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Radiological Health Hazard Indices and Excess Life Time Cancer Risk of Oil Producing Communities in Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author HUE collected the samples, did the laboratory analysis and designed the study. Author BN wrote the first draft of the manuscript and managed the analyses of the study. Authors KA and CON managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The γ radiation exposure due to radioactivity concentration of ^{40}K, ^{238}U and ^{232}Th in soil samples from 250 different locations from 40 communities in the oil – producing region of Nigeria was carried out. The radioactivity concentrations of these radionuclides were used to determine the absorbed dose, annual effective dose equivalent, the health hazard indices and cancer risk using standard analytical methods. The range of values for the absorbed dose are 6.97 $nGyh^{-1}$ to 33.29 $nGyh^{-1}$, annual effective dose equivalent

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(outdoor) are 8.55 μSvy^{-1} to 40.83 μSvy^{-1} and (indoor) are 34.19 μSvy^{-1} to 163.36 μSvy^{-1}. The external hazard index ranges from 0.038 to 0.174 while the internal health hazard index is from 0.045 to 0.191. The cancer risk obtained for the communities ranges from 0.030 x 10^{-3} to 0.143 x 10^{-3}. All these values are below the standard limits when compared to the world permissible United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR) values for such environment. This shows that the exploration and exportation of crude oil in Nigeria did not pose a radioactive health hazard to the oil producing communities.

Keywords: Radioactivity concentration; absorbed dose; effective dose equivalent; health hazard indices, excess lifetime cancer risk.

1. INTRODUCTION

Petroleum products are very useful substances derived from crude oil. These products supply more than 80% of the world's energy needs [1]. Crude oil is a complex mixture of compounds of hydrocarbon molecules among many other materials. When they pass through a process of fractional distillation in the refinery, they yield different kinds of petroleum products, which include various grades of fuel oil, gasoline, aviation fuel, asphalt, tar, paraffin wax, lubricating and other heavy oil, which are energy – producing substances. Crude oil is a mineral deposit found mostly below the sub – surfaces and under – water surfaces. It means that they have to be discovered, drilled out before they are refined into energy – producing petroleum products.

Crude oil was first discovered in commercial quantity in Nigeria in January 1956 in Oloibiri, a small town in the Niger – Delta region of the country. Exploration started in 1958 and has continued until date. Moreover, the activities of the oil exploration companies have been on the increase in the area with so much conflicts and agitations from the host communities. These conflicts arise because of environmental degradation and oil spillages, which pollute the water and the farmlands, since all of Nigerian crude oil comes from this region of the country [2]. An average of 240,000 barrels of crude oil is spilled in the region every year [3]. Hazards posed by such pollutions are not only in terms of odor, presence of disease causing micro – organisms and destruction of their means of lively hood, but also from radiation emanating from such pollutions [4]. Nigeria is endowed with abundant deposit of crude oil and hence, the financial relevance to the country is remarkable. According to [5], production of oil and gas resources, which have been ongoing for the past five decades, accounts for over 85 % of the country's gross domestic product (GDP) and over 95% of nation's foreign exchange revenues.

At present, the petroleum industry is the highest importer and user of radioactive substances in Nigeria [6]. In most of the sectors of oil and gas exploration, radioactive materials and radiation generators are used on a large scale. These applications of radioactive materials in both off shore and on shore drilling includes industrial radiography, use of radiotracers in pipes, well logging, automatically ionizing radiation gauge, mapping, evaluation of geological formations and the extraction of other natural hydrocarbon resources [7,8].

In the world over, anywhere there is oil exploration, there is always a health concern associated with environmental degradation, oil pollution and radiation implications to the host communities. Some of the countries that are involved in exploration and exportation of crude

oil in the descending order according to their quantity of exportation includes: Russia, Saudi Arabia, United States of America USA, Iran, China, Canada, Iraq, United Arab Emirates Venezuela, Mexico, Kuwait, Brazil and Nigeria (13^{th} on the world list and the highest in Africa) [9]. Some of these countries have been able to adequately assess and address these concerns locally. Exploration for and production of petroleum, have caused local detrimental impacts to soil surfaces, groundwater and ecosystems in the 36 producing states in the United States of America (USA) [10,11]. Hence, new environmental laws and improved industrial practices and technologies have been introduced in USA to reduce the most detrimental effects of petroleum activities [12]. Nigeria has not been able to do much in that direction. Although some studies has been done on the radionuclide concentration of the water and soil samples in the area, as reported by [2,3,7,13], none of these focused on the radiation health hazard and the excess lifetime cancer risk. The purpose of this research work is therefore to:

1. Determine how much the five decade of oil exploration in the area has imparted on the natural radionuclides concentration compared to world standard.
2. Determine the cancer risk and the health hazard implications to the oil producing communities in Nigeria.
3. Obtain a radiometric data for the area under review for future references and research.

2. MATERIALS AND METHODS

Soil samples were collected from two hundred and fifty (250) different locations across forty (40) communities in the oil – producing communities of the Niger – Delta region of Nigeria. This is to ensure a very good coverage of the entire region. Samples at each site were collected to a depth of about 150 mm to 200 mm below the soil surface. Table 2 shows the number of samples collected against each community. Then the map of the study area is in Fig. 1. The samples were placed in a labeled waterproof nylon bag and transferred to the laboratory for analysis. Then they were air – dried and homogenized to pass 1mm mesh sieve. About 0.2kg of each sample were weighed and fed into a plastic container of about 8cm in height and 7cm in diameter. The containers were sealed for twenty eight (28) days for the short – lived members of Uranium and Thorium series to reach a secular equilibrium. The samples were placed symmetrically on top of the detector and measured for 10 hours (36000 seconds). The net area under the corresponding photopeaks in the energy spectrum was computed by subtracting count due to Compton scattering of the background source from the total area of the photopeaks. The radionuclides were computed using the algorithm of the multichannel analyzer (MCA).

The scintillation detector used in this work is a lead shield Canberra 76mm x 76mm NaI(TI) crystal models number 802 – series. One face of the cylindrical detector is free while the other is optically coupled to a Photomultiplier tube that detects the small visible light photons produced in the crystal and converts them into amplified electrical pulses, which is fed into analyzer systems (Canberra series 10 plus multichannel analyzer MCA) through a preamplifier base.

The gamma spectrometry detector was calibrated before it was used for analysis. This was done to ensure that the radiation parameters in the samples could be expressed in physical radiometric units. This calibration was done in two stages. These are energy and efficiency calibrations. The energy calibration converts channel numbers to γ - ray energy in Mev. This was done by placing different gamma sources of known energy in the detector. After a

preset counting time of 10 hours (36,000s), the channels of the various photopeaks corresponding to the gamma energies were then identified. Then the efficiency calibration was to determine the gamma ray counting efficiencies over energy range of 0.662 – 2.615 Mev. This was done by converting the count per seconds under the photopeaks to activity concentration $Bqkg^{-1}$ of certified reference standard samples. The certified reference standard samples have activity concentrations of 7.24 $Bqkg^{-1}$ for ^{137}Cs (0.662 Mev), 578.40 $Bqkg^{-1}$ for ^{40}K (1.460 Mev), 20.90 $Bqkg^{-1}$ for ^{238}U (1.760 Mev) and 10.47 $Bqkg^{-1}$ for ^{232}Th (2.615 Mev). Efficiencies at different gamma energy peaks are given in Table 1.

Table 1. Efficiencies at different gamma energy peaks

Radionuclide	Activity of the reference sources ($Bqkg^{-1}$)	Energy (Mev)	Gamma yield	Peak net area (count/s)	Efficiency (%)
Cs-137	7.24	0.662	0.852	2476	5.57
K- 40	578.40	1.460	0.107	8342	1.87
U-238	20.90	1.760	0.159	400	1.67
Th-232	10.47	2.615	0.358	364	1.35

The reference standard sources were counted for 10 hours (36,000s) after which the counting efficiencies of the different gamma energies were determined. According to [14,15], the count rate A_{net} under the photopeak of each of the three primordial radionuclides is related to activity concentration by the equation 1.

$$A_s = \frac{A_{net}}{\varepsilon_y Y_\gamma M_s t} \quad (1)$$

Where

A_s = activity concentration in $Bqkg^{-1}$

ε_γ = the efficiency of the detector at a particular γ – energy

A_{net} = count rate under the photopeak of the three primordial radionuclides,
Y_γ = the yield of the gamma ray at a particular energy,
M_s = the mass of the samples (0.2kg)
T_s = the counting time in seconds.

The efficiencies (ε_γ) for each of the four gamma energies are given in Table 2.

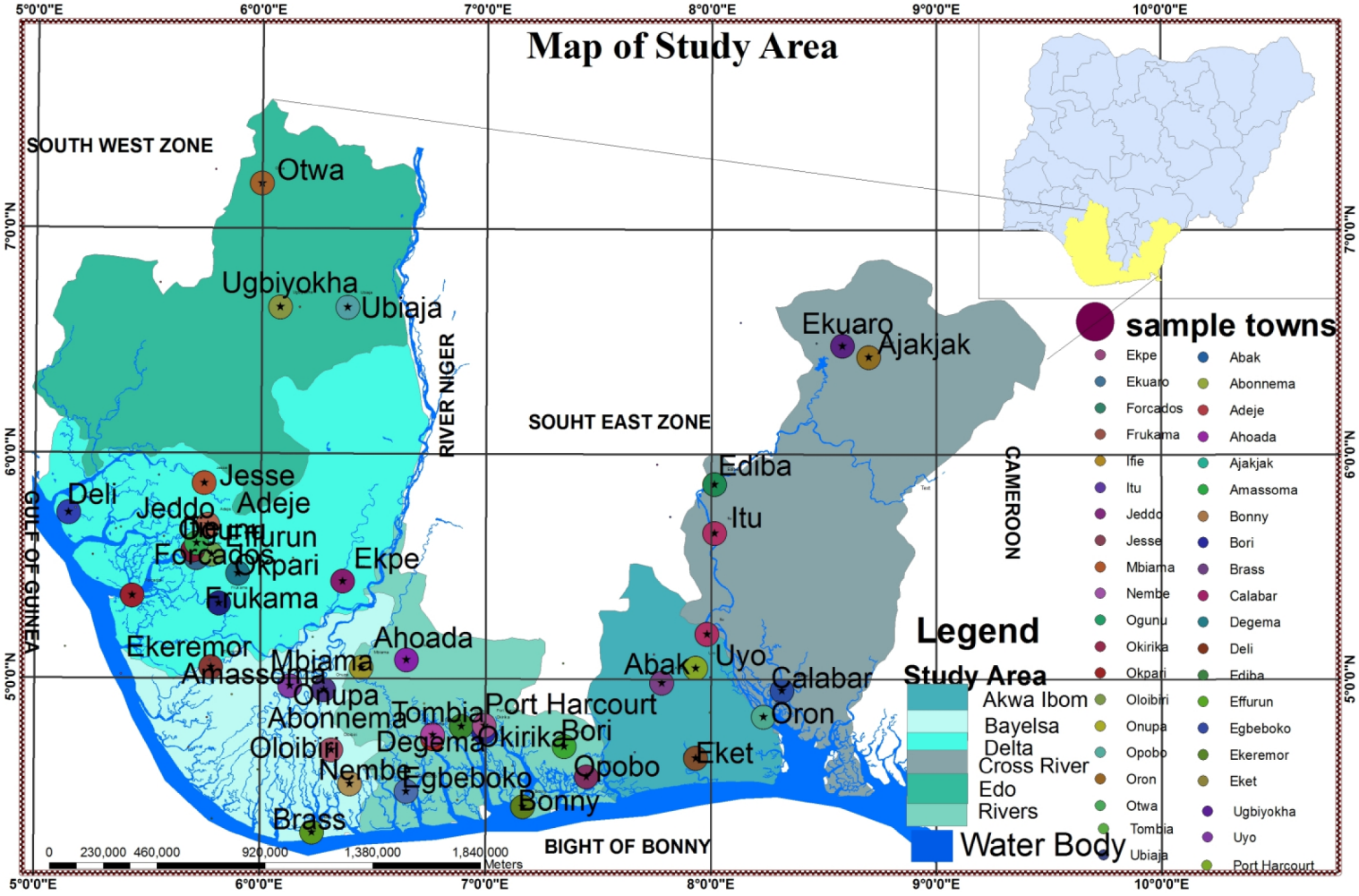

Fig. 1. The map of the study area, showing the different communities in different colors

3. RESULTS AND ANALYSIS

In this study, the following parameters were determined in order to adequately assess the health hazard indices and excess lifetime cancer risk. These parameters are:

3.1 Radioactivity Concentration

The radioactivity concentrations of the three primordial radionuclides were computed using equation 1 above. The values of the mean concentration in the 40 communities are recorded in Table 2.

Table 2. The activity concentrations of the three primordial radionuclides of the soil samples from the communities

s/n	Communities	No of Samples collected	Mean conc. Of ^{40}K ($Bqkg^{-1}$)	Mean conc. of ^{238}U ($Bqkg^{-1}$)	Mean conc. of ^{232}Th ($Bqkg^{-1}$)
1	Abak	6	552.3±46.5	3.1±1.6	2.2±0.7
2	Abonnema	4	372.3±72.1	7.7±3.9	3.7±1.5
3	Adeje	6	497.4±24.8	9.2 ±3.1	7.7 ±4.3
4	Ahoada	6	403.9±31.4	3.4±1.6	7.1±3.1
5	Ajakjak	5	99.6±9.7	3.4±1.0	2.0±0.3
6	Amassoma	6	399.8±88.6	7.9±3.3	5.6 ± 3.9
7	Bonny	8	259.9±91	3.7±1.1	7.7±1.2
8	Bori	8	91.9±14.6	9.7±3.1	3.6±2.1
9	Brass	6	198.3±9.7	10.1±3.8	2.1±0.9
10	Calabar	10	491.7±37.2	10.3±7.7	3.5±2.1
11	Degema	10	521.9±31.1	2.1±0.3	3.4±1.1
12	Deli	4	96.6±13.6	5.2±0.5	3.5±0.3
13	Ediba	6	436.6±98.2	3.1±1.2	4.6±2.0
14	Effurun	4	272.4±47.6	7.4±4.9	5.8±1.7
15	Egbeboko	5	309.4±63.6	10.6±2.4	8.8 ±3.4
16	Ekeremor	4	364.5±98.7	2.2±0.9	1.9±1.1
17	Eket	10	309.4±31.2	3.3±1.2	0.9±0.1
18	Ekpe	7	397.6±22.0	4.9±1.4	6.0±2.3
19	Ekuaro	4	104.7±91.9	1.5±0.9	4.0±1.6
20	Focados	4	277.7±8.1	10.2±3.5	5.2±3.1
21	Frukama	5	126.3±88.2	7.5±4.6	5.1±3.2
22	Ifie	3	91.5±14.7	17.6±2.4	1.6±0.8
23	Itu	9	299.4±29.1	5.7±3.1	2.2±1.9
24	Jeddo	5	284.6±29.6	1.2±0.4	4.1±2.6
25	Jesse	5	194.5±47.1	2.1±0.9	1.4±0.2
26	Mbiama	5	489.3±98.1	10.1±3.7	4.9±3.3
27	Nembe	6	374.8±31.1	10.6±4.5	6.3±3.2
28	Ogunu	6	191.1±10.7	3.4±0.9	1.6±0.1
29	Okirika	5	321.9±73.2	7.2±3.1	4.0±1.1
30	Okpari	8	109.7±41.3	2.1±0.9	7.7±2.5
31	Oloibiri	10	257.6±94.3	7.4±2.2	2.1±3.2
32	Onupa	4	588.3±199.7	6.5±2.9	8.7±1.6
33	Opobo	8	249.8±35.4	7.7±3.1	4.7±1.9
34	Oron	6	114.7±13.6	7.5±1.3	3.5±1.7
35	Otwan	5	265.9±77.6	10.3±3.6	7.1±3.7
36	Port Harcourt	10	497.9±21.8	3.4±1.6	3.3±2.6
37	Tombia	5	493.8±93.1	3.7±1.9	7.2±3.1
38	Ubiaja	5	342.7±66.0	3.2±1.8	3.9±2.4
39	Ugbiyoka	7	245.5±65.0	7.9±3.1	9.3±3.6
40	Uyo	10	509.5±31.2	7.1±3.1	0.9±0.6

3.2 Radium Equivalent Activity (Ra_{eq})

The distribution of ^{40}K, ^{238}U and ^{232}Th in the soil is not uniform. Uniformity with respect to exposure to radiation has been defined by radium equivalent activity Ra_{eq} in $Bqkg^{-1}$. This compares the specific activity of materials containing different amounts of ^{40}K, ^{238}U and ^{232}Th. It is defined as an estimation of radiation 370 $Bqkg^{-1}$ of ^{238}U, 259 $Bqkg^{-1}$ of ^{232}Th and 4810 $Bqkg^{-1}$ of ^{40}K that produces the same gamma dose rate. Ra_{eq} was calculated using the formula [16].

$$Ra_{eq} = \left[C_U/370 + C_{Th}/259 + C_K/4810 \right] x370 \quad (2)$$

The values of Ra_{eq} are in Table 3. The maximum tolerable value is 370 $Bqkg^{-1}$ [17].

3.3 Annual Gonad Equivalent Dose (AGED)

The gonads, the activity bone marrow and the bone surface cells were considered as organs of interest [18]. The AGED for the communities was calculated using equation 3 and the values got are recorded in Table 3.

$$AGED = 3.09C_U + 4.18C_{Th} + 0.314C_K \quad (3)$$

C_k, C_U, and C_{Th} are the activity concentrations of Potassium, Uranium and Thorium respectively.

3.4 External Hazard Index (H_{ex})

The external hazard index is an evaluation of the outdoor hazard of the natural gamma radiation. This is defined by equation 4 [16].

$$H_{ex} = C_U/370 + C_{Th}/259 + C_K/4810 \leq 1 \quad (4)$$

3.5 Internal Hazard Index (H_{in})

Internal radiation hazard indices was also considered in this work because this could cause respiratory diseases like asthma and cancer. This is defined by equation 5. [16]

$$H_{in} = C_U/185 + C_{Th}/259 + C_K/4810 \leq 1 \quad (5)$$

The values of the health hazard indices in this work are recorded in Table 3, while the chat comparing them to the world standard value is in Fig. 2. This must also be less than unity for the radiation hazard to be negligible.

3.6 Gamma Absorbed Dose Rate ($nGyh^{-1}$)

The gamma absorbed dose rate (D) in the outdoor air at 1m above the ground level was equally computed using equation 6 [19].

$$D = 0.042C_K + 0.429C_U + 0.666C_{Th} \quad (6)$$

Where C_k, C_U and C_{Th} are the activity concentrations of potassium (k), Uranium (U) and Thorium (Th) respectively. The values of the gamma absorbed dose rate (D) for the communities are recorded in Table 3. The world's permissible level is $60nGyh^{-1}$ [19].

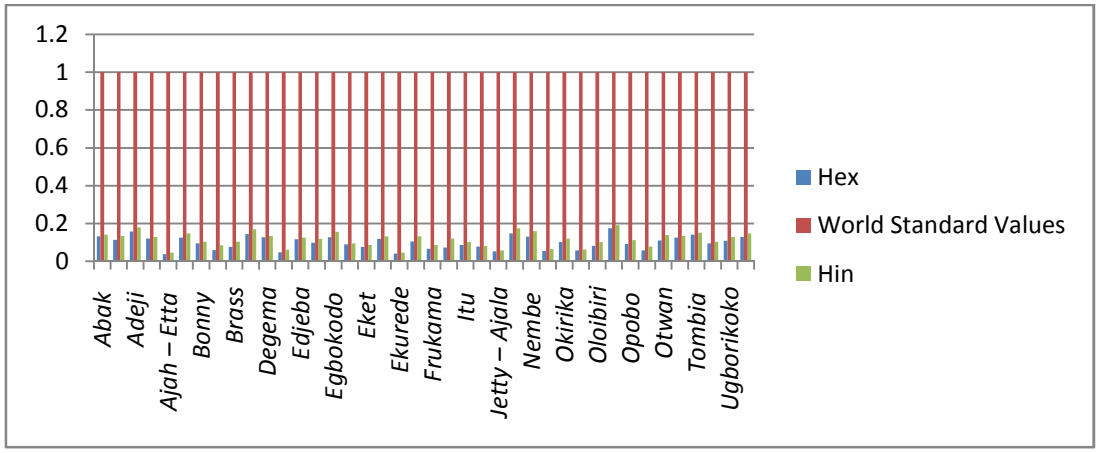

Fig. 2. The Health hazard indices compared to the World Standard values

3.7 Annual Effective Dose Equivalent (AEDE)

The annual effective dose equivalent radiation is computed from absorbed dose rate by applying a dose conversion factor of 0.7 Svy^{-1} and occupancy factor of 0.8 (19/24) for outdoor radiation and 0.2 (5/24) for indoors. This was done on the estimation that an average person spends about 19 hours outdoors and 5 hours indoors according to [20]. The equations used for outdoor and indoor AEDE are given in equations 7 and 8 respectively.

AEDE (outdoor) = absorbed dose x 8760 hrs x 0.7 Svy^{-1} x 0.2 x 10^{-3}
AEDE (indoor) = absorbed dose x 8760hrs x 0.7 Svy^{-1} x 0.8 x 10^{-3}

The values obtained for the communities are recorded in Table 3. The world annual effective dose equivalent is 70μSvy^{-1} for the outdoor AEDE and 450μSvy^{-1} for the indoor AEDE [18].

3.8 Excess Lifetime Cancer Risk (ELCR)

Excess lifetime cancer risk deals with the probability of developing cancer over a lifetime at a give exposure level. ELCR is given as equation 9 [21].

$$ELCR = AEDE \times DL \times RF \quad (9)$$

Table 3. Radium equivalent activity, health hazard indices, annual effective dose equivalent and the cancer risk

	Communities	Ra_{eq} Bqkg^{-1}	AGED Bqkg^{-1}	H_{ex}	H_{in}	DGyh^{-1} (10^{-9})	AEDE (outdoor) Svy^{-1} (10^{-6})	AEDE (indoor) Svy^{-1} (10^{-6})	ELCR 10^{-3}
1	Abak	48.77	192.20	0.132	0.140	25.99	31.87	122.64	0.112
2	Abonnema	41.66	156.16	0.113	0.133	21.40	26.24	104.98	0.092
3	Adeje	58.50	216.77	0.158	0.180	29.96	36.74	146.97	0.129
4	Ahoada	44.65	167.00	0.121	0.129	23.15	28.39	113.56	0.099
5	Ajakjak	13.93	50.14	0.038	0.046	6.97	8.55	34.19	0.030
6	Amassoma	46.69	173.36	0.126	0.147	23.91	29.32	117.29	0.103
7	Bonny	34.02	120.58	0.094	0.104	17.63	21.62	86.48	0.076
8	Bori	21.92	73.88	0.059	0.085	10.42	12.78	91.11	0.045
9	Brass	28.37	102.25	0.077	0.104	14.06	17.24	68.97	0.060
10	Calabar	53.17	200.85	0.144	0.170	27.40	33.60	134.40	0.118
11	Degema	47.29	184.58	0.127	0.133	25.09	30.77	123.08	0.108
12	Deli	17.64	61.03	0.048	0.061	8.62	10.57	42.29	0.037
13	Ediba	43.30	165.90	0.117	0.125	22.73	27.88	111.50	0.098
14	Effurun	36.68	132.64	0.099	0.119	18.48	22.66	90.66	0.079
15	Egbeboko	47.01	166.69	0.127	0.155	23.40	28.70	114.78	0.101
16	Ekeremor	32.98	129.19	0.089	0.095	17.52	21.49	85.95	0.075
17	Eket	28.41	111.11	0.077	0.086	15.00	18.39	73.58	0.064
18	Ekpe	44.10	165.07	0.119	0.132	22.80	27.96	111.85	0.098
19	Ekuaro	15.28	64.23	0.041	0.045	7.70	9.44	37.77	0.033
20	Focados	39.02	140.45	0.105	0.132	19.50	23.91	95.66	0.084
21	Frukama	24.52	84.15	0.066	0.086	11.91	14.61	58.43	0.051
22	Ifie	26.93	89.80	0.073	0.120	12.46	15.28	61.12	0.054
23	Itu	31.90	120.82	0.086	0.101	16.49	20.22	80.89	0.071
24	Jeddo	28.98	110.21	0.078	0.082	13.40	16.43	65.74	0.058

	Communities	Ra_{eq} Bqkg^{-1}	AGED Bqkg^{-1}	H_{ex}	H_{in}	DGyh^{-1} (10^{-9})	AEDE (outdoor) Svy^{-1} (10^{-6})	AEDE (indoor) Svy^{-1} (10^{-6})	ELCR 10^{-3}
25	Jesse	19.08	73.41	0.052	0.057	10.00	12.26	49.06	0.043
26	Mbiama	54.78	205.33	0.148	0.175	17.38	21.31	85.26	0.075
27	Nembe	48.47	176.78	0.131	0.159	24.48	30.02	120.09	0.105
28	Ogunu	20.40	77.20	0.055	0.064	23.68	29.04	116.16	0.102
29	Okirika	37.71	140.04	0.102	0.121	19.27	23.63	94.53	0.083
30	Okpari	21.56	73.12	0.058	0.063	10.64	13.05	52.19	0.046
31	Oloibiri	30.24	112.53	0.082	0.102	15.50	19.01	76.04	0.067
32	Onupa	64.24	241.18	0.174	0.191	33.30	40.84	163.36	0.117
33	Opobo	33.66	103.88	0.091	0.111	16.88	20.71	82.81	0.059
34	Oron	21.34	73.82	0.058	0.078	10.37	12.72	50.87	0.045
35	Otwan	40.94	145.00	0.110	0.138	20.32	24.92	99.68	0.087
36	Port Harcourt	49.46	180.64	0.125	0.134	24.70	30.29	121.17	0.106
37	Tombia	52.02	196.58	0.140	0.150	27.12	33.26	133.04	0.116
38	Ubiaja	35.17	133.80	0.095	0.103	23.10	28.33	113.32	0.099
39	Ugbiyoka	40.10	140.37	0.108	0.129	19.90	24.41	97.62	0.085
40	Uyo	47.62	185.68	0.128	0.148	25.00	30.66	150.31	0.107
	World Values	370	300	1.0	1.0	60	70	450	0.290

Where AEDE is the annual effective dose equivalent,

DL is the average duration of life (estimated to be 70 years) and

RF is the risk factor i.e. fatal cancer risk per sievert. For stochastic effects, the International Commission on Radiological Protection (ICRP) uses RF as 0.05 for the public [21]. The result obtained for ELCR is recorded in Table 3 and the chart comparing the values to the world permissible standard of 0.290 x 10^{-3} is shown in Fig. 3 below.

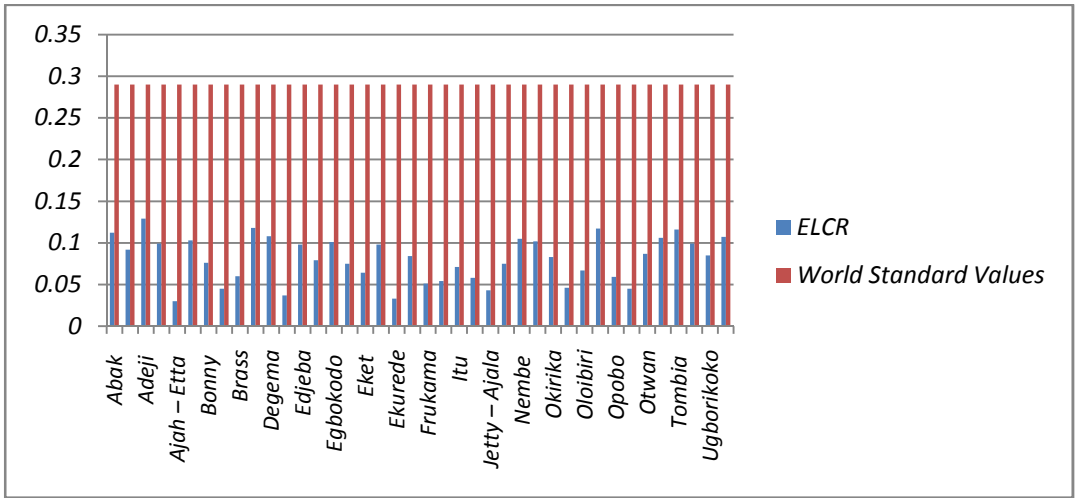

Fig. 3. Excess Lifetime Cancer Risk compared to the World standard values

4. CONCLUSION

The evaluation of radiation health hazard indices and excess lifetime cancer risk of 40 oil-producing communities in the Niger – Delta region of Nigeria has been carried out. The values obtained when compared with the various world permissible values were found to be below the standard for such environment and hence the exploration and exportation of oil did not pose any significant health threat to the communities.

CONSENT

Not applicable.

ETHICAL APPROVAL

Not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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