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Background Radiation Studies from NORM within the Eastern Oilfields and Facilities in Nigeria

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Abstract: *The results of annual effective dose rate of radiation (ED_m) and excess lifetime cancer risk (ELCR) have been computed based on the radiation exposure rates (RE_m) measured using Model 3A- Ludlum radiation survey meter. This study was carried out within some selected Shell Petroleum Development Company of Nigeria operational locations in the Niger Delta Region of Nigeria. RE_m results ranged from 0.015±0.002 to 0.033±0.004 mR/hr with a mean of 0.023±0.003 mR/hr. These results are high relative to the standard external radiation level of 0.011 mR/hr set by the United States Nuclear Regulatory Commission. ED_m results ranged from 1.46±0.175 mSv/yr to 2.92±0.350 mSv/yr and are greater than the permissible dose limit of 1 mSv/yr set by the International Commission on Radiological Protection. Results of ELCR ranged between 4.59 x 10^{-3} and 10.22 x 10^{-3} and are high when compared with the world average value of 0.29 x 10^{-3}. All these results were pictorially presented using geographical- location- based 3-D contour maps. Efforts should be made by concerned personnel and authorities to avert undue disposal of Naturally Occurring Radioactive Materials (NORM) into oil producing environments through production activities in order to forestall radiation health related impacts.*

Keywords: *NORM; Impact; Oilfields; Facilities, Ludlum Meter*

1. Introduction

In as much as the role of oil production activities in the economic sustenance of Nigeria cannot be undermined, its attendant negative environmental consequences cannot be over looked, the major environmental set back being anchored largely on the crude way the exploration companies operate. Commercial Crude oil exploration and exploitation from deposits and gas reserves in the Niger–Delta region of Nigeria have brought about negative alteration of the regions environment as the vegetations are destroyed to make way for seismic lines, dynamites are detonated and animals and fishes' habitats are destroyed. Produced oil and drilling mud for oil productions find their ways into aquatic bodies and reduce their potency. Millions of barrels of crude oil spillages that result from various production operations and pipe leakages, continuous gas flaring, etc, contribute largely to environmental degradation in the oil rich delta of Nigeria.

NORM, an acronym for Naturally Occurring Radioactive Materials refers to materials containing radionuclides from natural sources [1]. It can also be defined as materials which may contain any of the primordial radionuclides or radioactive elements as they occur in nature. These radionuclides include; radium, uranium, thorium, potassium, and their radioactive decay products when they exist in their undisturbed state [2].

Natural radioactivity of Uranium and its progenies occur in rocks and specific ores and these radioactive substances disintegrate to emit radioactive particles of alpha, beta and gamma radiations [3]. Oil production activities have been identified to be associated with some form of radioactive substances that have been naturally deposited in the rocks where oil formations take place and in the rock pores through which the oil products are transported and brought to the surface as produced oil. In the course of interaction between the rocks and produced oil, natural radioactive materials find their ways to the environment. Produced oil comes out with its associated natural and induced radionuclides (from drilling materials). This phenomenon could raise the background radiation level of oil producing environments [4]. Fluids produced from oil or gas fields and aquifers are naturally radioactive owing to the presence of the natural radionuclides of K-40, U-238 and Th-232 and their progenies in the reservoirs where oil is naturally trapped. Thus, when petroleum or geothermal reservoirs are drilled and oil produced, the products get to the subsurface together with naturally occurring radioactive materials [5]. This act of enhancing the natural radioactivity level of the environment is often referred to as TENORM, an acronym for Technologically Enhanced Naturally Occurring Radioactive Materials- defined as natural radioactive materials that have been concentrated or exposed to the accessible environment as a result of human activities such as manufacturing, mineral extraction, or water processing [2].

The results of radionulide analyses of ingested water from some estuaries within the coastal area of Akwa Ibom State, Nigeria showed that most of the radiation risk parameters computed were higher than the standard limits and these were attributed to oil production activities within the area [6]. Oil and gas industry produce NORM in the form of oil scales due to co-precipitation of radium isotopes with barium sulphate added to production water [7]. These radioactive scales are formed in production tubes and transferred to the environment when these tubing materials are disposed. The enhanced levels of radionuclides in oil facilities can potentially raise a problem to operating and cleaning personnels because of exposure to emission of either alpha particles, beta particles, gamma rays or a combination of these [5].

Environmental radiation monitoring within oil producing areas is very important as this method is frequently used for early notification of the increase in the ambient level of local gamma radiation [8]. It is based on the above premise that we were motivated to embark on this research within some selected operational oilfields and facilities within the Eastern Niger Delta Region.

2. METHODOLOGY

2.1. Study Area

This study was carried out within the Shell Petroleum Development Company of Nigeria (SPDC) operational locations within the Niger Delta Area of Nigeria. The Niger Delta region is located in southern Nigeria, between latitude 4^{o} N and 6^{o} N and longitude 3^{o} E and 9^{o} E. It is bounded in the west by the Benin Flank and in the east by the Calabar Flank, to the south by the Gulf of Guinea (extending offshore to the Atlantic) and to the north by older Cretaceous tectonic elements, such as the Abakaliki Anticlinorium and the Afikpo syncline [9]. The Tertiary lithostratigraphic section of the Niger Delta is divided into three formations, representing prograding depositional facies that are distinguished mostly on the basis of sand-shale ratios. The first underlying section at the base of the delta is the Akata Formation which is of marine origin and is composed of thick shale sequences (potential source rock). The Akata Formation is about 7,000 meters thick. Overlying the Akata Formation is the Agbada Formation which is the major petroleum-bearing unit. This Agbada formation is about 3700 meters thick and consists of shale and sandstone beds deposited in equal proportions in the lower section while the upper portion is mostly sand with only minor shale interbeds. The Agbada Formation is overlain by the third formation, the Benin Formation, a continental latest Eocene to recent deposit of alluvial and upper coastal plain sands that are up to 2000 m thick [10]. However, only SPDC operational locations in Rivers state within the Niger Delta Area of Nigeria were considered in this research. The map of the Niger Delta region is presented in Figure 1 and the map of the surveyed areas (part of the Niger Delta region) is presented in Figure 3.

Figure1. *The States in the Niger Delta region*

Figure2. *Model 3A- Ludlum meter*

2.2. Method of Measurement

The method adopted in this survey was an *in situ* measurement and this was preferred since *in situ* gamma ray spectrometry has been used in many situations and environments and has proved to be a fast and accurate tool for determination of activity concentration levels in the environment [8]. The survey meter used in this measurement is Model 3A- LUDLUM. This meter utilizes Geiger Muller Tube (G-M) detector to probe the radiation level within an environment. It is a general purpose survey meter which is capable of measuring radiation exposure ranging from 0 – 200 mR/hr with built in alarm. The picture of Model 3A- Ludlum Meter is presented in Figure 2.

This survey was carried out at 12 different facilities/locations as presented in Table 1 and shown in Figure 3. At each location, 6 readings were taken bringing the number of readings to a total of 72. Also, twelve other additional readings (which served as control readings) were taken outside the operational areas but within the same geological area.

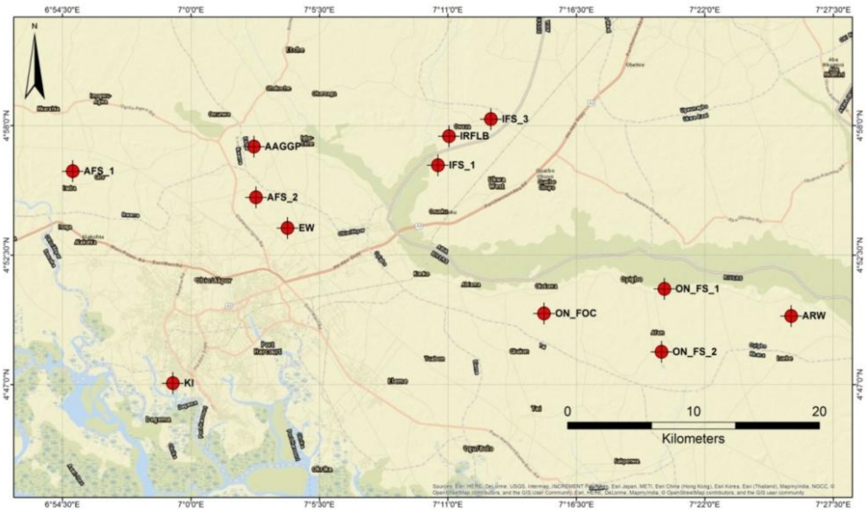

Figure3. *The Surveyed locations (represented with red spots)*

Table1. *Surveyed facilities/locations*

S/N	Location/Facilities	Site Identity	Latitude	Longitude
1	Kidney Island	KI	04.78° N	06.99° E
2	Agbada 2 Flow Station	AFS_2	04.93° N	07.05° E
3	Agbada 2 Associated Gas Gathering plant	ASGGP	04.93° N	07.05° E
4	Agbada 1 Flow Station	AFS_1	04.94° N	06.94° E
5	Obigbo North Field Operation Camp	ON_FOC	04.81° N	07.28° E
6	Obigbo North Flow Station	ON_FS	04.81° N	07.38° E
7	Obigbo North Associated Gas Gathering plant	ONAGGP	04.84° N	07.40° E
8	Imo River Field Logistic Base	IRFLB	04.95 ° N	07.17° E
9	Imo 1 Flow Station	IFS_1	04.92° N	07.17° E
10	Imo 3 Flow Station	IFS_3	04.99° N	07.22° E
11	Afam Rumuosi Well	ARW	04.80° N	07.45° E
12	Elelenwo Well	(EW)	04.89° N	07.07° E

2.3. Data Computation and Analyses

The Mean Radiation Exposure Rate (RE_m) in mR/hr for each of the surveyed locations was computed using the equation;

$$RE_m = \frac{\sum_1^n RE}{n} \quad (1)$$

Where RE represents the exposure rate measured at the six points for each of the 12 oil facilities surveyed and n=12.

The Mean Annual Effective Dose Rate of radiation (ED_m *in* mSv/yr) was computed based on the expression; $ED_m = \frac{RE_m \times 8760}{100}$ (2)

(Since 1mR/hr = 8760 mR/yr; 1mR/hr = 0.01 mSv/hr. So, 8760 mR/yr = 87.60 mSv/yr.)

The excess lifetime cancer risk (ELCR) which deals with the probability of developing cancer during an exposed person's life time at a given exposure level (one who lives or works permanently within this surveyed areas) was computed using [11];

$$ELCR = ED_m \times L_E \times RF \quad (3)$$

Where L_E is life expectancy (estimated to be 70 years) and RF is dose to risk factor, 0.05 Sv^{-1} or 5 x 10^{-5} $(mSv)^{-1}$.

All the data analyses were performed using MINITAB (Release 14) Statistical Software manufactured by Minitab Incorporated, State College, Pennsylvania, USA [4]. This software was used in computing the mean Radiation Exposure Rate (RE_m), its standard deviation (σ), standard error of the mean (SEM) and t-test.

Where, $SEM = \frac{\sigma}{\sqrt{n}}$ (4)

$$\sigma = \sum \sqrt{\frac{(RE - RE_m)^2}{n}} \quad (5)$$

A T-test at 95 % Confidence Interval (CI) was performed so as to obtain the range of estimates for the sample mean (RESM) because, for each location, our sample size is n = 6 < 30 (which is relatively small). This test was carried out to reduce the level of uncertainty of the calculated mean which was based on a relatively small sample size. The range of estimates of the sample mean for all the parameters (RESM) was calculated using the equation adopted from [4];

$$RESM = RE_m \pm t(SEM) \quad (6)$$

where t is the t-table value for 'n-1' degrees of freedom.

The percentage deviation of the computed ED_m (within the oil facilities) from the ED_c (which was computed from the control readings) was calculated from the equation;

$$\% \text{ Dev.} = \frac{(ED_m - ED_c) \times 100}{ED_c} \quad (7)$$

2.4. Contour Mapping of the Surveyed Area

Surfer 8 software was adopted in the 3- D surface mapping and contouring of the surveyed area. This software enabled us to project a 3- dimensional representation of the Mean Radiation Exposure Rate, Mean Annual Effective Dose Rate of Radiation and Excess Lifetime Cancer Risk vis-a-vis the geographical locations of the surveyed points. This software was produced by Golden Software, Inc., in Colorado, United States of America [12].

3. RESULTS AND DISCUSSION

3.1. Presentation of Results of Mean Radiation Exposure Rate (RE_m) in mR/hr.

The results of mean radiation exposure rate for each of the surveyed locations are presented in Table 2. Also, contour map showing the mean radiation exposure rate for all the surveyed locations is as shown in Figure 4. These results range from 0.015±0.002 to 0.033±0.004 mR/hr with a mean of

0.023±0.003 mR/hr. The mean radiation exposure rate was also estimated to range from 0.010 mR/hr to 0.044 mR/hr at 95% Confidence Interval. These results are high relative to the standard external or outdoor radiation level of 0.011 mR/hr stipulated by the by the US Nuclear Regulatory Commission (USNRC) [13, 14].

The perturbation of the normal background radiation of the surveyed environment could be attributed to oil production activities going on within these environments.

Table2. *Mean Radiation Exposure Rate (RE_m) in mR/hr*

S/N	Site Identity	Mean Radiation Exposure Rate (RE_m) in mR/hr	Standard Deviation (mR/hr)	Range of Estimates for Sample Mean at 95% Confidence Interval (mR/hr)
1	KI	0.017±0.002	0.006	0.010 – 0.023
2	AFS_2	0.025±0.004	0.010	0.014 – 0.036
3	ASGGP	0.017±0.002	0.006	0.010 – 0.023
4	AFS_1	0.015±0.002	0.006	0.008 – 0.022
5	ON_FOC	0.033±0.004	0.010	0.022 – 0.044
6	ON_FS	0.022±0.003	0.007	0.014 – 0.030
7	ONAGGP	0.020±0.003	0.006	0.013 – 0.027
8	IRFLB	0.020±0.004	0.009	0.011 – 0.029
9	IFS_1	0.027±0.005	0.012	0.014 – 0.039
10	IFS_3	0.025±0.004	0.010	0.014 – 0.036
11	ARW	0.028±0.004	0.009	0.018 – 0.039
12	EW	0.022±0.003	0.007	0.015 – 0.029
Mean Radiation Exposure = 0.023±0.003 **mR/hr**				

3.2. Presentation of Results of Results of Mean Annual Effective Dose Rate of Radiation (ED_m) *in* mSv/yr

The results of mean annual effective dose rate of radiation for each of the surveyed locations are presented in Table 3. Also, contour map showing the mean annual effective dose rate of radiation for all the surveyed locations is as shown in Figure 5. These results which range from 1.46±0.175 mSv/yr to 2.92±0.350 mSv/yr are greater than the permissible dose limit of 1 mSv/yr stipulated by the International Commission on Radiological Protection as the maximum effective dose rate one should receive owing to internal and external sources of radiation excluding the background radiation [6]. Also, these results are high when compared with the maximum value of Dose Rate of Radiation of 0.13 mSv/yr (measured from the same geologic location but far away from areas of oil exploration activities) which resulted to a deviation of 22361 % from the normal background radiation. These elevations could be attributed to oil production activities going on within these identified and survey environs. The results of the present research are in agreement with that of other researchers who are of the opinion that produced oil and water that find their ways into oil producing environments enhance the background radiation levels of such environments [4, 5, and 7].

Table3. *Mean Annual Effective Dose Rate of radiation (ED_m) in mSv/yr*

S/N	Site Identity	ED_m (mSv/yr) within the facilities	ED_m (mSv/yr) outside the facilities	% Deviation of ED_m from ED_c
1	KI	1.46±0.175	0.009	16122
2	AFS_2	2.19±0.350	0.009	24233
3	ASGGP	1.46±0.175	0.009	16122
4	AFS_1	1.31±0.175	0.009	14455
5	ON_FOC	2.92±0.350	0.013	22361
6	ON_FS	1.90±0.263	0.009	21011
7	ONAGGP	1.75±0.263	0.009	19344
8	IRFLB	1.75±0.350	0.009	19344
9	IFS_1	2.33±0.438	0.009	25788
10	IFS_3	2.19±0.350	0.009	24233
11	ARW	2.48±0.350	0.009	27455
12	EW	1.86±0.263	0.009	20566

3.3. Presentation of Results of Results of the Excess Lifetime Cancer Risk (ELCR)

The Results of the Mean Excess Lifetime Cancer Risk (ELCR) for each of the surveyed locations are presented in Table 4, with a range of values of between 4.59 x 10^{-3} and 10.22 x 10^{-3}. Also, contour map showing the Excess Lifetime Cancer Risk for all the surveyed locations is as shown in Figure 6. These values are greater than the world average value of 0.29 x 10^{-3} [6] and imply that people who are occupationally exposed to these surveyed environs may have additional likelihood of developing cancer in their lifetime. Nevertheless, studies on radiation induced cancer at low dose rates through the use of a simple proportional relationship as is the case in our computed ELCR in this research has some scientific assumptions, though plausible but with their attendant uncertainties [15].

Table4. *Excess Lifetime Cancer Risk (ELCR)*

S/N	Site Identity	Mean ELCR x 10^{-3} (Within the facilities)	Mean ELCR x 10^{-3} (Outside the facilities)
1	KI	5.11	0.03
2	AFS_2	7.67	0.03
3	ASGGP	5.11	0.03
4	AFS_1	4.59	0.03
5	ON_FOC	10.22	0.05
6	ON_FS	6.65	0.03
7	ONAGGP	6.13	0.03
8	IRFLB	6.13	0.03
9	IFS_1	8.16	0.03
10	IFS_3	7.67	0.03
11	ARW	8.68	0.03
12	EW	6.51	0.03

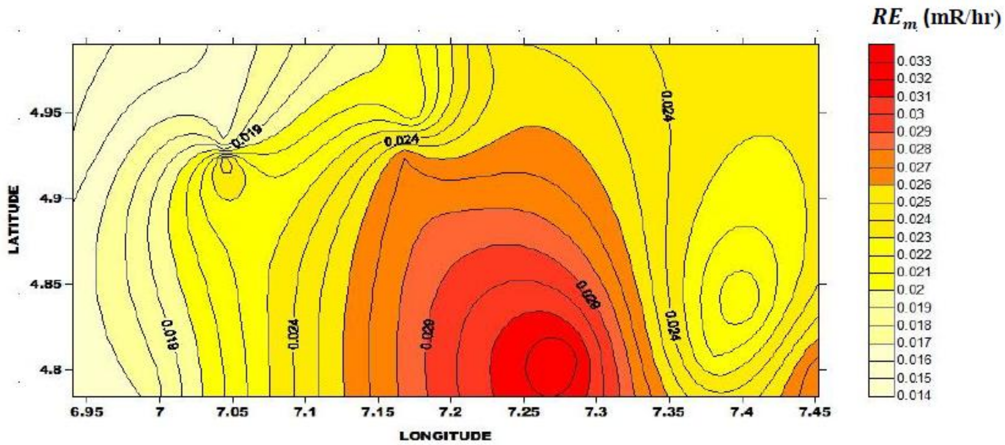

Figure4. *Contour Map for Radiation Exposure Rate (RE_m) in mR/hr*

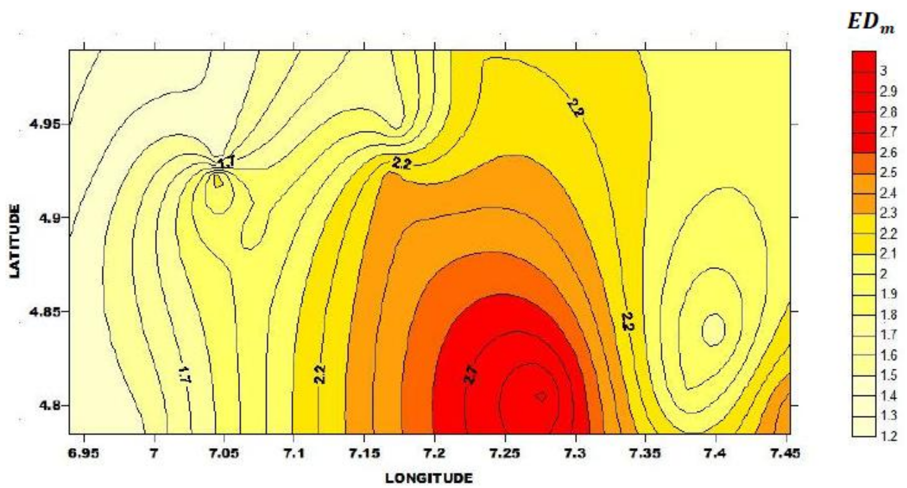

Figure5. *Contour Map for Mean Annual Effective Dose Rate of radiation (ED_m) in mSv/yr*

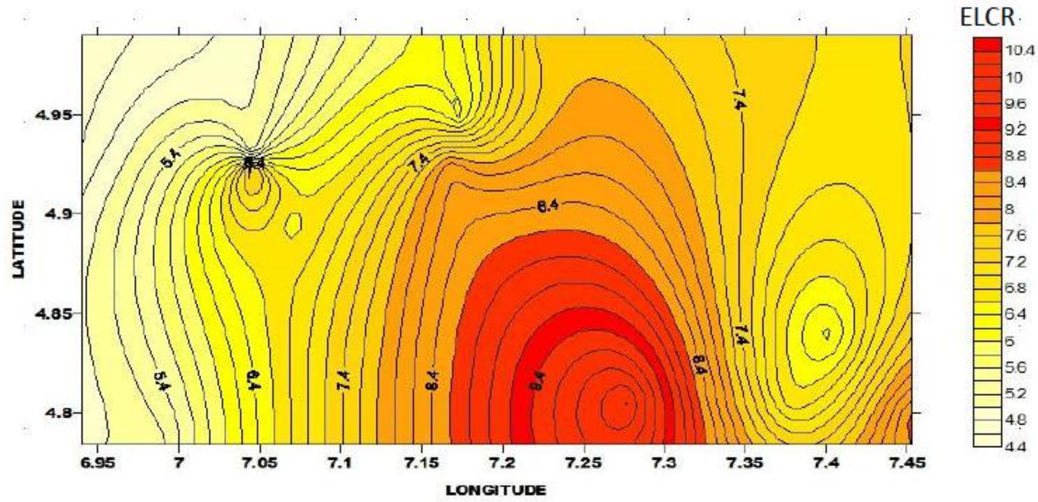

Figure6. *Contour Map for Excess Lifetime Cancer Risk (ELCR)*

4. CONCLUSION

The results of the annual effective dose rate of radiation and excess lifetime cancer risk have been computed from the measured radiation exposure rates for each of the surveyed locations. These results are above standard limits of radiation exposure set by the US Nuclear Regulatory Commission and International Commission on Radiological Protection. These high results could be attributed to oil exploration and production activities going on within the surveyed areas.

The researchers are therefore of the opinion that efforts should be made by the oil producing companies to avert unnecessary oil spillages and gas flaring that currently go on within the Niger Delta region. Radiation safety officers should be part of the working personnel in these oil companies so as the monitor the radiation levels within the producing areas and its environments and report any unusual radiation levels to appropriate authorities so that precautionary measures can be taken. This is very important based on the non perception of elevated levels of radiation based on human sense organs without the use of radiation monitoring equipment. It is important to note that human exposure to radiation ought to be limited, as low as reasonably achievable because of the carcinogenic impact of undue exposure of humans to radiation.

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