mSv/y) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Latitude | Longitude | | $^{40}$K | $^{238}$U | $^{232}$Th | | |
| 1 | **ONDO WEST** | SALUWA | 07°05.865' | 04°50.129' | 2.29 | 196.43 ± 6.56 | 44.85 ± 4.63 | 9.06 ± 1.54 | 34.38 | 0.042 |
| 2 | | STATION 4 | 07°06.050' | 04°50.683' | 3.05 | 232.23 ± 7.72 | 47.32 ± 4.88 | 9.1 ± 1.55 | 37.04 | 0.045 |
| 3 | | STATION 5 | 07°08.453' | 04°53.631' | 2.29 | 191.04 ± 6.38 | 37.23 ± 3.84 | 6.96 ± 1.18 | 29.37 | 0.036 |
| 4 | | SURULERE | 07°06.011' | 04°49.554' | 2.28 | 169.27 ± 5.65 | 47.37 ± 4.88 | 9.49 ± 1.61 | 34.68 | 0.043 |
| 5 | | YABA | 07°06.840' | 04°51.480' | 3.05 | 258.32 ± 8.62 | 98.82 ± 10.19 | 25.5 ± 4.34 | 71.83 | 0.088 |
| | | **Mean** | | | **2.59** | **209.46 ± 35.46** | **55.12 ± 5.68** | **12.02 ± 2.04** | **41.46** | **0.051** |
| 6 | **AKURE SOUTH** | AJIPOWO | 07°15.833' | 04°10.912' | 2.29 | 132.61 ± 4.42 | 32.84 ± 3.38 | 4.65 ± 0.79 | 23.51 | 0.029 |
| 7 | | ARAROMI | 07°14.548' | 04°09.692' | 3.81 | 189.1 ± 6.31 | 64.84 ± 6.69 | 8.73 ± 1.48 | 43.11 | 0.053 |
| 8 | | AYEDUN | 07°15.455' | 04°10.621' | 1.53 | 263.06 ± 8.78 | 63.29 ± 6.53 | 8.24 ± 1.4 | 45.19 | 0.055 |
| 9 | | GBOBI | 07°15.643' | 04°11.621' | 3.05 | 203.12 ± 6.78 | 56.21 ± 5.80 | 10.5 ± 1.78 | 40.78 | 0.05 |
| 10 | | IJOMU | 07°15.380' | 04°11.907' | 2.29 | 224.68 ± 7.5 | 48.37 ± 4.99 | 8.55 ± 1.45 | 36.88 | 0.045 |
| | | **Mean** | | | **2.59** | **202.51 ± 43.00** | **53.11 ± 5.48** | **8.13 ± 1.38** | **37.89** | **0.047** |
| 11 | **IDANRE** | ALADE 1 | 07°11.711' | 04°01.456' | 3.81 | 240.42 ± 8.03 | 56.98 ± 5.88 | 12.37 ± 2.1 | 43.82 | 0.054 |
| 12 | | ATOSIN | 07°11.714' | 04°01.456' | 3.81 | 106.52 ± 3.56 | 33.81 ± 3.48 | 8.26 ± 1.4 | 25.05 | 0.031 |
| 13 | | AYETORO 1 | 07°11.591' | 04°01.271' | 2.29 | 218.64 ± 7.30 | 76.81 ± 7.92 | 18.06 ± 3.07 | 55.51 | 0.068 |
| 14 | | ALADE 2 | 07°08.539' | 04°05.766' | *5.48* | 561.9 ± 18.56 | 344.34 ± 35.54 | 83.4 ± 14.21 | 232.89 | 0.286 |
| 15 | | AYETORO 2 | 07°11.589' | 04°01.270' | 3.81 | 236.32 ± 7.89 | 75.2 ± 7.76 | 18.69 ± 3.18 | 55.89 | 0.069 |
| | | **Mean** | | | **3.84** | **272.76 ± 152.67** | **172.94 ± [illegible]** | **28.16 ± 4.79** | **82.63** | **0.101** |
| 16 | **ONDO** | GAS STATION 1 | 07°08.476' | 04°53.476' | 2.29 | 146.19 ± 4.88 | 32.81 ± 3.38 | 3.29 ± 0.56 | 23.24 | 0.029 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 17 | **EAST** | GAS STATION 2 | 07°09.796’ | 04°56.013’ | 3.05 | 89.05 ± 2.97 | 20.26 ± 2.09 | 5.82 ± 0.99 | 16.59 | 0.02 |
| 18 | | IREJE | 07°09.911’ | 04°56.026’ | 1.53 | 146.41 ± 4.89 | 26.82 ± 2.76 | 4.65 ± 0.79 | 21.3 | 0.026 |
| 19 | | OBOTO1 | 07°10.015’ | 04°56.411’ | 3.05 | 139.94 ± 4.67 | 24.42 ± 2.52 | 4.26 ± 0.72 | 19.69 | 0.024 |
| 20 | | OBOTO2 | 07°09.896’ | 04°56.419’ | 4.56 | 152.66 ± 5.1 | 24.57 ± 2.53 | 6.19 ± 1.05 | 21.46 | 0.026 |
| | | **Mean** | | | **2.90** | **134.85 ± 4.50** | **25.78 ± 2.66** | **4.84 ± 0.82** | **20.46** | **0.025** |
| 21 | | IGBARAOKE 1 | 07°20.829’ | 04°06.291’ | 3.05 | 86.68 ± 2.89 | 32.39 ± 3.34 | 5.08 ± 0.86 | 21.65 | 0.027 |
| 22 | | ILARA3 | 07°20.840’ | 04°06.309’ | 3.05 | 129.81 ± 4.33 | 46.35 ± 4.78 | 12.09 ± 2.06 | 34.13 | 0.042 |
| 23 | **IFEDORE** | ILARA1 | 07°20.830’ | 04°06.271’ | 4.58 | 324.73 ± 10.84 | 135.66 ± 14.00 | 38.28 ± 6.52 | 99.34 | 0.122 |
| 24 | | ILARA2 | 07°24.230’ | 04°00.877’ | 4.58 | 192.55 ± 6.43 | 59.44 ± 6.13 | 14.19 ± 2.41 | 44.06 | 0.054 |
| 25 | | IGBARAOKE 2 | 07°20.831’ | 04°06.287’ | 3.05 | 111.69 3.73 | 33.64 ± 3,47 | 5.66 ± 0.96 | 23.62 | 0.029 |
| | | **Mean** | | | **3.66** | **169.09 ± 5.64** | **61.50 ± 6.34** | **15.06 ± 2.56** | **44.56** | **0.055** |
| | **Overall Mean** | | | | **3.12** | **197.74 ± 6.59** | **62.59 ± 6.46** | **3.12** | **3.12** | **0.056** |

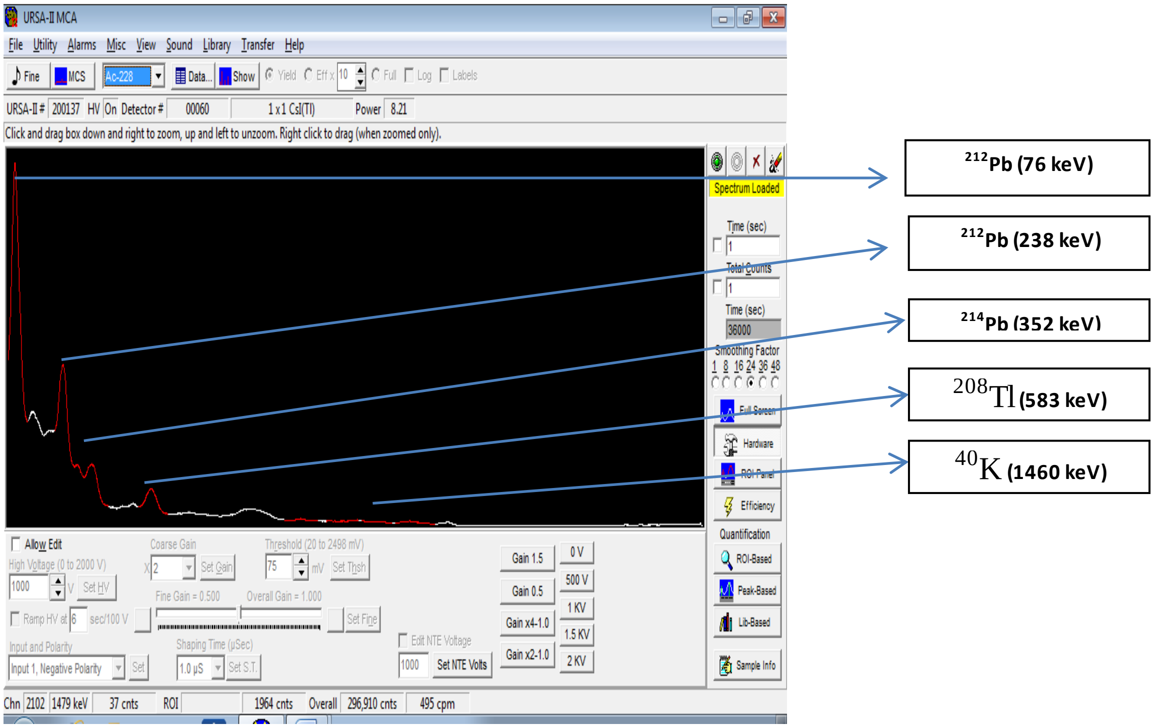



**Figure 2a:** Typical Gamma Ray Spectrum of Sample with High Activity Concentration

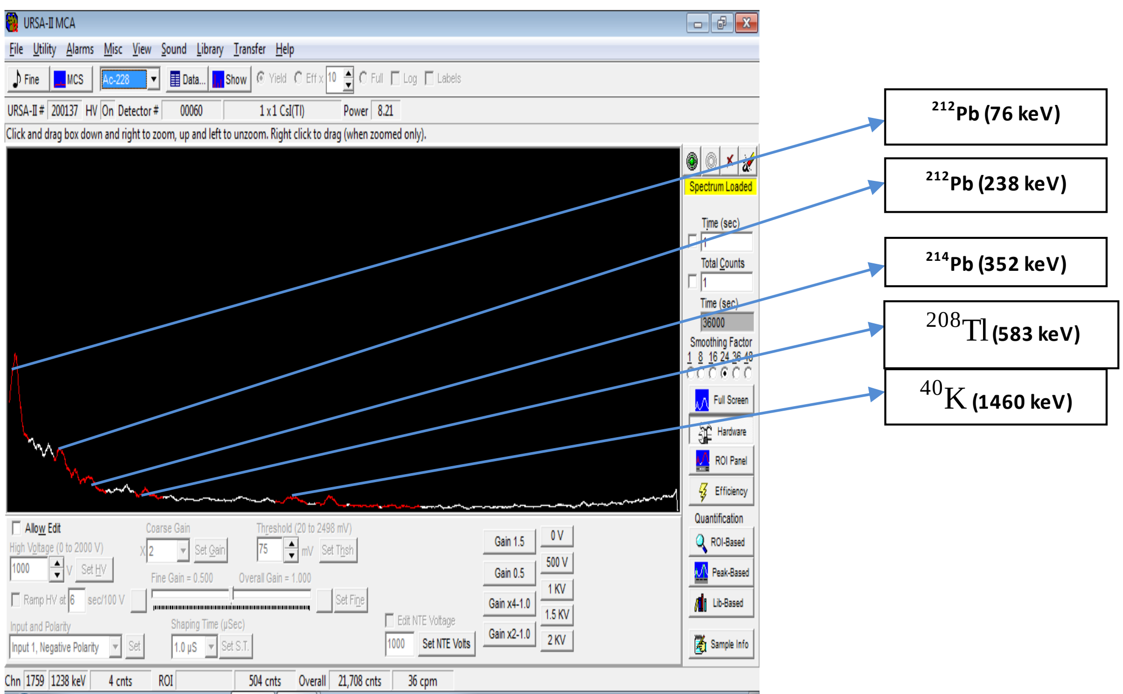



**Figure 2b.** Typical Gamma Ray Spectrum of Sample with Low Activity Concentration

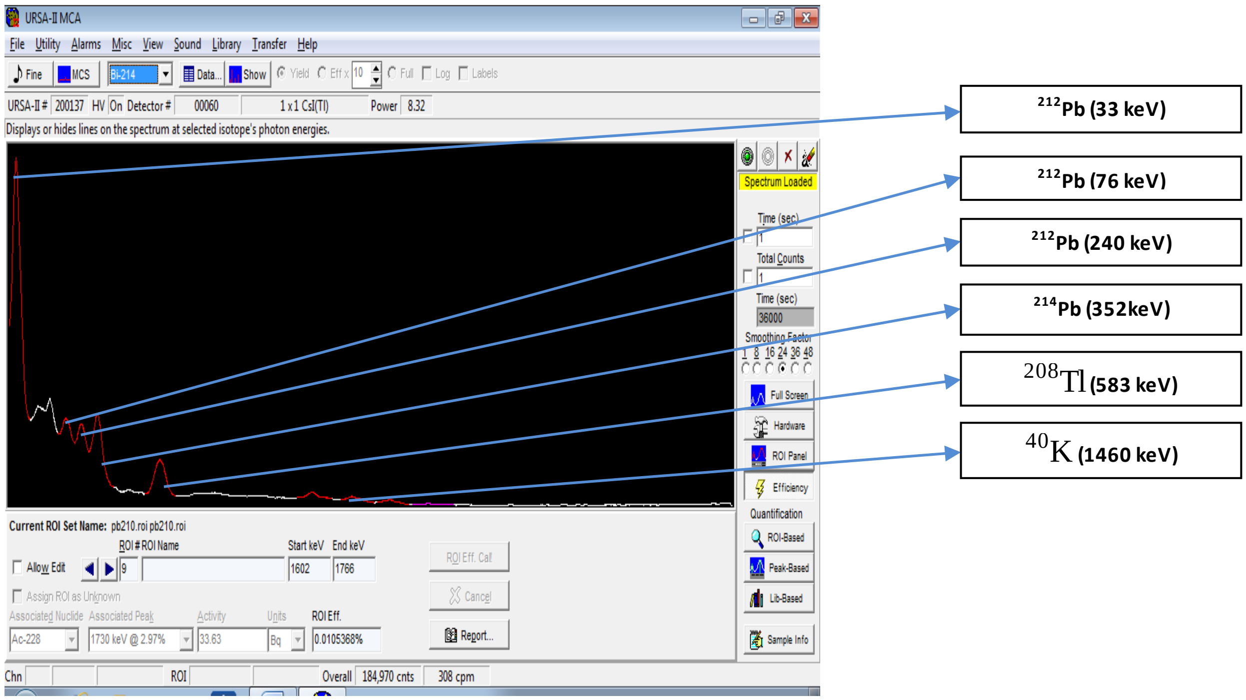



**Figure 2c.** Typical Gamma Ray Spectrum of Standard Sample (IAEA SOIL-357)

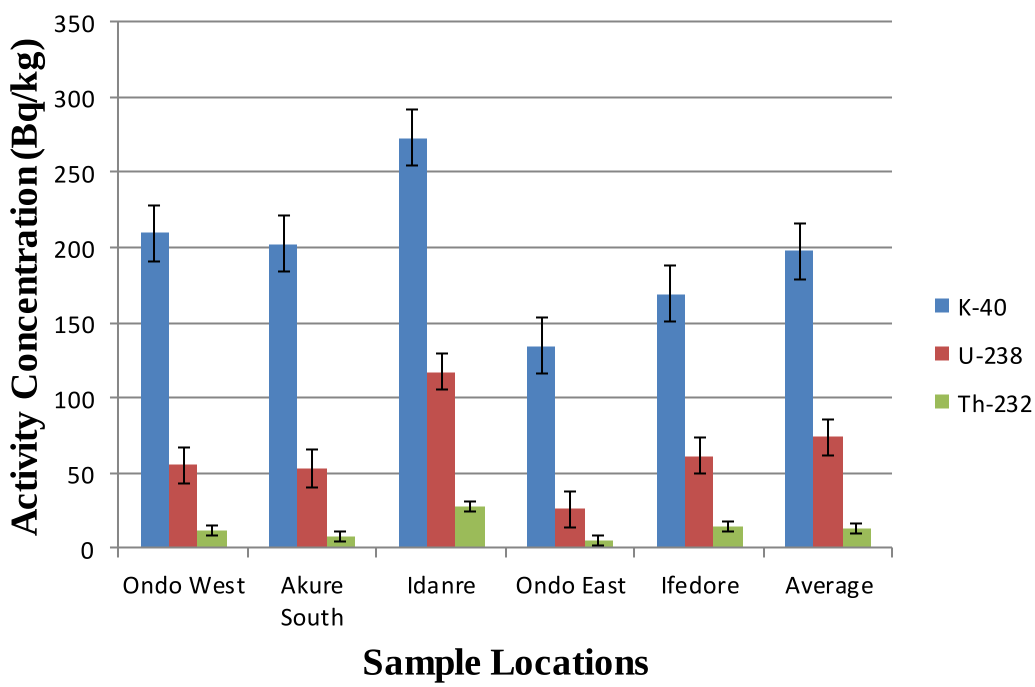



**Figure 3:** Mean activity concentrations (Bq/kg) in the selected Local Governments in Ondo state

**Absorbed Dose Rates for Soil**

The external absorbed dose rate, D (nGy/hr) in air at 1 m above the ground level for soils containing the concentrations of the radionuclides measured in the samples was calculated using the usual conversion equation (Avwiri *et al.,* 2014b; UNSCEAR, 2000), (equation 3)

$$D = cU\,CU + cTh\,CTh + cK\,CK. \qquad (3)$$

Where CU, CTh, CK are the radioactivity concentration in Bq/kg and cU, cTh, and cK are dose conversion factors which are 0.462, 0.604 and 0.0417for $^{238}$U, $^{232}$Th and $^{40}$K respectively.

The results obtained are shown in Figure 4. The values ranged from 17 to 233 nGy/hr. The overall average value of the absorbed dose rate for the five (5) Local governments was 45 nGy/hr.

The absorbed dose rate at Gas Station 2 (Ondo East LGA) was observed to be the lowest while the highest was found at Alade 2 (Idanre LGA). These results do not correlate with the order of cancer prevalence as Ondo West and Ifedore were expected to have the highest and the lowest values respectively. From Table 2, it can be seen that Idanre LGA had the highest mean absorbed dose rate, followed by Ifedore, Ondo West, and Akure Local Government consecutively. Ondo East LGA had the lowest mean absorbed dose rate value. It can also be observed that the average absorbed dose rates in Ondo West, Akure South, Ondo East and Ifedore LGAs are lower than the recommended limit of 57 nGy/hr (UNSCEAR, 2000; Avwiri *et al.,* 2014b). However some places in Ondo West and Ifedore LGAs had higher values than this recommended limit. The average value for Idanre LGA shows a significant high value compared with the recommended limit due to Alade 2 which has a value that is about 400% the recommended limit.

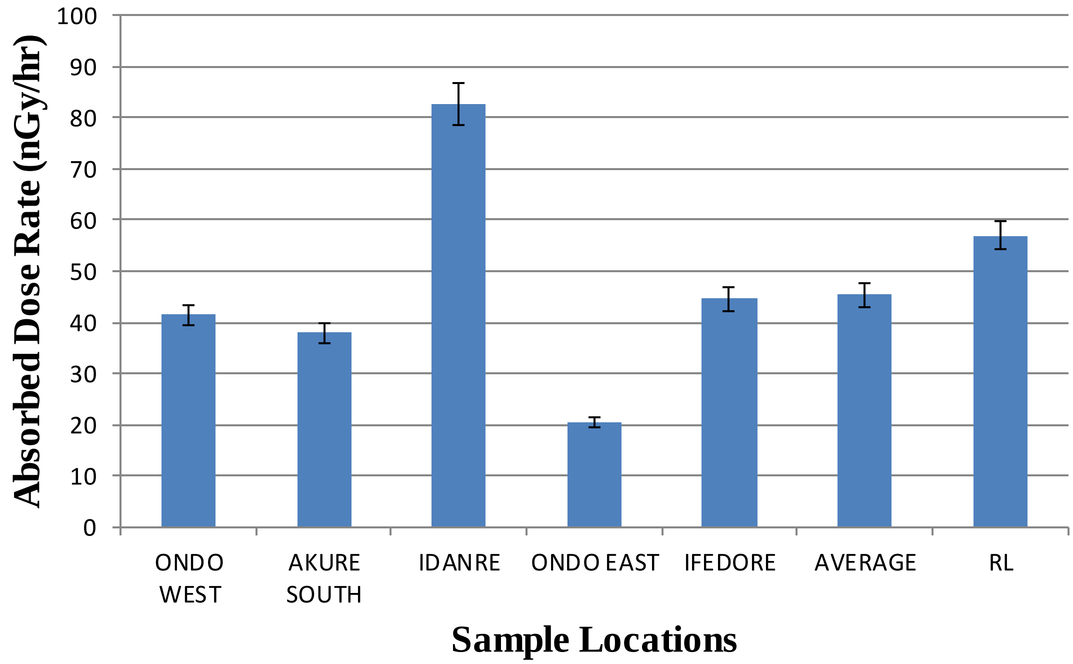



**Figure 4:** A comparison of the absorbed dose rate (nGy/hr) in the selected Local Governments in Ondo state, Nigeria**.** RL is the threshold limit by UNSCEAR (2000)

### 3.4 Annual Effective Dose (AEDE)

The annual effective dose received outdoor from soil was calculated from the absorbed dose rate by applying dose conversion factor of 0.7 Sv/Gy and occupancy factor for outdoor of 0.2 (Avwiri, *et al.*, 2014b). The AEDE was determined using (Issa *et al.*, 2013; Avwiri *et al.*, 2014b):

$$AEDE_{outdoor}\ (\mu Sv/y) = D(nGy/h) \times 8760h \times 0.7\ (Sv/Gy) \times 0.2 \times 10^{-3}$$

The results are shown in Table 2. The values ranged from 0.020 to 0.286 mSv/y. The overall average values of the effective dose received was 55.7 µSv/y for the five (5) Local Governments.

The annual effective dose in Gas station 2 (Ondo East LGA) was observed to be the lowest and the highest was found in Alade 2 (Idanre LGA). These results do not correlate with the order of cancer prevalence as Ondo West and Ifedore were expected to have the highest and the lowest values respectively. From Table 2, it can be seen that Idanre LGA had the highest annual effective dose followed by Ifedore, Ondo West, and Akure South LGA consecutively. Ondo East LGA had the lowest annual effective dose values.

## Correlation of Activity Concentration and Cancer Prevalence

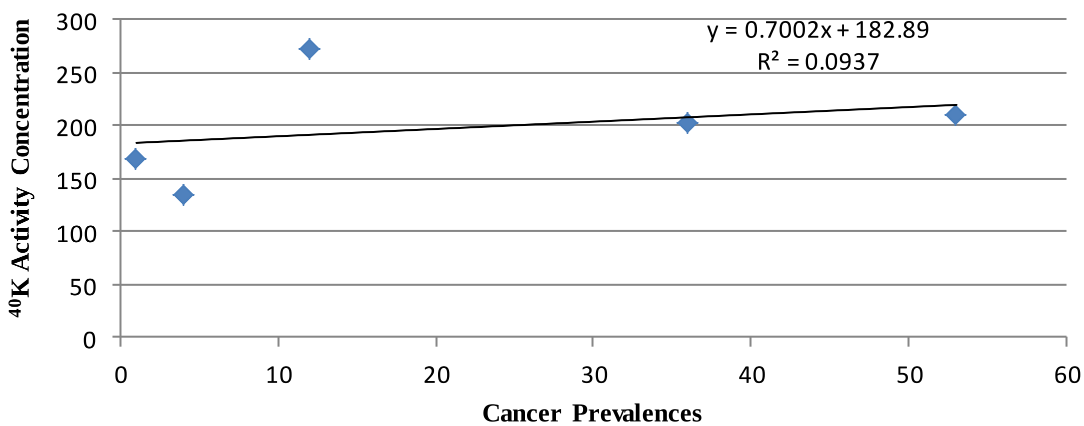
The Pearson correlation co-efficient values gotten for the pairs of cancer prevalence and $^{40}$K, $^{238}$U and $^{232}$Th are 0.31, -0.07 and -0.18 respectively. From statistical tables, the critical value for these correlations to be significant at p=0.1 level is 0.801. These values are therefore not statistically significant. The correlations are illustrated by the scattergraphs in Figures 5 (a-c). For these preliminary analyses with limited database, all cancer types are grouped together. This obviously will introduce confounding factors which may hide possible correlations. These authors believe that confounding factors, rather than hormesis, is responsible for the decreasing trend (even if not statistically significant) of cancer prevalence as activity concentrations of $^{238}$U and $^{232}$Th increased. The hormesis theory suggesting that chronic exposure to low-dose ionizing radiation may in fact be beneficial with respect to carcinogenesis has sometimes been put forward as a possible explanation of this trend. For instance, Mortazavi *et al*. (2006), confronted with such data as obtained here concluded "that prolonged exposure to high levels of natural radiation possibly triggers processes such as the production of antioxidants and repair enzymes, which decreases the frequency of chromosome aberrations and the cancer incidence rate."

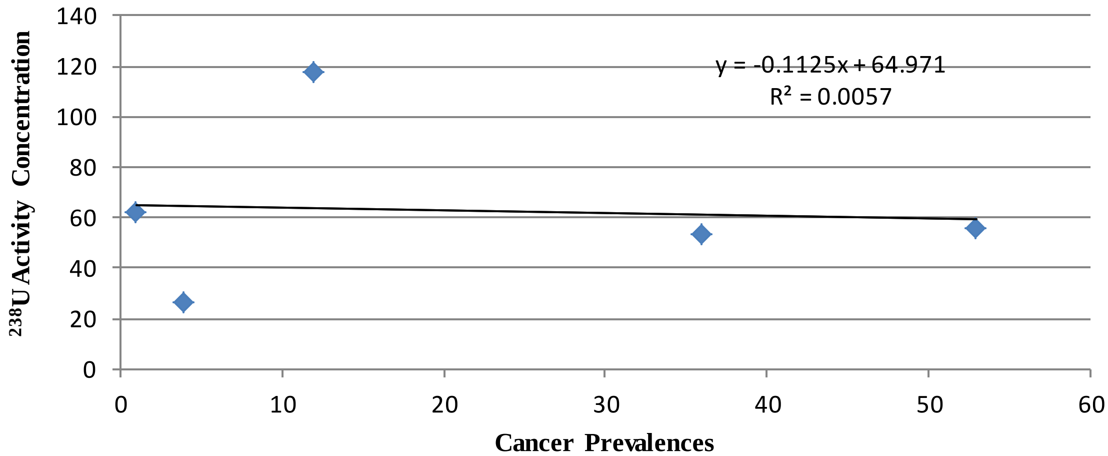
However, Nussbaum and Kohnlein (1995) felt that most results being used to suggest hormesis in the actions of low-dose ionizing radiation actually were more or less a reflection of the importance of several ignored confounding factors. Unfortunately, many investigators still continue to downplay such factors as socio-economics and lifestyle in carcinogenesis. Nussbaum and Kohnlein (1995) pointed out, citing references, that "when several such studies were critically reanalysed with a focus on neglected confounding factors…. no valid support could be found for their claim of beneficial effects at low doses".

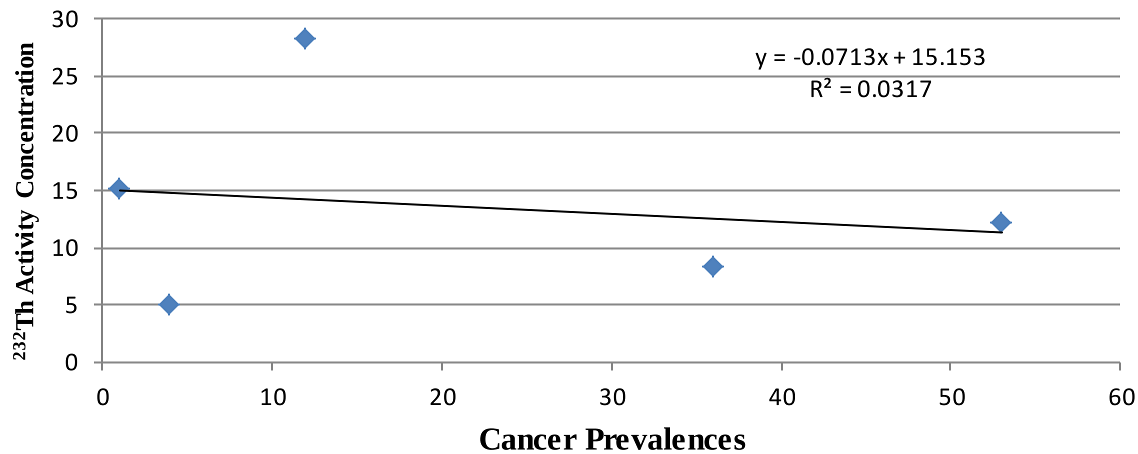
In the present situation, it is proposed that some factors associated with $^{238}$U and $^{232}$Th are strongly at play. Such factors could for instance be some essential elements whose occurrence are associated with $^{238}$U and $^{232}$Th; and which serving as antioxidants, are protecting against cancer far more than $^{232}$Th and $^{238}$U are promoting cancer. In another paper (Oluwasina *et al.*

2016), our Research Group showed that the levels of the anti-oxidant essential trace element Manganese, is significantly elevated ($p<0.03$) in soil samples from Ondo East compared with those from Ondo West. The data obtained here could provide a useful basis for closer investigations of similar factors that might be at play in this regard.

It should be noted that the fraction of cancer cases reported at the Ife-Ijesha Cancer Registry from the different LGAs in Ondo State may also be influenced by other factors (apart from distance, which has been assumed to be uniform in this work). These include the tendency of patients to seek medical assistance in non-orthodox centres where records are not kept or reported. In addition, some other major cancer risk factors such as physical activity, weight, dangerous chemicals (including pesticides in agricultural belt), sun exposure, asbestos, exposure to infections like hepatitis, HPV, and HIV may influence cancer prevalence, apart from levels of radioactivity (IARC, 2014). Finally, it should be noted that the population data used in computing the prevalence was based on 2006 census, and the rate of population growth/migration might not be uniform as implicitly assumed here. This could affect the prevalence values used in this work.






**Figures 5 a-c:** Correlation between Mean Activity Concentrations and Registry-Reported Cancer Prevalencies in Ondo State

**Correlation between Annual Effective Dose and Cancer Prevalence**

The impact of all the three types of gamma radioactivity (from $^{40}$K, $^{232}$Th, and $^{238}$U) is described by the Effective Dose. As described previously, the Effective Dose is obtained by multiplying each Activity Concentration by a factor, weighted to reflect the relative absorption of the gamma energies in air/tissue. Correlation co-efficient value gotten for the pairs of cancer prevalence and annual effective dose was -0.07. This shows no meaningful relationship with the order of prevalence of cancer in the five (5) selected Local Governments in Ondo state as the correlation coefficient is approximately zero (Figure 6). Obviously, the influence of $^{238}U$ and $^{232}Th$ series has overshadowed that of $^{40}K$ (which had the smallest weighting factor of 0.0417 in equation 3)

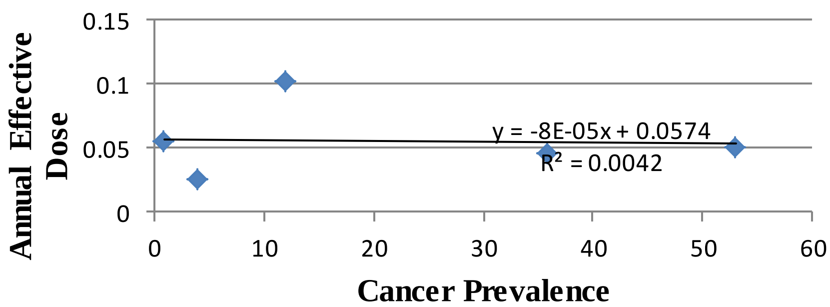



**Figure 6:** Correlation diagram between annual effective dose and cancer prevalence in the selected Local Government in Ondo state

**Correlation between Exposure Rate and Annual Effective Dose**

The Pearson correlation co-efficient value gotten for the pairs of exposure rate and annual effective dose was 0.70. This shows a positive relationship between the exposure rate and the annual effective doses. This correlation between the two different methods used to assess radioactivity in this work (spectrometry and survey meter) is a good indication of the goodness of the data obtained (Goodman, 1970). This result is illustrated in Figure 7.

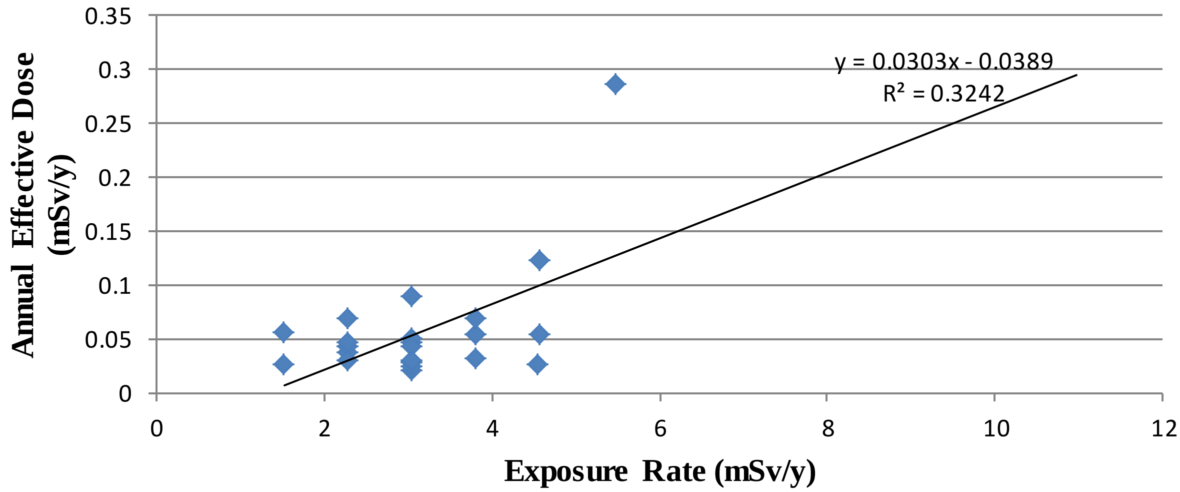



**Figure 7:** Correlation between Annual Effective Dose and Exposure Rate in the selected Local Governments in Ondo state

**Comparison of Radioactivity in Regions with Low and High Cancer Prevalences**

In view of the absence of significant correlations between cancer prevalence and radioactivity in the five class-interval levels as described above, it was decided to improve the data sizes involved by considering only two class intervals, designated simply as High and Low Cancer Prevalence Groups. Idanre, Akure South, and Ondo West Local Governments with cancer prevalence of 93, 103 and 187 per million respectively were designated as the High Prevalence Group, while Ifedore and Ondo East LGAs with respective prevalence of 6 and 54 per million were designated as the Low Prevalence Group.

The activity concentration of $^{40}$K for the Low Region ranged from 89.1 ± 2.9 to 324.7 ± 10.8 Bq/kg while for the High Region, it ranged from 106.5 ± 3.6 to 561.9 ± 18.6 Bq/kg. Similar results for $^{238}$U are 20.3 ± 2.1 to 135.7 ± 14.0 Bq/kg for low prevalence region while 32.8 ± 3.4 to 344.3 ±35.5 Bq/kg for the High prevalence region. For $^{232}$Th, gamma activity ranged from 3.3 ± 0.6 to 38.2 ± 6.5 Bq/kg for the Low Region and from 4.7 ± 0.8 to 83.4 ± 14.2 Bq/kg for the High Region. These values are shown in Figure 8. Furthermore, the values of the absorbed dose rate ranged from 16.6 to 99.3 nGy/hr for Low Prevalence Region and 23.5 to 232.9 nGy/hr for High Prevalence Region. The values ranged from 0.020 to 0.121 mSv/y for Low Prevalence Regions and 0.028 to 0.286 mSv/y for High Prevalence Regions.

Result of t-test (two-tail) checking for significant differences in the mean values for the two regions showed a statistically significant difference in $^{40}K$ levels. The mean value of $^{40}K$ levels in the High Cancer Region was significantly higher (with p = 0.0501) than the level at the Low Cancer Region. The differences in activity levels from $^{238}U$ and $^{232}Th$ series in the High and Low Regions were however not statistically significant. The values were: $^{238}U$, p = 0.2354; and for $^{232}Th$, p = 0.3707.

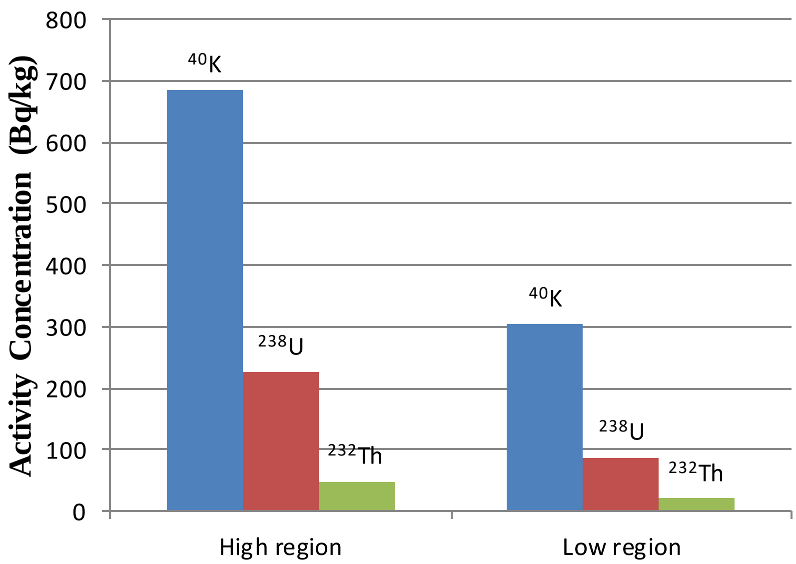



**Figure 8**: Activity Concentrations of Radioactivity in Designated High (383 cancer cases per million population) and Low (60 cancer cases per million population) regions of Cancer Prevalence

**Comparison of Radioactivity between Ondo East LGA and Ondo West LGA**

Finally, it was noted that two Local Government Areas with wide disparity in cancer prevalence (Ondo West: Prevalence of 187 per million; and Ondo East: Prevalence of 54 per million) were actually located in the same city of Ondo. This provided an opportunity to further reduce the influence of various confounding variables (socio-economics, dietary, genetics, culture, weather, *etc)* from the data analyses. The radioactivity levels of all three series were found to be significantly higher in Ondo West which has the higher cancer prevalence. The p-levels of the differences were respectively for $^{40}K$ (p=0.025), $^{238}U$ (p=0.066), and for $^{232}Th$ (p= 0.081). The Activity Concentrations are shown on Figure 9.

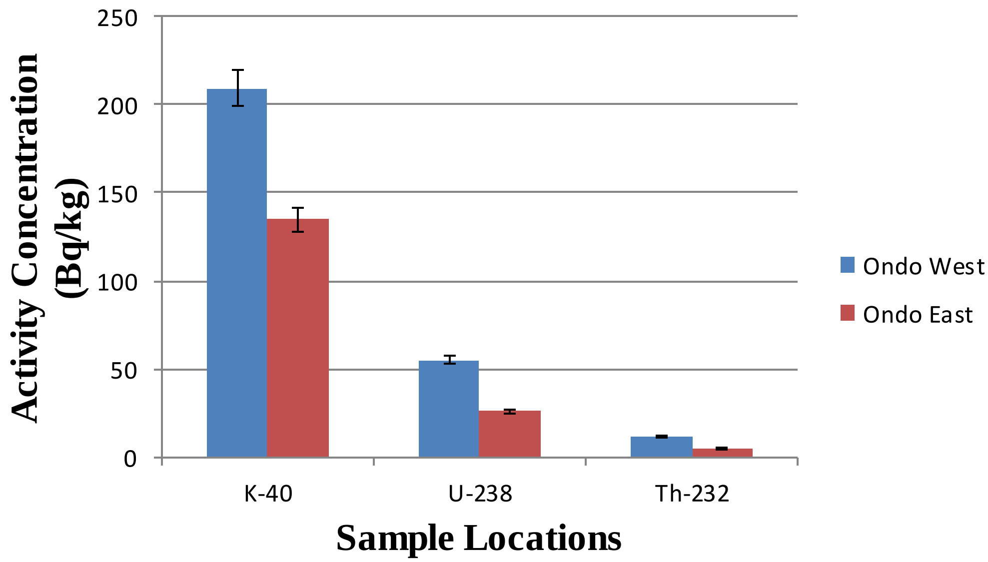



**Figure 9:** A comparison of Activity Concentrations in the city of Ondo. (Ondo East LGA and Ondo West LGA)

## CONCLUSION

All 5 categories (class intervals) of cancer prevalence identified in Southwest Nigeria by a geospatial analysis of cancer cases reported at the Ife-Ijesha Cancer registry within years 2010 and 2014 were represented in Ondo State. Therefore Local Government Areas representing each class interval were chosen from Ondo State in order to exclude as much as possible factors such as culture, diet, *etc* which may confound the results. With this initial setting, the only correlation found between soil radioactivity level and Cancer prevalence in the LGAs was observed with the Activity Concentrations of $^{40}K$. This correlation was however not statistically significant (p>0.1 two-tailed). When the five LGAs under study were categorized simply as regions of High and Low prevalence of cancer, the correlation between $^{40}K$ and cancer prevalence became more highly expressed and statistically significant (p=0.050). Finally when the focus was set in particular on Ondo city where the two LGAs had widely disparate cancer prevalence rates, significant correlations were obtained between number of cancer cases reported and radioactivity levels for all types of radioactivity studied: from $^{40}K$, $^{238}U$, $^{232}Th$. This suggests an association between cancer prevalence and radioactivity in this city. It would be interesting to determine the major pathways of radioactivity from soil into people (through water and diet) in order to be able to further clarify this association.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