International Journal of Innovative Research and Advanced Studies (IJIRAS)
Volume 4 Issue 11, November 2017

ISSN: 2394-4404

Natural Radioactivity Measurements To Determine The Radiation Hazards From Surface Soil And Effluents In Agbara Industrial Estate, Ogun State, Nigeria

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Abstract: *The present study was carried out to determine the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in surface soil and effluent samples. Fifty five surface soil samples and five effluent samples were collected from different locations in Agbara Industrial Estate, Ogun State, Nigeria, using a high purity germanium (HPGe) detector. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples from the studied area ranged from 1.53 Bq kg^{-1} to 10.17 Bq kg^{-1}, 3.19 Bq kg^{-1} to 17.73 Bq kg^{-1} and 57.88 Bq kg^{-1} to 397.51 Bq kg^{-1} with overall mean values of 5.05, 9.11 and 171.33 Bq kg^{-1} respectively. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the effluent samples from the studied area ranged from 2.03 Bq L^{-1} to 5.24 Bq L^{-1}, 5.20 Bq L^{-1} to 8.82 Bq L^{-1} and 13.54 Bq L^{-1} to 21.84 Bq L^{-1} with overall mean values of 3.74, 6.73 and 16.84 Bq L^{-1} respectively. In soils, the mean values of the absorbed dose rate is14.77 nGy h^{-1}. Which yields the annual effective dose of 0.02 mSvy^{-1} which is well below the permissible limit. The mean radium equivalent (Ra_{eq}) and outdoor radiation hazard index (H_{ex}) for the area under study were determined as 31.28 Bq kg-1 and 0.08 respectively. The excess lifetime Cancer Rate with an arithmetic mean of 0.06×10^{-3}.In Effluents, the mean value of the absorbed dose rate is 6.34 nGy h^{-1}. Which yields the annual effective dose of 0.01 mSvy^{-1} which is well below the permissible limit. The mean radium equivalent (Ra_{eq}) and outdoor radiation hazard index (H_{ex}) for the area under study were determined as 14.66 Bq kg-1 and 0.04 respectively. The excess lifetime Cancer Rate with an arithmetic mean of 0.03×10^{-3}. The measured values are comparable with other global radioactivity measurements and are found to be save for public and environment. This study would be useful for establishing base line data on the gamma background radiation levels in the study areas for assessment of radiation exposures to the population.*

Keywords: *Soil Radioactivity, Effluents, Radionuclides, Activity concentration, Global Positioning System*

I. INTRODUCTION

Radionuclides are ubiquitous in nature and they emit energy in form of radiations to attain stability. The earth's crust contains various radioactive isotopes such as uranium, thorium, radon, tritium, carbon, and potassium among others. These isotopes and their progenies have different half lives, which emit various types of radiations such as alpha, beta and gamma rays. Additionally, cosmic radiation from the sun contributes to gamma rays surrounding the human body. In other words, the controlled manmade-artificial background radiation results from several sources such as fallouts of weapons testing, radioactive waste, and the use of radioisotopes in radiation-therapy. (McGraw-Hill, 1980).

Natural Radiation contributes to 80% of the total dosage the body may receive, while artificial radiation accounts for the other 20% dosage of human exposure (IAEA, 1986). Exposure to this radiation can cause damage to living cells resulting to either death as a result of exposure to large dose of radiation. Exposure to radiation has been associated with most form of leukemia and with cancer of several organs like lung, breast and thyroid (UNSCEAR 2000). There is an increase

ISSN: 2394-4404

chance of developing cancer as a result of exposure to radiation about the global average level of natural radiation (UNSCEAR 2000).

Environmental radiation monitoring has been carried out in some industries and industrial areas in Nigeria and other parts of the world. (Nwankwo and Akosile (2003); Avwiri and Ebeniro, (1998); Al Ghandi, (2014); James et al., (2013).

The importance of studying the exposure level of ionizing radiation cannot be over emphasized because it is very significant in epidemiological and dosimetric studies as well as forming a basis for the assessment of the degree of radiation contamination or pollution in the environment in the future. Hence this study has been undertaken to assess the exposure of ionizing radiation in Agbara Industrial Estate, Ogun State, Nigeria.

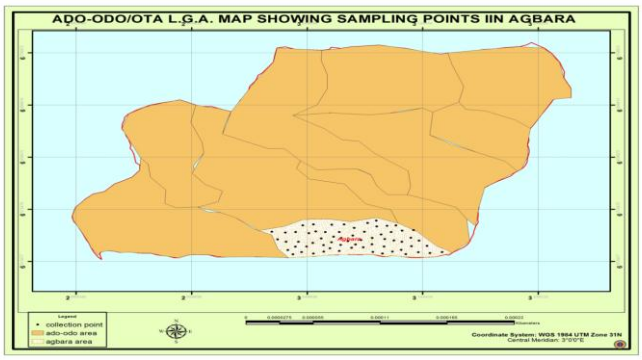
The specific objectives are to measure the natural radioactivity in Agbara Industrial Estate and substantiate any abnormality in the radiation by calculating the radiation hazard indices in these area. This work will serve as reference data for future investigations and observations in the study area.

Agbara Estate is the foremost private initiative in New Town development in Nigeria, located between latitude 3°00 and 3°15 and longitude 6°15 and 63°5. The estate is a model integrated Town developed on 454.1 hectares of land being managed by AE Property Services Limited, a subsidiary of Lawsons Corporation Nigeria Limited. It is situated in Ado-odo otta local government in Ogun state.

The Estate has been divided into the Northern and Southern Industrial areas; three separate phased residential areas, commercial and recreational areas. The industrial areas constitute 41.55% (188.289 hectares) of the whole estate and provide sites for industries, some of which are members of multinational conglomerates, operating some of their most modern purpose built factories in the country. Some of these factories are Beta Glass Nigeria PLC, Vitamalt PLC, Pharma Deko (Nig.) PLC, Nestle Nig PLC, Lotus Plastic, Reckitt Benckiser Nig. Limited, DIL/Maltex (Nig.) PLC, Evans Medical Nig. PLC, Cometstar Cables Ltd, Henley Industries, GlaxoSmithkline Nig. PLC, Pace Factory, etc. most of these industries belong to the food and beverages and pharmaceutical group.

There are 3 residential areas in the Estate, the Residential Phase I accommodates about 5000 inhabitants while the Estate receives an extraneous human traffic of more than 50,000 daily. These people come to the various industries daily to transact one business or the other. Plans are afoot to commence the development of Phases II and III which will accommodate about 15000 to 20000 inhabitants each.

There is a Sewage Treatment Plant, an Aerated Lagoon system that collects and treats both domestic and industrial effluents through oxidation process before discharging the treated effluents into the Ologe Lagoon through a stream. The plant is the first of its type in Nigeria. Sewage pipes are laid to connect individual residential, commercial and industrial properties to the treatment plant and manholes are provided at road boundaries of all plots.



Map 1: Map of Ado-oddo Ota local government showing the sampling points in Agbara

II. MATERIALS AND METHODS

A. SAMPLE COLLECTION AND PREPARATION

55 Soil samples were taken from 4 locations; residential, industrial, dumpsites and sewage areas.5 effluent samples were taken from the sewage of Agbara Industrial Estate. Before collecting a soil sample, an area of about 1.0 m × 1.0 m was marked and carefully cleared of debris. Soil samples were then taken from different points randomly at a depth of 10 cm within the marked and cleared location and homogenized thoroughly, in order to obtain a representative sample of that location.

Since the presence of extraneous materials may introduce an error in the analytical results, glass pieces, twigs, stones, and leaves were removed from the soil samples. After the removal of these unwanted particles, each soil sample was packed into a polyethylene bag to prevent cross contamination and the bag was labeled. The label included soil information such as; location, sample code and sample collection date.

The soil samples were dried to constant weight. The dried samples were pulverized, and then sieved with a standard 2-mm mesh size sieve. Each sample (with a mass of about 60 g) was placed in a Marinelli beaker.The Marinelli beakers were sealed with PVC tapes to prevent the escape of ^{222}Rn and ^{220}Rn from the samples. The samples in the Marinelli beakers were stored for four weeks to allow time for ^{222}Rn to attain a state of secular equilibrium with its short-lived progenies prior to gamma spectroscopy. The 5 effluent samples collected from the sewage were taken from the residential compartment, industrial compartment that are yet to be treated while the other three (3) effluents are taken from cell one(1), two(2) and three (3) that has been treated. These samples were collected in bottles and the bottles were tightly closed and well labelled to avoid mix up. The effluents samples were acidified with 0.1 m of HCl, at a rate of 10 ml per litre to minimize the precipitation of the radionuclide present in the effluent samples. After these, the samples were taken to the Ghana Atomic Energy Commission (G.A.E.C), Legon, Accra, Ghana for analysis with the high-purity germanium detector.

Location Code	Sample Label	Sample Collection Date	Location	Latitude	Longitude
L1	S1	27-11-2015	Benin rd 1	6.5094160399	3.0926445129
L2	S2	27-11-2015	Benin rd 2	6.5125917124	3.0899949934
L3	S3	27-11-2015	Unilever PLC 1	6.5098122096	3.0843229921
L4	S4	27-11-2015	Unilever PLC 2	6.5068667213	3.0829029967

ISSN: 2394-4404

L5	S5	27-11-2015	Unilever PLC 3	6.5146199231	3.0787617712
L6	S6	27-11-2015	Unilever Warehouse	6.5162754293	3.0783550141
L7	S7	27-11-2015	Dear gate	6.5171710387	3.0780838091
L8	S8	27-11-2015	Komex hotel	6.5171709615	3.0785812731
L9	S9	27-11-2015	Ago eto block ind.	6.5087486085	3.0811124648
L10	S10	27-11-2015	Oppcomesa, Ago eto	6.5199662774	3.0781927797
L11	S11	28-11-2015	Area 4	6.5234637782	3.0745328722
L12	S12	28-11-2015	Area 8a	6.5224811417	3.0779399123
L13	S13	28-11-2015	Area 8b	6.5258642362	3.0789625152
L14	S14	28-11-2015	Area 8c	6.5260808364	3.0821373299
L15	S15	28-11-2015	Area 8d	6.5253658744	3.0840637871
L16	S16	28-11-2015	Area 4	6.5234657833	3.0747648998
L17	S17	28-11-2015	Area 1	6.5456784333	3.0758934595
L18	S18	28-11-2015	Opp. Agbara hotel	6.5224811417	3.0779399123
L19	S19	28-11-2015	Komex hotel	6.5214563892	3.0773542567
L20	S20	28-11-2015	Area 1a	6.5243587934	3.0773427683
L21	S21	28-11-2015	Area 1	6.5246788654	3.0765498765
L22	S22	28-11-2015	Kurogboji 1	6.5027955499	3.0853624449
L23	S23	28-11-2015	Kurogboji 2	6.5025602061	3.0862125917
L24	S24	28-11-2015	Kurogboji 3	6.5025059201	3.0862668496
L25	S25	28-11-2015	Kurogboji 4	6.5026326263	3.0859141342
L26	S26	1-12-2015	Jamaica 1	6.5020541222	3.0832278111
L27	S27	1-12-2015	Jamaica 2	6.5017374895	3.0833362033
L28	S28	1-12-2015	Jamaica 3	6.5014842095	3.0832638954
L29	S29	1-12-2015	Jamaica 4	6.5007786062	3.0832909129
L30	S30	1-12-2015	Jamaica 5	6.5000728817	3.0840505342
L31	S31	1-12-2015	Jamaica 6	6.5001633325	3.0841138606
L32	S32	1-12-2015	Jamaica 7	6.5019726936	3.0833091984
L33	S33	1-12-2015	Jamaica 8	6.5013302845	3.0841140546
L34	S34	1-12-2015	Jamaica 9	6.5018008169	3.0833091701
L35	S35	1-12-2015	Jamaica 10	6.5073364583	3.0868465293
L36	S36	1-12-2015	Sewage 1	6.5103567342	3.0595632437
L37	S37	1-12-2015	Sewage 2	6.5103457352	3.0595503449
L38	S38	1-12-2015	Sewage 3	6.5103431736	3.0595503563
L39	S39	1-12-2015	Sewage 4	6.5103434342	3.0595503896
L40	S40	1-12-2015	Sewage 5	6.5103471739	3.0959550344
L41	S41	2-12-2015	Stone company	6.5307010098	3.0957237338
L42	S42	2-12-2015	GSK	6.5103228451	3.0798012392
L43	S43	2-12-2015	P&G	6.5103245456	3.0798021397
L44	S44	2-12-2015	Eko supreme	6.5060347046	3.0815009473
L45	S45	2-12-2015	Flour mill	6.5380125387	3.0829985674
L46	S46	2-12-2015	Stone company 2	6.5346556736	3.0732468566
L47	S47	2-12-2015	P&G 2	6.5015832457	3.0780565438
L48	S48	2-12-2015	P&G 3	6.5015845476	3.0780542679
L49	S49	2-12-2015	Afri fertilizer 1	6.5306765234	3.0762959047
L50	S50	2-12-2015	Afri fertilizer 2	6.5325315727	3.0767746515
L51	S51	2-12-2015	GSK 2	6.5114629897	3.0776759152
L52	S52	2-12-2015	GSK 3	6.5116862933	3.0944086452
L53	S53	2-12-2015	Stone Company	6.5085576213	3.0872266141
L54	S54	2-12-2015	Flourmill	6.4978003498	3.0950753433
L55	S55	2-12-2015	Nestle	6.5006316394	3.0957723012
L56	E56	22-12-2015	Ind. Comp.(untreated)	6.5103443561	3.0959550844
L57	E57	22-12-2015	Res. Comp. (untreated)	6.5103477953	3.0959594344
L58	E58	22-12-2015	Cell 1	6.5103471845	3.0959574654
L59	E59	22-12-2015	Cell 2	6.5103471643	3.0959574453
L60	E60	22-12-2015	Cell 3	6.5103471782	3.0959574321

Table 1: Sample codes, sample collection dates, locations and GPS coordinates

B. SAMPLE ANALYSIS

In this study, the activity concentrations of the samples were determined by a non-destructive analysis using a computerized gamma ray spectrometry system with high purity germanium (HPGe) detector. The relative efficiency of the detector system was 40%, and resolution of 1.8 keV at 1.33MeV of ^{60}Co. The gamma spectrometer was coupled to conventional electronics connected to a Multichannel Analyzer (MCA) card installed in a desktop computer. A software program called MAESTRO-32 was used to accumulate and analyze the data. The detector was located inside a cylindrical lead shield of 5 cm thickness with internal diameter of 24cm and height of 60cm. The lead shield was lined with various layers of copper, cadmium and Plexiglas, each 3mm thick. A counting time of 36,000 seconds (10hours) was used to acquire spectral data for each sample**.** The activity concentrations were determined using gamma-ray emission of ^{214}Bi at 609.3 keV (44.8%) for ^{226}Ra, and for the ^{232}Th-series, the emissions of ^{228}Ac at 911 keV (26.6%), ^{212}Pb at 238.6 keV (43.3%) and ^{208}Tl at 583 keV (30.1%) were used. The ^{40}K activity concentration was determined directly from its emission line at 1460.8 keV (10.7%). The specific activity concentrations (A_{sp}) of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}for the soil core samples were determined using the following expression (Ebaid, 2010)

$$A_{sp} = \frac{N_{sam}}{P_E \cdot \varepsilon \cdot T_c \cdot M} \qquad (1)$$

where;

N_{sam}- net counts of the radionuclide in the sample

P_E - gamma ray emission probability (gamma yield)

ε - total counting efficiency of the detector system

T_c - sample counting time

M - mass of sample (kg)

III. RESULTS AND DISCUSSION

A. ACTIVITY CONCENTRATION OF ^{226}Ra, ^{232}Th AND ^{40}K

By using gamma-ray spectrometer, activity concentrations of the natural radionuclides were investigated in the soil samples. The three most important primordial radionuclides investigated in the study area were ^{226}Ra, ^{232}Th and ^{40}K. Tables 4 and 5 shows the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in soil and effluent samples respectively. The activity of ^{226}Ra in the soil ranged from 1.53 ± 0.23 Bq kg^{-1} to 10.17 ± 1.53 Bq kg^{-1} with a mean 5.05 ± 0.76 Bq kg^{-1}, ^{232}Th ranged from 3.19 ± 0.48 Bq kg^{-1} to 17.73 ± 2.66 Bq kg^{-1} with a mean of 9.11 ± 1.36 and ^{40}K ranged from 57.88 ± 8.68 Bq kg^{-1} to 397.51 ± 59.63 Bq kg^{-1} with a mean of 171.33 ± 24.80 Bq kg^{-1}. The activity concentration of ^{40}K is higher than ^{232}Th and ^{226}Ra in all measured samples. Figure 2 shows the comparison of the mean activity concentrations values of the four locations. In effluent samples, the activity concentration of ^{226}Ra in the soil ranged from 2.03 ± 0.30 Bq L^{-1} to 5.24 ± 0.78 Bq kg^{-1} with a mean 3.74 ± 0.56 Bq L^{-1}, ^{232}Th ranged from 5.20 ± 0.78 Bq L^{-1} to 8.82 ± 2.66 Bq L^{-1} with a mean of 6.73 ± 1.04 and ^{40}K ranged from 13.54 ± 2.03 Bq L^{-1} to 21.84 ± 3.23 Bq kg^{-1} with a mean of 16.84 ± 1.50 Bq L^{-1}. Also, the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples from the studied areas was compared with those from similar investigations in other countries and summary results were given in Table 5. The comparison shows that the values of soils under consideration are extremely low in accordance with others. It is found that the mean value of ^{232}Th, ^{226}Ra and ^{40}K in the present study were lower than reported for soils of Yemen, China, Turkey and Sweden, but ^{226}Ra and ^{232}Th is found to be higher than reported value for Jeddah and Riyadh, Saudi Arabia. ^{40}K is found to be lower than reported value for Jeddah, Saudi Arabia. The comparison of 40K activity concentration shows that the values of this radionuclide in the soil of United State, Yemen, Nigeria, Algeria and China are lower than the present study mean

ISSN: 2394-4404

value. The variations in the concentrations of the radioactivity in the soil of the various locations of the world, depend upon the geological and geographical conditions of the area and the extent of fertilizer applied to the agriculture lands (UNSCEAR 2000).

SAMPLE ID	ACTIVITY CONCENTRATION IN Bq kg^{-1}		
	^{226}Ra	^{232}Th	^{40}K
S1	4.87±0.73	7.52 ± 1.13	96.43 ±14.46
S2	2.00±0.31	3.57 ± 0.53	293.01 ± 43.95
S3	5.37± 0.81	9.50 ±1.43	397.51 ± 59.63
S4	7.08± 1.06	10.96 ±1.64	167.06 ± 25.06
S5	9.83± 1.47	9.93 ± 1.49	210.21 ± 31.53
S6	6.80± 1.02	17.73 ±2.66	79.64 ± 11.95
S7	2.11± 0.32	6.58 ±0.99	310.15 ± 46.52
S8	2.86± 0.43	3.19 ±0.48	292.76± 43.91
S9	5.53± 0.83	7.99±1.20	300.42 ± 45.06
S10	3.21±0.48	4.63 ±0.69	374.77 ± 56.22
S11	2.97± 0.45	6.44 ± 0.97	132.13 ± 19.82
S12	6.22± 0.93	7.83 ±1.17	296.32 ± 44.45
S13	4.02± 0.60	8.54 ±1.28	667.55 ± 10.13
S14	1.76± 0.26	2.89 ±0.43	137.34 ± 20.60
S15	7.98± 1.20	5.02 ±0.75	92.25 ± 13.84
S16	5.66± 0.89	9.95 ±1.49	107.53 ± 10.13
S17	2.83± 0.42	8.09±1.21	421.69 ± 63.25
S18	4.65±0.67	6.66 ±1.00	61.23± 9.18
S19	6.22±0.93	12.05 ±1.81	246.33± 36.95
S20	3.55± 0.53	7.17 ±1.08	152.33± 22.85
S21	2.41± 0.36	4.19 ±0.63	320.15± 14.02
S22	3.01± 0.45	6.26 ±0.94	273.65 ± 41.05
S23	4.77± 0.71	8.21 ±1.23	151.72 ± 22.76
S24	3.10± 0.45	9.31 ±1.40	82.96± 12.44
S25	5.77± 0.87	7.56 ± 1.13	103.29 ± 15.49
S26	7.48± 1.12	13.48±2.02	139.75 ± 20.96
S27	4.60± 0.69	5.01± 0.75	74.06 ± 11.11
S28	4.75± 0.71	12.36± 1.85	100.20 ± 15.03
S29	6.99± 1.05	13.01± 1.95	96.80 ± 14.52
S30	5.88± 0.88	10.80± 1.62	131.05 ± 19.66
S31	3.34± 0.50	6.20± 0.93	109.42 ± 16.41
S32	7.22± 1.08	16.72± 2.51	68.10 ± 10.21
S33	5.23± 0.78	11.68± 1.75	91.54 ± 13.73
S34	3.65± 0.55	8.32± 1.25	72.14 ± 11.16
S35	6.85± 1.03	15.80± 2.37	121.52 ± 18.23
S36	6.96± 1.04	10.43± 1.56	87.13 ± 13.07
S37	6.94± 1.04	7.64± 1.15	113.88 ± 17.08
S38	1.61± 0.24	5.51± 0.83	81.52 ± 12.23
S39	5.03± 0.75	7.45± 1.12	72.14 ± 10.82
S40	9.39± 1.41	12.83± 1.92	90.21 ± 13.53
S41	6.51± 0.98	5.15± 0.77	106.18 ± 15.93
S42	5.41± 0.82	9.56± 1.43	156.53 ± 23.48
S43	3.49± 0.52	11.31± 1.69	340.67± 51.10
S44	1.53± 0.23	5.89±0.88	267.48± 40.12
S45	7.52± 1.13	7.30± 1.94	316.76± 47.51
S46	5.13± 0.77	14.54± 2.18	77.28± 11.59
S47	10.17± 1.53	12.70± 1.91	90.62± 13.59
S48	2.49± 0.37	13.74± 1.06	125.83± 18.88
S49	1.60± 0.24	12.34± 1.85	137.05± 20.56
S50	2.79± 0.42	8.99± 1.35	57.88± 8.68
S51	8.85± 1.37	6.48± 0.97	103.74± 15.56
S52	8.16± 1.22	15.10 ± 2.26	72.00± 10.80
S53	6.04± 0.91	14.24±2.14	90.62± 13.59
S54	5.91± 0.89	8.13± 1.22	125.83± 18.87
S55	1.89± 0.28	6.78±1.02	137.05± 10.52
Mean Activity	5.05 ± 0.76	9.11 ± 1.36	171.33 ± 24.80

Table 2: Activity concentrations of natural radionuclides in the soil samples

Sample ID	Activity Concentration (Bq L^{-1})		
	^{238}U	^{232}Th	^{40}K
E 56	5.24 ± 0.78	7.54 ± 1.13	15.55 ± 0.02
E 57	2.03 ± 0.30	5.20 ± 0.78	21.84 ± 3.28
E 58	4.16 ± 0.62	6.74 ± 1.01	13.54 ± 2.03
E 59	3.16 ± 0.47	5.34 ± 0.80	18.82 ± 0.02
E 60	4.11 ± 0.61	8.82 ± 1.47.	14.44 ± 2.16
Mean Activity	3.74 ± 0.56	6.73 ± 1.04	16.84 ± 1.50

Table 3: Activity concentrations of natural radionuclides in the effluent samples

Location	Activity Concentration (Bq L^{-1})		
	^{238}U	^{232}Th	^{40}K
Residential	4.58 ± 0.69	7.67 ± 1.15	230.74 ± 33.01
Dumpsites	5.60 ± 0.84	11.34 ± 1.70	100.46 ± 15.10
Sewage	5.97 ± 0.90	8.77 ± 1.32	88.98 ± 13.35
Industrial	5.17 ± 0.78	10.15 ± 1.51	147.03 ± 21.89
Effluent	3.74 ± 0.56	6.73 ± 1.04	16.84 ± 1.50

Table 4:Mean Activity concentrations of natural radionuclide at each location

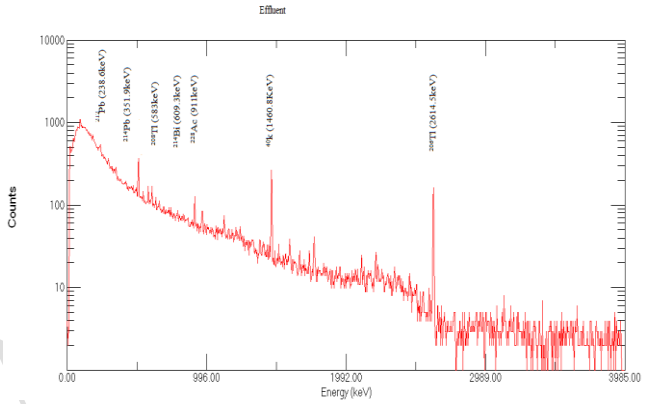


Figure 1: Typical sample spectrum

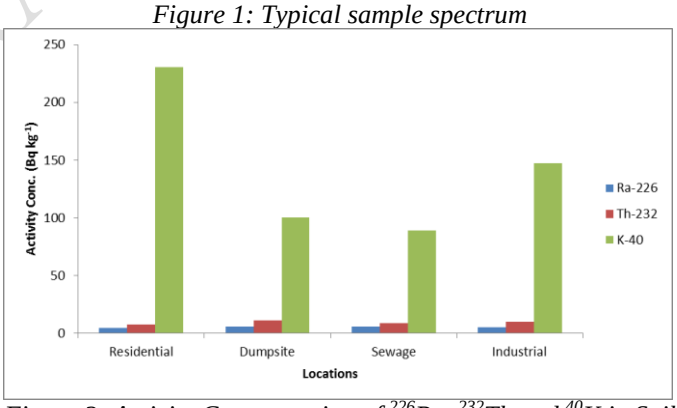


Figure 2: Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K in Soil samples

Country	Mean and range activity concentration (Bqkg-1)			References
	^{226}Ra	^{232}Th	^{40}K	
AgbaraIndustial Estate, Ogun State.	5.05	9.11	171.33	Present Research
Industrial, Yanbu city, Saudi Arabia.	40.65	42.89	513.16	Al- Ghamdi, 2014
Sadiat Industrial City, Egypt.	10.69	10.94	164.09	Tahawy *et al.* 2006
6th of October Industrial city, Egypt.	10.91	9.13	105.03	Tahawy *et al.* 2006
Minna, Nigeria.	7.08	23.5	229	Kolo *et al.* 2012
Karabu, Turkey.	21.0	23.5	363.5	Ridvan *et al.* 2001
Pakistan	25.8	49.2	561.6	Akhtar *et al.* 2005
India	26.4	51.2	5.6	Rani A. and Surrinder S. 2005
Kuwait	13.6	2.4	110.4	Saad H. R. and

				Al-Azani D. 2002
Saudi Arabia	30.77	27.59	161.8	Zane K. A. and Almugren K.S. 2010
Algeria	50	25	370	UNSCEAR, 2000
China	32	41	440	UNSCEAR, 2000
Sweden	42	42	680	UNSCEAR, 2000
World Average	32	45	420	UNSCEAR, 2000

Table 5

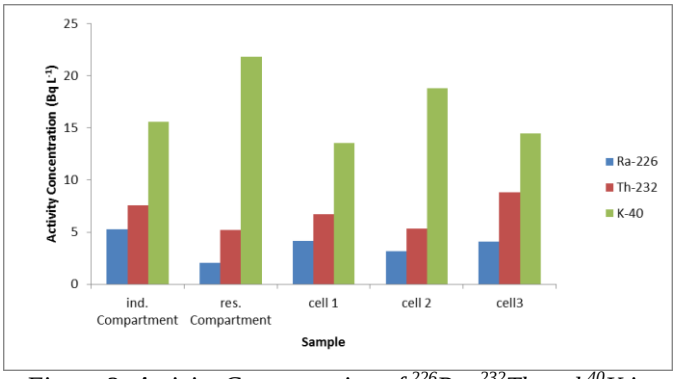


Figure 3: Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K in Effluent samples

B. RADIOLOGICAL PARAMETERS

In order to assess any radiological hazard, the exposure to radiation arising from radionuclides present in soil and effluents was determined in terms of many parameters. Different known radiation health hazard indices analysis is being used in radiation studies to arrive at a reliable conclusion on the health status of an irradiated person and environment in recent studies (Diab *et al.*2008; Agbalagba and Onoja, 2011). To assess the radiation hazards associated with the collected soil and effluents samples, eight quantities have been defined (Zarie and Al Mugren, 2010).

Location	*Radiation Hazard Indices*							
	D (nGy h^{-1})	AEDE (mSv y^{-1})	Ra_{eq} (Bq kg^{-1})	H_{ex}	H_{in}	AGED (mSv y^{-1})	I_γ	ELCR $\times 10^3$
Residential	16.18	0.02	33.32	0.09	0.10	118.68	0.26	0.07
Dumpsite	13.39	0.02	29.55	0.08	0.09	96.24	0.22	0.06
Sewage	11.52	0.01	25.38	0.07	0.08	83.10	0.19	0.05
Industrial	14.43	0.02	31.00	0.08	0.10	104.56	0.23	0.06
Average	14.77	0.02	31.28	0.08	0.10	107.51	0.24	0.06

Table 6: Mean Radiation hazard indices of soils of different locations of the study area

Location	*Radiation Hazard Indices*							
	D (nGy h^{-1})	AEDE (mSv y^{-1})	Ra_{eq} (Bq kg^{-1})	H_{ex}	H_{in}	AGED (mSv y^{-1})	I_γ	ELCR $\times 10^3$
E56	7.40	0.01	17.22	0.047	0.06	52.59	0.12	0.03
E57	4.90	0.01	11.15	0.03	0.04	34.87	0.08	0.02
E58	6.38	0.01	14.84	0.04	0.05	45.28	0.10	0.03
E59	5.34	0.01	12.25	0.03	0.04	38.00	0.09	0.02
E60	7.66	0.01	17.83	0.05	0.06	54.10	0.13	0.03
Average	6.34	0.01	14.66	0.04	0.05	44.97	0.10	0.03

Table 7: Radiation hazard indices of effluents of the study area

a. ABSORBED DOSE RATE IN AIR (D)

A direct connection between activity concentrations of natural radionuclides and their exposure is known as the absorbed dose rate in the air at about 1 m above the ground surface. The absorbed dose rate is important in radiation risk analysis since it measures the amount of radiation deposited per unit time.

The mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K ($Bqkg^{-1}$) in the soil samples were used to calculate the absorbed dose rate given by the equation (Turham and Gundiz, 2008)

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

where, D is the absorbed dose rate in nGy h^{-1}, A_{Ra}, A_{Th} and A_K are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K, respectively. The dose coefficients in units of $nGyh^{-1}$ per Bq kg^{-1} were taken from the UNSCEAR (2000) report. The absorbed dose rate in air in the study area ranged from 7.40 nGy h^{-1} to 34.68 nGy h^{-1} with an average of 14.77 nGy h^{-1}, which is below the world average value of 65 nGy h^{-1} (UNSCEAR 2000). The residential, dumpsites, sewage and industrial areas have an average absorbed dose-rate in air of 16.18 nGy h^{-1}, 13.39 nGy h^{-1}, 11.52 nGy h^{-1}, 14.43 nGy h^{-1} respectively which are below the world average. Fig. 4 shows the mean absorbed dose rate in air in all locations. The absorbed dose rate in air is highest at the residential areas than other areas and this may be as a result of higher population and agricultural activities in the area have impacted the activity concentration of the natural radionuclides which determines the level of absorbed dose rate in air. Also it shows that the industrial activities in the study area have minimal effect on the activity concentration of natural radionuclides. Fig. 5 shows the contributions of ^{226}Ra, ^{232}Th and ^{40}K to the absorbed dose rate in air in the study area. ^{40}K accounts for 48% of the absorbed dose rate in air, while ^{232}Th and ^{226}Ra accounts for 37% and 15% respectively. The absorbed dose rate in air in all locations is below the world average value of 60 nGy h^{-1} (UNSCEAR, 2000).

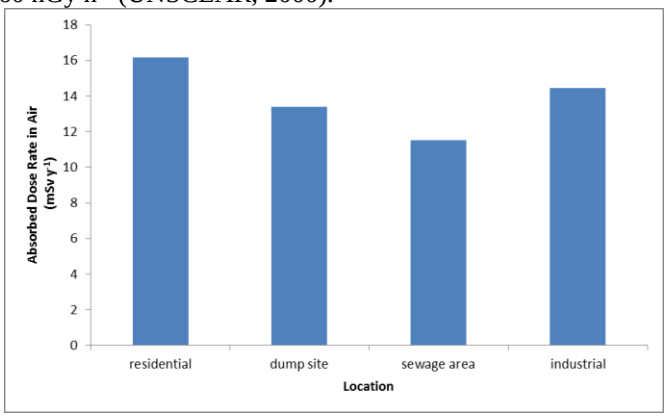


Figure 4: Mean absorbed dose rate in air in all locations

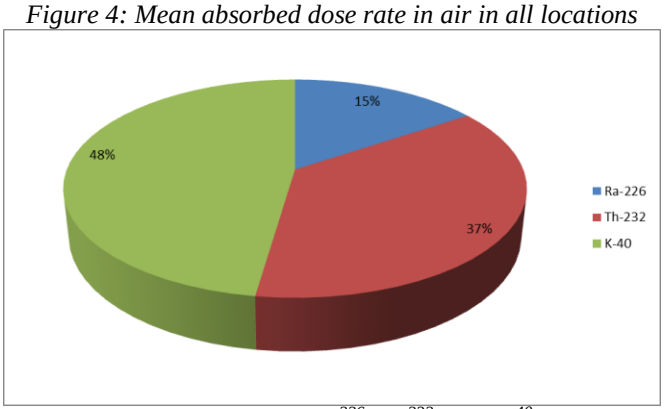


Figure 5: Contributions of ^{226}Ra, ^{232}Th and ^{40}K to the absorbed dose rate air

For effluents, the absorbed dose rate in air in the study area ranged from 4.90nGy h^{-1} Residential compartment (E57) to 7.66 nGy h^{-1} Cell 3 (E60) with an average of 6.34 nGy h^{-1}, which is below the average world value of 65 nGy h^{-1} (UNSCEAR 2000). Fig. 6 shows the chart of absorbed dose rate in air in effluents, Cell 3 (E60) is the highest followed by residential compartment (E56) while industrial compartment (E57) is the lowest.

^{232}Th accounts for 62% of the absorbed dose in air while ^{226}Ra and ^{40}K accounts for 27% and 11% respectively as shown in Fig. 7.

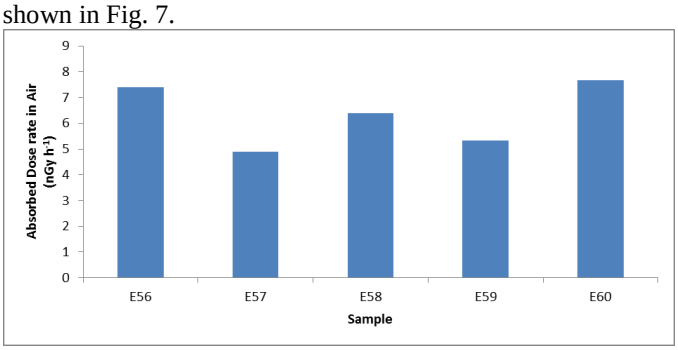


Figure 6: Absorbed dose rate in air in effluent samples

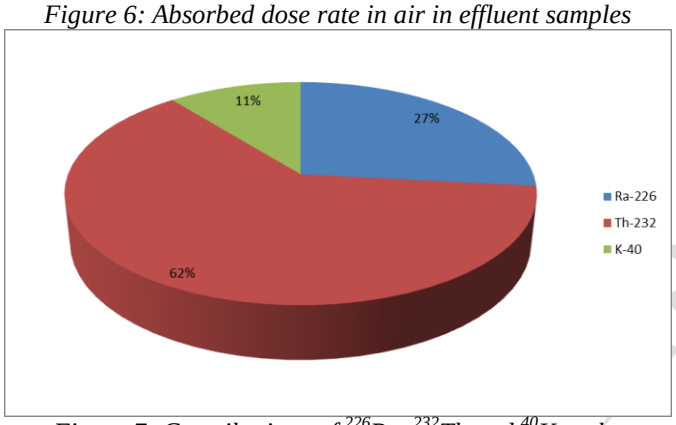


Figure 7: Contributions of ^{226}Ra, ^{232}Th and ^{40}K to the absorbed dose rate air

b. ANNUAL EFFECTIVE DOSE EQUIVALENT (AEDE)

To estimate annual effective doses, the following must be considered: (a) the conversion coefficient from absorbed dose in air to effective dose and (b) the indoor or outdoor occupancy factor. The annual, estimated, average, effective-dose equivalent received by a member is calculated using a conversion factor of 0.7 Sv Gy^{-1}, which is used to convert the absorbed rate to human effective-dose equivalent with an outdoor occupancy of 20% and 80% for indoors (UNSCEAR, 1993).

The annual effective doses are determined as follows:

Effective dose rate (mSv y^{-1})

$$= D\ (nG{\cdot}h^{-1}) \times 8760\ (h{\cdot}y^{-1}) \times 0.7 \times (10^3\ mSv/nGy\ 10^9) \times 0.2 \quad (4)$$

where, D is the absorbed dose rate in air

To avoid any somatic, epidemiological and radiological health side effect, ICRP recommended and consequently set the maximum permissible limit for non-radionuclide industrial worker and public as 1.0 mSv y^{-1}(ICRP, 1991). The annual effective dose equivalent from outdoor terrestrial gamma radiation ranged from 0.01 mSv y^{-1} to 0.04 mSv y^{-1} with a mean value of 0.02 mSv y^{-1} which is below the corresponding world average value of 0.07 mSv y^{-1}(UNSCEAR 1988). For effluents, the mean value of annual effective dose equivalent (AEDE) is 0.01 mSv y^{-1} which is below the world average.

c. RADIUM EQUIVALENT ACTIVITY (Ra_{eq})

Radium equivalent activity (Ra_{eq}) is a common index used to compare the specific activities of materials containing ^{226}Ra, ^{232}Th and ^{40}K by a single quantity, which takes into account the radiation hazards associated with them (Baratta, 1990). The activity index provides a useful guideline in regulating the safety standard.

The radium equivalent activity represents a weighted sum of activities of the above mentioned natural radionuclides and is based on the estimation that 1 Bqkg^{-1} of ^{226}Ra, 0.7 Bq kg^{-1} of ^{232}Th, and 13 Bq kg^{-1} of ^{40}K produce the same radiation dose rates. The radium equivalent activity index is given as (Beretka and Mathew, 1985):

$$Ra_{eq}\ (Bq\ kg^{-1}) = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (5)$$

Where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}, respectively. The permissible maximum value of the radium equivalent activity is 370 Bq kg^{-1} (UNSCEAR, 2000) which corresponds to an effective dose of 1 mSv for the general public (Ajayi, 2009). The mean radium equivalent activity (Ra_{eq}) ranged from 15.17 Bq kg^{-1} to 67.63 Bq kg^{-1} with an average of 31.28 Bq kg^{-1}. This is below the permissible maximum value of 370 Bq kg^{-1} (UNSCEAR, 2000).

d. EXTERNAL HAZARD INDEX (H_{ex})

Many radionuclides occur naturally in terrestrial soils and rocks and upon decay, these radionuclides produce an external radiation field to which all human beings are exposed. In terms of dose, the principal primordial radionuclides are ^{232}Th, ^{238}U and ^{40}K. Thorium and uranium head series of radionuclides that produce significant human exposure.

The external hazard index (H_{ex}) is defined as (Beretka and Mathew 1985):

$$H_{ex} = {}^{A_{Ra}}/_{370} + {}^{A_{Th}}/_{259} + {}^{A_K}/_{4810} \quad (6)$$

where, A_{Ra}, A_{Th}, and A_K are the radioactivity concentrations in Bq kg^{-1}of ^{226}Ra, ^{232}Th and ^{40}K respectively. In order to keep the radiation hazard insignificant, the value of external hazard index must not exceed the limit of unity (Beretka and Mathew,1985). The maximum value of H_{ex} equal to unity corresponds to the upper limit of radium equivalent activity 370 Bq kg^{-1}(Nada *et al.* 2009). The values of outdoor radiation hazard index (H_{ex}) vary from 0.04 to 0.18 with a mean value of 0.08, these values are less than the critical value of unity.

e. INTERNAL HAZARD INDEX (H_{in})

The internal hazard index (H_{in}) is given as (Beretka and Mathew 1985):

$$H_{in} = {}^{A_{Ra}}/_{185} + {}^{A_{Th}}/_{259} + {}^{A_K}/_{4810} \quad (7)$$

H_{in} should be less than unity for the radiation hazard to be negligible. Internal exposure to radon is very hazardous, this can lead to respiratory diseases like asthma and lung cancer.

The values of indoor radiation hazard index (H_{in}) vary from 0.05 to 0.19 with a mean value of 0.10, which is less than the critical value of unity.

f. ANNUAL GONADAL EQUIVALENT DOSE (AGED)

The gonads, the bone marrow and the bone surface cells are considered as organs of interest (UNSCEAR, 2000) because they are the most sensitive parts of the human body to radiation. The annual gonadal dose equivalent (AGED) is calculated using the equation (Tufail *et al*. 2006)

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

where, A_{Ra}, A_{Th}, and A_K are the radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples. The mean annual gonadal equivalent dose (AGED) ranged from 53.60 mSv y^{-1} to 257.73 mSv y^{-1}. The AGED is highest at the Area 8b, Opic Estate (S13) and lowest at Sewage 3 (S38). An increase in AGED has been known to affect the bone marrow, causing destruction of the red blood cells that are then replaced by white blood cells. This situation results in a blood cancer called leukemia which is fatal. The mean values of the AGED for the study area is 107.51 mSv y^{-1}. This value is lower than the maximum permissible value of 300 mSv y^{-1} (UNSCEAR, 2000). So, the populace of the study area is not posed to the risk of developing blood cancer due to the exposure to the natural radionuclides present in the study area.

g. REPRESENTATIVE GAMMA INDEX (I_γ)

This is used to estimate the gamma radiation hazard associated with the natural radionuclides in specific investigated samples. The representative gamma index is given as (Tufail *et al.* 2006):

$$I_\gamma = {}^{A_{Ra}}/_{150} + {}^{A_{Th}}/_{100} + {}^{A_K}/_{1500} \quad (9)$$

The representative gamma index (I_γ) varies from 0.10 to 0.56 with an average of 0.24. An increase in the representative gamma index greater than the universal standard of unity may result in radiation risk leading to the deformation of epithelial and blood cells, thereby causing cancer (Turham and Gundiz, 2008). Since the values of the representative gamma index (I_γ) is lower than 1, thus, the populace of the study area does not suffer significant health risk due to the exposure to radiation from natural radionuclides in the soil of the study area.

This gamma index is also used to correlate the annual dose rate due to the excess external gamma radiation caused by superficial materials. It is a screening tool for identifying materials that might become a health concern when used for construction (Tufail *et al.* 2006).

Since gamma ray can pass through any material, it can cause severe damage to the cells of human beings. Hence, an increase in the representative gamma index greater than the universal standard of unity may result in radiation risk leading to the deformation of human cells thereby causing cancer (Turham and Gundiz, 2008).

h. EXCESS LIFETIME CANCER RISK (ELCR)

This deals with the probability of developing cancer over a lifetime at a given exposure level. It is presented as a value representing the number of cancers expected in a given number of people on exposure to a carcinogen at a given dose.

It is worth noting that an increase in the ELCR causes a proportionate increase in the rate at which an individual can get cancer of the breast, prostate or even blood. Excess lifetime cancer risk (ELCR) is given as (Taskin *et al.* 2009):

$$ELCR = AEDE \times DL \times RF \quad (10)$$

where, AEDE is the Annual Effective Dose Equivalent, DL is the average duration of life (estimated to 70 years), and RF is the Risk Factor (Sv^{-1}), i.e. fatal cancer risk per Sievert. For stochastic effects, ICRP uses RF as 0.05 for public (Taskin *et al.* 2009). The mean ELCR value was below the standard value of unity and all the areas had ELCR values below permissible limit.

IV. CONCLUSION

The activity concentrations of natural radionuclides in soil and effluent samples collected from Agbara Industrial area was determined so as to investigate the radiological hazard indices due to natural radionuclides in soils and effluents of the study area. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were determined by a non-destructive analysis using a high purity germanium (HPGe) detector. The mean activity concentrations of ^{226}Ra and ^{232}Th and ^{40}K are 5.05 Bq kg^{-1}, 9.11 Bq kg^{-1} and 171.33 Bq kg^{-1}, respectively. The study showed that the measured values of ^{226}Ra, ^{232}Th and ^{40}K are lower than the world wide soil reported in UNSCEAR (2000). The mean value of total absorbed dose rate is 14.77 nGy h^{-1}, which is much lower than the world average value of 65 nGy h^{-1}. The mean value 0.02 mSv y^{-1} of the annual effective dose equivalent, is lower than the average national and world recommended value of 1.0 mSv y^{-1}. The value of Ra_{eq} activity was found to be less than 370 Bq kg^{-1}, the external hazard indices were found to be less than acceptable limit of unity.Therefore, the study area is still in the zones of normal radiation level and does not pose health risks to the populace of this area. This data may provide a general background level for the area studied and may also serve as a baseline for future measurement and assessment of possible radiological risks to human health in this region.The annual effective dose equivalent calculated with the equivalent dose rate measured using the in-situ approach is well below the recommended value by ICRP which buttress the fact that the study area is very safe for the populace.

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