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Estimation of Radiological Health Risks in Soil Samples of oil and gas fields and Communities, Southern part of Bayelsa State

N.B. Esendu[1], G.O. Avwiri[2] and C.P. Ononugbo[3]

[1]Institute of Natural Resources, Environment and Sustainable Development (INRES), University of Port-Harcourt, Rivers State, Nigeria

[2,3]Department of Physics, University of Port-Harcourt, Rivers State, Nigeria

bennimifa@yahoo.com[1], gregory.avwiri@uniport.edu.ng[2], onochinyere@yahoo.co.uk[3]

Abstract

The radiological health risks in soil samples of oil and gas fields and communities in the southern part of Bayelsa State, Nigeria was estimated from the measured soil samples associated with naturally occurring radionuclide of ^{40}K, ^{238}U and ^{232}Th. The external hazard index varies between 0.095 and 0.635 which is less than unity. Also, the internal hazard index (H_{in}) is regarded as an internal exposure to alpha particles emitted from the short-lived radionuclide and from the estimation, (H_{in}) ranged from 0.113 to 0.695 which is less than the set limit of 1 as compared to world standard. The calculated results of the absorbed dose rate (D) from soil samples values ranged from 17.8 nGy^{-1} to 113.1 nGy^{-1} with an average value of 60.5 nGy^{-1} which is within the permissible maximum limit of 60 nGy^{-1}.The estimated results of the annual effective dose equivalent (AEDE) values ranged from 0.02 μSvy^{-1} to 0.14 μSvy^{-1} with an average value of 0.07 μSvy^{-1} and is far lower than the recommended safe limit of 0.48 mSvy^{-1}. The excess lifetime cancer risk (ELCR) estimated values ranged from 0.06 x 10^{-3} to 0.35 x $10^{-3}$with an average value of 0.19 x 10^{-3}. These values of ELCR were lower than the safe limit of 0.29 x 10^{-3}. This implies that the radiation hazard to the general public due to exposure to natural radionuclides is minimal but may have long term health risks.

Keywords: *External and Internal hazard indices, ELCR, Absorbed dose rate, AEDE, oil and gas fields and Communities*

Corresponding author: E-mail: bennimifa@yahoo.com;

1. Introduction

The earth's environment contains naturally occurring radioactive material (NORM) which spread widely in geological formations such as rocks, soil air and water. The environment we dwell in contains building, food, grasses and phantoms of elements. This element around us generates radiation emission and considered as radioactive substances or radionuclides. The humans that live in this environment are exposed to significant fractions of background radiation level and although, it can be considered as harmless to humans and living things except if there is an environmental effect caused by man-made activities involving radionuclides. Oil and gas firms use radioactive materials and devices that emit ionizing radiation and produces radioactive waste during drilling operations. These materials are brought to the surface generally referred to as 'technologically enhanced naturally occurring radioactive materials' (TENORM**)** [1, 6]

In the earth environment, many elements like uranium, radium, thorium and radon are found in naturally occurring radioactive materials that are dissolved into very low concentrations during normal reactions between water and rock or soil [3, 10]. The oil and gas activities in the Niger Delta environment are on the increase. Its environment is constantly surrounded by radioactive emissions over many years that have led to degradation and pollution of the areas. The exploration and exploitation of oil and gas operations in the region, radionuclides like ^{238}U and ^{232}Th decay series (notably ^{226}Ra, ^{210}Pb, 210Po, ^{214}Pb and ^{208}TI) have been found to be present in process water, precipitate to form scales and sludge in pipeline work, pumps, valves and drilling equipment [18, 19].These radionuclides found in the drilling sites emit ionizing radiation which very harmful to human health and the environment. Environmental problems occur as a result of oil and gas exploration leading to various issues such as oil spills, radioactive waste. These radioactive wastes have serious impact on communities and the ecosystem of the oil-producing areas. [2, 8]

We cannot completely avoid radiation because is present ubiquitously on the earth crust and in atmosphere. Several studies have been carried out on the health effects of ionizing radiation which humans are exposed and may cause detrimental health effects to individuals, environment and members of the public. Studies have shown that what causes cancer and mental disorder in offspring may be as a result of exposure to ionizing radiation. The effect of mental imbalance of the offspring occurs when a female is pregnant. There is a strong relationship between health hazards and radiation exposure among the populace and industrial workers in a given environment was reported by Agbalagba [4]. The principle of ALARA (As Low as Reasonably Achievable) was developed and included in radiation protection practice to ensure that human exposure to ionizing radiation is guided.

The estimation of radiological health risks in soil samples in different part of the world have been carried out by many researchers. According to Azionu *et al.*,2021 [5] who measured natural radioactivity levels of ^{226}Ra, ^{232}Th and ^{40}K in plants and soil samples around used crude oil production pipes stored locations in Niger Delta region of Nigeria using sodium-iodide Nal(TI) spectrometer. The radiation health hazard indices computed for radium equivalent activity, gamma index, external and internal hazard indices, absorbed dose of radiation, annual effective dose equivalent, annual gonadal equivalent dose, excess lifetime cancer risk and activity utilization index were within their International permissible standards. [5]

Edomi *et al.,* (2018) studied the radionuclides present in soils from selected oil and gas producing communities in Delta Central, Delta State, Nigeria, were determined using gamma-ray spectrometry with a view of evaluating the radiological health hazard fallout of the oil and gas activities in these areas. The results revealed the presence of ^{238}U, ^{232}Th and ^{40}K respectively. The calculated mean for the radiological hazard indices revealed radium equivalent activity (Raeq) (80.42) Bqkq^{-1}, absorbed dose (D) (37.95) nGyh^{-1}, effective dose equivalent value (0.038) mSvy^{-1}, AEDE (outdoor) (53.58) and (indoor) (186.06) mSvy^{-1}, Hex (0.216), Hin (0.336) and finally, ELCR (0.016 x 10^{-3}) respectively. The obtained results are below their respectively international radiological health standards. They concluded that the populaces are not radiologically overexposed [6].

Emelue *et al.*, (2014) studied the Gamma 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 (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 community's 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. They concluded that the exploration and exportation of crude oil in Nigeria did not pose a radioactive health hazard to the oil producing communities [7]. The radiation exposure to high level of gamma rays is detrimental to human health and environment which leads to a number of harmful effects in individuals such as various types of cancer and mutation. When biological and tissues of human are exposed to gamma radiation, it will cause both excitation and ionization in the process altered the structure of the cells and tissues. Therefore, this research work shall aim to evaluate radiological health risks in soil samples in oil and gas fields.

2. Materials and Methods

The soil samples were collected from selected sites or areas of elevated natural radioactivity around oil and gas fields and host Communities. An estimate of about Forty (40) Soil samples was collected from a pre-determined depth of 0.5m – 1.0m, with the aid of a shovel across mining/exploration areas (oil flow-stations, oil wells) and residential and farms of southern Bayelsa around Nembe communities. The map of the study areas of southern Bayelsa Nembe oil and gas fields and communities is in figure 1. The soil samples obtained were sealed in a transparent cellophane bag and labeled. A Marinelli beaker (size 500ml) is used to seal the soil samples accordingly to maintain its in-situ characteristics, before taken to the laboratory for analysis. The soil samples were dried and homogenized to pass through 1mm mesh sieve. The sealed sample containers were left for twenty-eight (28) days for the short-lived members of uranium and thorium series to attain a secular equilibrium. Therefore, the samples were placed on the detector and measured for 29000 seconds. The net area corresponding to the photopeak's in the energy spectrum was computed by subtracting count from the background source from the total area of the photopeak's. The multichannel analyzer (MCA) was used to compute the radionuclides [6, 12].

The Sodium Iodide (NaI-TI) detector is a scintillation detector that was used for this work. The detector is a lead shield Canberra 76mm x 76mm NaI(TI) crystal models number 802 series. The Scintillation Detector is a compatible sealed assembly which contains high-resolution NaI(Tl) crystal, a photomultiplier tube that detects the small visible light photons produced in the crystal and concerts them into amplified electrical pulses, which is fed into analyzer systems through a preamplifier base. The detector system was calibrated before carrying out actual measurement of soil and water samples collected from Nembe oil and gas fields and communities. The radiation parameters in the soil samples were expressed in physical radiometric units. In order to commence counting, three gamma standard sources Cs-137, Am-241 and Co-60 were placed into

6cm lead shield of Model 802 Sodium Iodide NaI (TI) detector chamber. This set up is aimed to minimize the effects of background and scattered radiation. The Cs-137 and Co-60 source that emits gamma rays with known energies of 662 keV, 1332 keV and 1173 keV were chosen for the calibration. These were done with the amplifier gain that gives 72% energy resolution for the 662 keV of Cs-137 and counted for 30 minutes. The count detected by the instrument varies as a result of natural fluctuation of radioactivity [9, 10]. The measured results were used to calculate radiological health indices such as Annual effective dose equivalent (AEDE), Excess Lifetime Cancer Risk (ELCR), Equivalent Dose Rate, effective dose rate to different organs and tissues and Annual Gonadal Equivalent Dose (AGED).

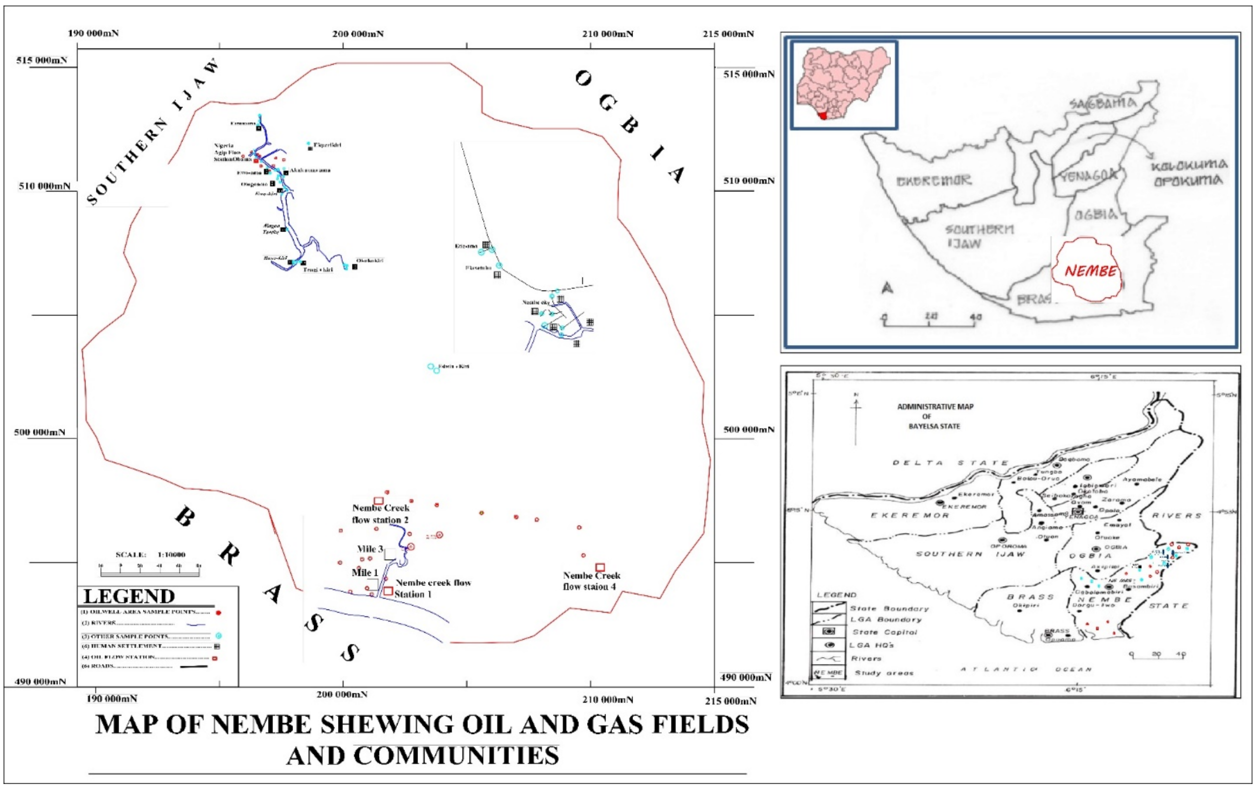

Fig 1: Map of the study areas of Southern Bayelsa, Nembe Oil and Gas fields and Communities

3. Radiological Health Parameters

The radiological health risks are standard parameters used in radiation studies to asses and estimate the effects of radiation exposure on the health of people and the environment. Some radiation health risks parameters associated with the studied soil samples are discussed below:

3.1 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. The measurement unit of radium equivalent is Bq/kg (Becquerel's per kilogram) and can be calculated using equation below:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_k \quad (1.0)$$

Where A (Ra), A (Th) and A (k) are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K (in Bq/kg). In defining radium equivalent activity, the assumption was made that 370Bq/kg of ^{226}Ra, 259 Bq/kg of ^{232}Th and 4810 Bq/kg of ^{40}K yields the same gamma dose rate [15, 16]

3.2 **Annual Effective Dose Equivalent (AEDE)**

The measurement of radionuclides in the environment due to terrestrial gamma radiation from ^{238}U, ^{232}Th and ^{40}K can be deduce from the average outdoor conversion coefficient from absorbed dose rate in the air to the average annual effective dose equivalent (AEDE) received by adult and the indoor occupancy factor. The conversion factor values estimated to be 0.7 $SvGy^{-1}$ for gamma ray exposure in the environment and the occupancy factor outdoor to be 0.2 considering that people on regular basis spent 20% of their time outdoors. The AEDE can be calculated as stated below:

$$\mathbf{AEDE}\left(\frac{\mu Sv}{y}\right) = \mathbf{D}\left(\frac{nGy}{y}\right) \mathbf{x\ 8760}\left(\frac{h}{y}\right) \mathbf{x\ 0.2\ x\ 0.7}\left(\frac{Sv}{Gy}\right) \mathbf{x\ 10^{-3}} \quad (1.1)$$

For indoor measurement, the occupancy factor for building materials is estimated to be approximately 0.8, hence the equation 1.1 becomes:

$$\text{AEDE}\left(\frac{\mu Sv}{y}\right) = D\left(\frac{nGy}{y}\right) x\ 8760\left(\frac{h}{y}\right) x\ 0.8\ x\ 0.7\left(\frac{Sv}{Gy}\right) x\ 10^{-3} \quad (1.2)$$

The world AEDE for both indoor and outdoor terrestrial gamma radiation is 0.460mSv/year [16]

3.3 **External Hazards Index (Hex)**

The estimation of external risk assessment (Hex) associated with gamma dose rays emanating from the soil sample. The prime objective is to limit the activity concentration of ^{226}Ra. ^{232}Th and ^{40}K to ensure that a permissible dose rate of 1mSv/y and is not exceeded. The equation below is used to define the external Index:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad \textit{(Without doors and windows)} \quad (1.3)$$

Where A_{Ra}, A_{Th} and A_k are the specific activities concentrations (Bq/Kg) of ^{226}Ra. ^{232}Th and ^{40}K respectively. For the hazard to be considered as negligible, Hex value must be less than unity [12, 16]

3.4 **Internal Hazard Index (H_{in})**

Inhalation to alpha emitter ^{222}Rn and ^{220}Rn is hazardous to the respiratory organs. The hazard which is defined as an internal hazard is represented by H_{in} respectively and can be determined as follows:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_k}{4810} \quad (1.4)$$

Where A_{Ra}, A_{Th} and A_k are the specific activities concentrations (Bq/Kg) of ^{226}Ra. ^{232}Th and ^{40}K respectively. For radiation hazard to be considered safely the internal hazard index should be less than unity and also radon and its daughter product are hazardous to human health [14]

3.5 **Excess Lifetime Cancer Risk (ELCR)**

Excess lifetime cancer risk is the probability of developing cancer over a period of lifetime due to radiation exposure level. The ELCR is also presented as a value representing the number of extra cancers expected in a given number of people on exposure to a carcinogen at a given dose. The ELCR was calculated using equation 1.6 below:

$$ELCR = AEDE\ x\ Average\ duration\ of\ life\ (DL) x\ Risk\ factor\ (RF) \quad (1.5)$$

Where AEDE is the annual effective dose equivalent, DL is the duration of life (estimated to 70 years) and RF is the risk factor (Sv^{-1}) respectively [13]

3.6. A**bsorbed Dose Rate (D)**

The absorbed dose rate is defined as the energy imported to matter (human body) from any type of radiation for a given period. It is also used to assess the potential for any biochemical changes in specific tissues. The absorbed dose rate due to terrestrial gamma rays can be estimated from ^{226}Ra, ^{232}Th and ^{40}K concentration in soil or water samples. The gamma absorbed dose rate (D) in the outdoor air at 1m above ground level was calculated using equations below; [1, 13]

$$D = 0.042C_k + 0.0429C_u + 0.666C_{Th} \quad (1.6)$$

Where C_k, C_U and C_{Th} are the activity concentrations of potassium (k), uranium (U) and

Thorium (Th) respectively

4.1 **Result**

The results of the estimation of radiological health risks in soil samples of oil and gas fields and communities, southern part of Bayelsa State, Nigeria has been computed in Table 1, Figures 2-6 show comparison of External hazard index values ($mSvy^{-1}$) in soil samples with world average standard, comparison of Internal hazard index values ($mSvy^{-1}$) in soil samples with world average standard, Comparison of Absorbed dose rate values ($nGyh^{-1}$) in soil samples with world average , Comparison of Annual effective dose equivalent (AEDE) values (μSvy^{-1}) in soil samples with world average standard, comparison of Excess life cancer risk (ELCR) values (x 10^{-3}) in soil samples with world average standard (UNSCEAR, 2000) across the study area.

Table 1: Calculated mean values for radiological health risk and hazard indices in soil samples across study area.

S/n	Sample codes	Sample locations	D ($nGyh^{-1}$)	H_{ex}	Hi_n	AEDE (μSvy^{-1})	AGDE ($mSvy^{-1}$)	ELCR x 10^{-3}
1	NCV 001-S	Nembe creek	40.2	0.219	0.268	0.05	283.7	0.12
2	NC1 003-S	Well 7	58.2	0.328	0.368	0.07	389.2	0.18
3	NC1 004-S	Well 27	67.7	0.377	0.430	0.08	460.3	0.21
4	NC1 007-S	Well 10	69.3	0.397	0.537	0.09	477.6	0.21
5	NC1 009-S	Well 74/8	73.4	0.413	0.467	0.09	493.9	0.23
6	NC1 010-S	Well 5	58.6	0.325	0.378	0.07	401.8	0.18
7	NC2 011-S	Well 34	65.1	0.364	0.405	0.08	439.5	0.19
8	NC2 014-S	Well 50	97.2	0.549	0.636	0.12	652.7	0.29
9	NC1 015-S	Well 20	71.8	0.405	0.472	0.09	484.1	0.22
10	NC4F020-S	NC4FS	66.5	0.380	0.459	0.08	445.3	0.20
11	NC1F022-S	NC1FS	84.7	0.482	0.542	0.10	560.1	0.26
12	NCV 023-S	Okokokiri	82.1	0.461	0.556	0.10	560.5	0.25
13	NCV 024-S	Akakumama	81.2	0.457	0.546	0.09	550.9	0.25
14	NCV 025-S	Alagoa-tereke	113.1	0.635	0.695	0.14	755.4	0.35
15	NCV 026-S	Ologoama	77.3	0.435	0.510	0.09	523.9	0.24
16	NCV 029-S	Ologoama-Farm	101.8	0.567	0.601	0.12	680.3	0.31

		Area						
17	NCV 030-S	Edwinkiri fishing Port	39.5	0.224	0.266	0.05	266.7	0.12
18	NCV 031-S	Nembe City water front	28.7	0.159	0.171	0.04	193.9	0.09
19	NCV 032-S	Etieama 1	18.5	0.104	0.136	0.02	129.2	0.06
20	NCV 033-S	Etieama 2	72.9	0.411	0.498	0.09	497.2	0.22
21	NCV 034-S	Ekese-tubo	74.4	0.415	0.481	0.09	506.9	0.23
22	NCV 035-S	Basanbiri - Nembe	79.3	0.441	0.548	0.09	552.8	0.24
23	NCV 036-S	Nembe City Market Area	60.9	0.347	0.426	0.08	411.5	0.19
24	NCV 037-S	Tombi -Nembe	17.8	0.095	0.113	0.02	127.2	0.06
25	NCV 038-S	Nembe city Center	36.7	0.196	0.213	0.05	257.3	0.11
26	NCV 039-S	Amasara Polo-Nembe	22.6	0.127	0.169	0.03	158.7	0.07
27	NCV 040-S	Otatubo- Nembe	32.8	0.186	0.229	0.04	221.9	0.10
28	NC1 006-S	Well 13	56.9	0.322	0.413	0.07	391.5	0.17
29	NC2 013-S	Well 64	60.5	0.349	0.473	0.07	414.1	0.19
30	NC4 019-S	Well 41	60.8	0.344	0.429	0.08	416.5	0.19
31	NCV 027-S	Ewoama	32.9	0.175	0.175	0.04	229.1	0.10
32	NC1 005-S	Well 19	98.8	0.559	0.598	0.12	651.1	0.31
33	NC4 018-S	Well 28	25.8	0.143	0.143	0.03	171.4	0.08
34	NC2 016-S	Well 49/51/39	69.3	0.386	0.437	0.09	471.5	0.21
35	NC2 021-S	Well 22	72.0	0.408	0.489	0.09	486.9	0.22
36	NC1 002-S	Well 16	64.5	0.360	0.397	0.08	433.6	0.19
37	NC1 008-S	Well 12	60.4	0.335	0.361	0.07	407.7	0.19
38	NC4 017-S	Well 61	20.1	0.114	0.135	0.03	135.8	0.06
39	NC2F012-S	NC2FS	38.4	0.215	0.247	0.05	260.1	0.12
40	NCV 028-S	Well X	66.5	0.371	0.414	0.08	450.3	0.20
Mean			**60.5**	**0.339**	**0.395**	**0.07**	**410.1**	**0.19**
World Average			**84**	**1.00**	**1.00**	**1.00**	**300**	**0.29**

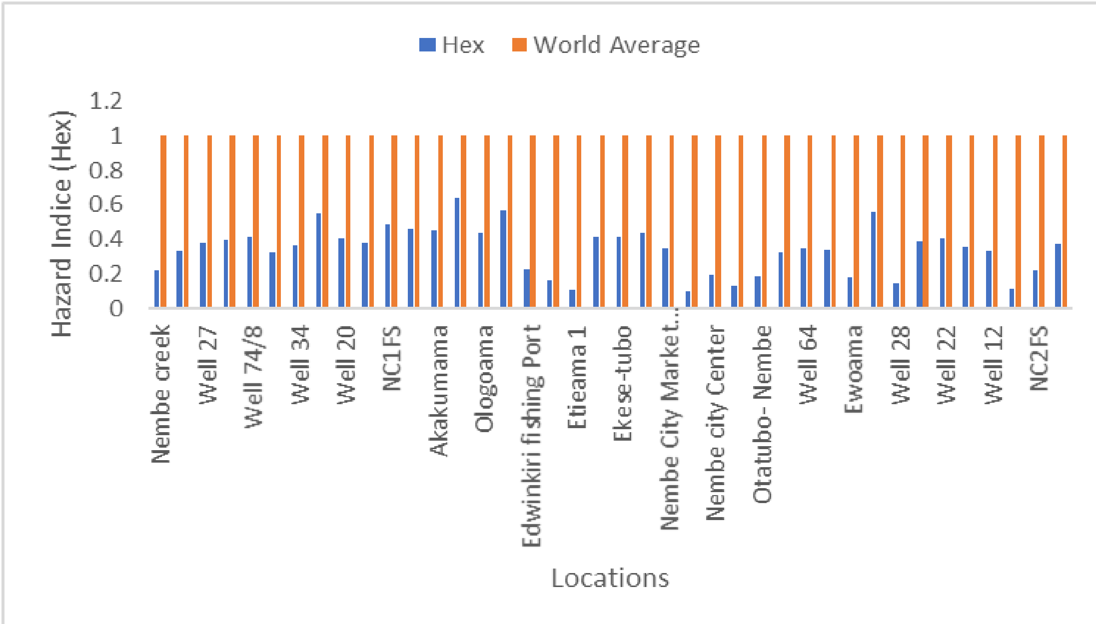

Fig.2: External hazard index values ($mSvy^{-1}$) in soil samples with world average standard

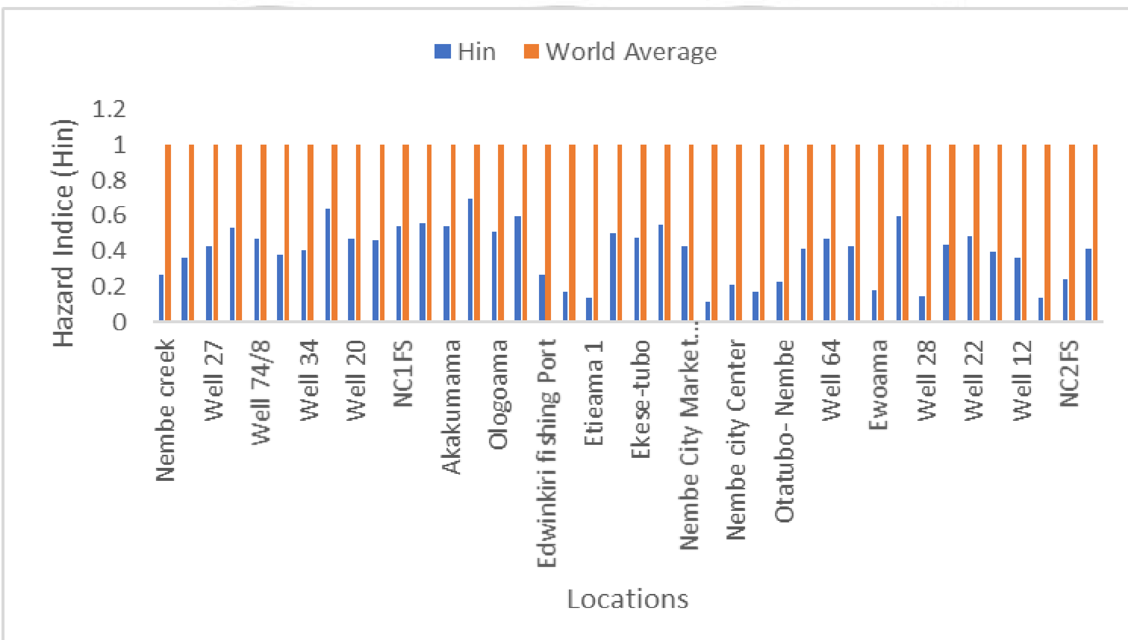

Fig.3: Internal hazard index values ($mSvy^{-1}$) in soil samples with world average standard

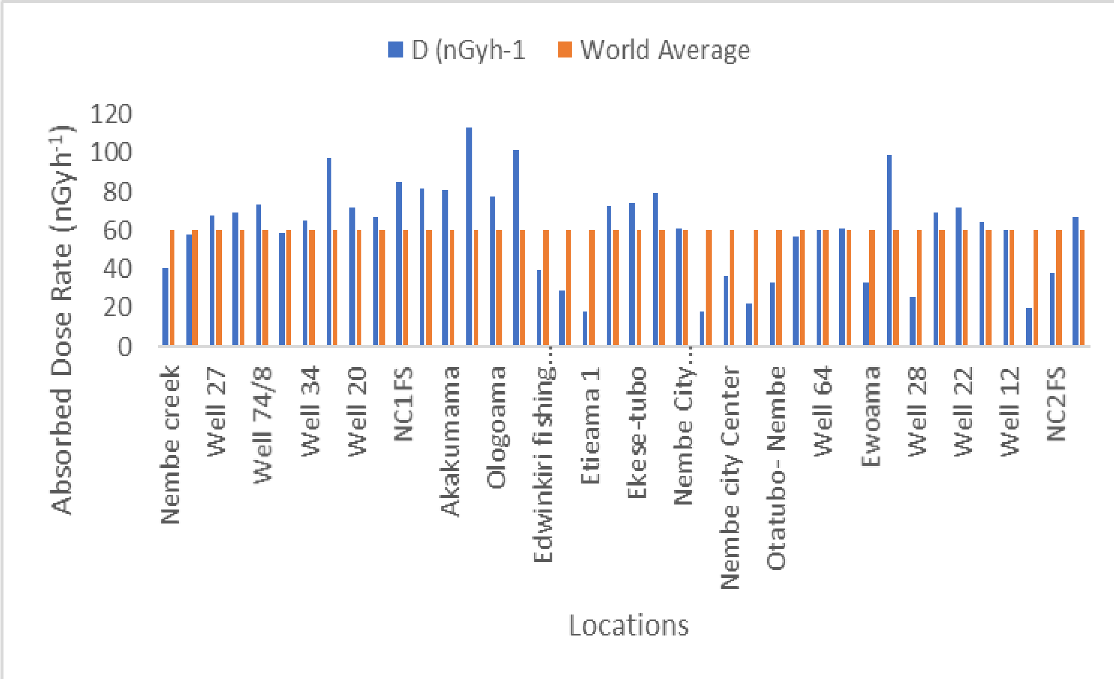

Fig.4: Absorbed dose rate values (nGyh^{-1}) in soil samples with world average standard

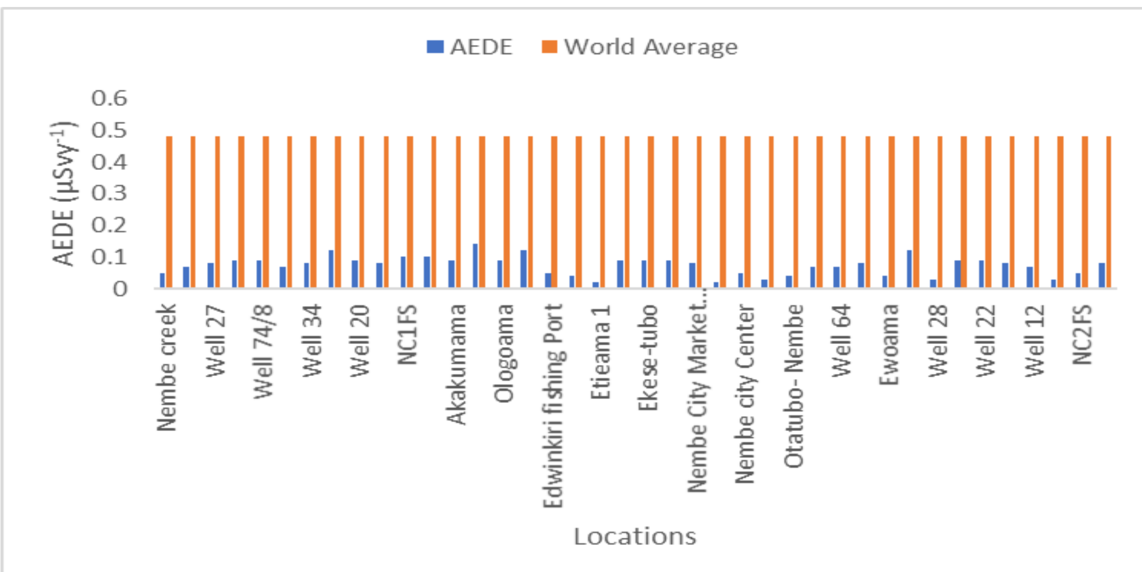

Fig.5: Annual Effective Dose Equivalent (AEDE) values (µSvy^{-1}) in soil samples with world average standard

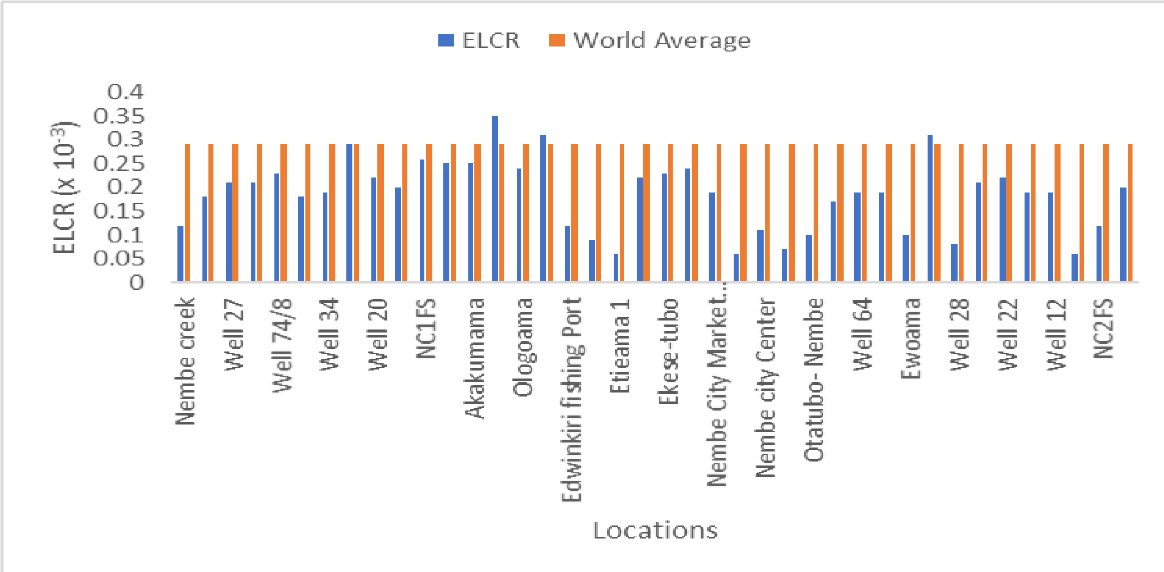

Fig.6: Excess Life Cancer Risk (ELCR) values (x 10^{-3}) in soil samples with world average standard

4.2 **Discussion**

The external hazard index (Hext) was estimated by the use of a model for a room in the building where inhabitant live without windows and doors, but having thick walls all round. However, external hazard index varies between 0.095 and 0.635 which is less than unity. Also, the internal hazard index (H_{in}) is regarded as an internal exposure to alpha particles emitted from the short-lived radionuclide and from the estimation, (H_{in}) ranged from 0.113 to 0.695. All the samples of soil have external hazard indices less than the set limit of 1 and also, (H_{in}) values recorded is still lower than the safe limit (i.e. less than unity). Internal hazard is the cause of harmful effects to the lungs due to the internal contact of alpha particles of the sample. Its effects lead to higher ionization power to sensitive tissues of the lungs and other parts of the respiratory system. The results of (H_{ext}) and (H_{in}) obtained in this current work are similar to that reported by Ovuomarie-kelvin [20] in Bayelsa State, Nigeria, by Avwiri [22] in Delta State, Nigeria and by Anekwe [21] in River State, Nigeria. The result shown that internal hazard indices is in safe limit because the values are nearly unity, therefore using the soil as a building material might pose health risks for long term exposure.

The calculated results of the absorbed dose rate (D) from soil samples are presented in Table 1 and the obtained values ranged from 17.8 nGy^{-1} to 113.1 $nGy^{-1}$with an average value of 60.5 nGy^{-1} which is lower than the permissible maximum limit of 84 nGy^{-1}.These values are converted to effective dose equivalent since the absorbed dose rate itself does not show possible biological effects. The absorbed dose rate has its highest value as observed at NCV 025-S and the lowest at NCV 037-S.

The estimated results of the annual effective dose equivalent (AEDE) are presented in Table 1 and the obtained values ranged from 0.02 μSvy^{-1} to 0.14 $\mu Svy^{-1}$with an average value of 0.07 μSvy^{-1} and is far lower than the recommended safe limit of 1.00$mSvy^{-1}$ meanwhile the outdoor effective dose of all the samples are within their safe value and this could lead to injurious health risk of individuals that were exposed to the soil for long term effect. The calculated values of annual gonadal dose equivalent (AGDE) in the soil samples ranged from 127.2$mSvy^{-1}$ to 755.4$mSvy^{-1}$ with an average value of 410.1$mSvy^{-1}$. The values obtained for AGDE in the samples were higher than the recommended safe limit of 300$mSvy^{-1}$. The excess lifetime cancer risk (ELCR) estimated values ranged from 0.06 x 10^{-3} to 0.35 x 10^{-3} with an average value of 0.19 x 10^{-3}. These values of ELCR were lower than the safe limit of 0.29 x 10^{-3}, except for NC1 005-S, NCV 029-S and NCV 025-S where we have elevated values higher than the safe limit. This means that in years to come the three selected areas of Nembe oil and gas field and host communities might have radiological risk or might be eventually safe within limit. The estimation results of all the radiological health risk parameters compared well with values obtained by Darwish *et al.*, (2015) and Avwiri *et al*., (2017). All the hazard indices and activity utilization index are less than unity set by UNSCEAR (2000) for radiation protection. This implies that the radiation hazard to the general public due to exposure to natural radionuclides in the current study samples is minimal, but might likely cause effect for long term exposure in the near future.

5. Conclusion

The estimation of radiation health risks of forty (40) soil samples of oil and gas fields and communities, southern Bayelsa state, Nigeria has been carried out. The following conclusions were made from the study;

1. The external and internal hazard indices were determined and are lower than the set limits of 1 in all the selected Nembe oil and gas fields and host communities.
2. The calculated values of ELCR were found lower than the safe limit of 0.29 x 10^{-3}, except for NC1 005-S, NCV 029-S and NCV 025-S which have elevated values.
3. The estimated values of the annual effective dose equivalent (AEDE) were far lower than the recommended safe limit of 1.00$mSvy^{-1}$
4. The calculated values of annual gonadal dose equivalent (AGDE) in the soil samples were higher than the recommended safe limit of 300$mSvy^{-1}$.

5. Hence, radiation hazard to the general public due to exposure to natural radionuclides is minimal, but may have long term health risks.

Competing Interests

The Authors declared that no competing interest exist

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