

Occupational and Public Health Potential Radiological Risk Assessment and Health Implications of Medical Facilities in Southern Niger Delta, Nigeria

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ABSTRACT

The occupational and public potential radiological assessment and the health implications of medical facilities of southern Niger Delta, Nigeria on patients, health workers and the general public were conducted using a well calibrated Red-Alert 200 nuclear meter with Geiger-Muller tube. This study was conducted to established radiation safety level of the medical facilities and to ascertain health implication of patients, health workers and the general public. The mean radiological results of Private clinics, General Hospitals and Health Centres are 0.015 mR/hr, 0.012 mR/hr and 0.013 mR/hr respectively. The obtained mean result does not surpass the world recommended limit 0.013 mR/hr. The mean computed radiological risk values of absorbed dose rate (ADR), annual effective dose equivalent (AEDE) and Excess lifetime cancer risk (ELCR) are 116.0 nGy/hr, 0.572 mSv/yr and 0.199 respectively; the values are all within recommended limit. Also, the mean computed body organ (BD_{organ}) effective dose results and the contributed percentage of the three medical facilities studied are 0.3830 (15%), 0.3316 (13%), 0.3945 (15%), 0.4687 (18%), 0.3544 (14%), 0.2630 (10%) and 0.3888 (15%) mSv/yr for lungs, ovaries, bone marrow, testes, kidney, liver and whole body respectively. The obtained results of the medical facilities are all below recommended world limit of 1.0 mSv/yr. The measured, computed results of radiological risk and body organ (BD_{organ}) effective dose of the medical facilities studied does not pose significant radiological health risk on patients, health workers and the general public. However, precautions should be taken to avoid accumulation of radiations in the medical facilities.

Keywords:

Medical Facilities,
Occupational Health,
Radiological,
Body Organ,
Nuclear Meter.

INTRODUCTION

The application of modern medical equipments is an essential instrument in medical diagnosis and therapy for patient's examinations (Teghware *et al.*, 2023 Avwiri *et al.*, 2014; Abdullahi *et al.*, 2018; Salama *et al.*, 2016). These modern medical equipments may have led to occupational exposures of patients, health workers and the general public which could be attributed to scattered ray been emitted from radiation source of medical equipments. Exposure to emitted radiation from diagnostic equipments such as X-ray machines, CT scan, mammogram and other medical equipments is increasing daily and it is of global concern (Kathmann, 2017; Abu-Zer *et al.*, 2016; Avwiri and Esi, 2015; Dehaghi *et al.*, 2017; Rafique *et al.*, 2014). Extensive and frequent uses of the imaging technology has led to increased in background radiation exposure of most medical facilities as a result of radiation leakage from medical equipments

such as X-ray tubes (Abu-Zer *et al.*, 2016; Panicker *et al.*, 2013; Adhikari *et al.*, 2012; Achuka *et al.*, 2019). Hence, medical facilities are not radiologically safe, as the emitted ray from radiation source machines can lead to occupational potential health challenge of patients, health workers and the general public (Rafique *et al.*, 2014; Mora and Acuña, 2011; Adhikari *et al.*, 2012). It will be of good standing for occupational health workers to practice the three basic radiation protection standard rules; adequate shielding, distance from the source and exposure time reduction (Avwiri *et al.*, 2016; Mokobia *et al.*, 2020; Blessing and Muiyiwa, 2018; Osimobi *et al.*, 2015). Inadequate practices of these radiation protection principles may lead to exposure of patients, health workers and the general public in medical facilities causing radiological hazards such as stochastic effects, chronic effects, deterministic effects, genetic effects to patients, health workers and the general public (Esi *et al.*,

2024; Chad-Umoren and Briggs-Kamara, 2010; Agbalagba and Esi, 2023; Sivakumara *et al.*, 2016). This can be correlated with the increasing likelihood of radiological health challenges of the residents of the southern Niger Delta within the last two decades. Therefore, there is need for constant monitoring and measurement of the background radiation of medical facilities to ensure compliance with operational radiological safety regulatory or generally accepted dose limits. Several scientific research have been conducted on background ionizing radiation in medical facilities around the world and some part of Nigeria (Ononugbo and Nwokeoji, 2017; Chukwuemeka and Avwiri, 2013; Omogunloye *et al.*, 2021; Valuckas *et al.*, 2017; Jabeen *et al.*, 2010; Okedayo *et al.*, 2015) but much has not been reported in the medical facilities within southern part of the Niger Delta, Nigeria. Hence this research is aim at ascertaining the occupational and public potential radiological risk and the health implications of medical facilities of southern Niger Delta, Nigeria to patients, health workers and the general public.

MATERIALS AND METHODS

Study Area

The southern Niger Delta consist of Edo State, Delta State, Bayelsa State, Rivers State, Akwa-Ibom State and Cross River State. The area comprises of various city, towns and villages where medical facilities are established for the purpose of examination and treatment of patient. The areas consist of government Hospitals, government health centres and Private Hospitals which are use for medical examination and treatment of its residents.

Experimental Method

The radiation levels of medical facilities (Private clinics, General Hospitals and Health Centres) were measured in the southern Niger Delta, Nigeria. A total of thirty medical facilities (ten per medical facility) were measured at different locations within the medical facilities using a well calibrated Red-Alert 200 nuclear meter. The instrument, Red-Alert 200 nuclear meter uses a Geiger-Muller tube which allows radiation to go through it and induces ionization by generating electric current pulse. These pulses are detected electrically with the results displayed in the measuring instrument screen and recorded in milli-Roentgens per hour (mRhr⁻¹). To measure the radiation level of the medical facilities, the radiation measuring instrument was suspended 1 m above the ground level and its liquid crystal display (LCD) unit was made to face towards the source of radiation at a particular location (Anekwe, 2024; Osimobi *et al.*, 2015; Ugbede and Echeweozo, 2017; Md Mostafizur *et al.*, 2023; Avwiri and Esi, 2015; Esi *et al.*, 2019). The measuring instrument was switched on and readings were taken and repeated after a period of time. The measured radiation results were used for computing

potential health implications in the medical facilities that may be associated to both patients and occupational staffs using entrenched mathematical equations.

RESULTS AND DISCUSSION

Background Ionizing Radiation Exposure Dose Rate

The measured radiological mean results of medical facilities and health implication indices of southern Niger Delta, Nigeria are accessible in Table 2-4 while calculated radiological mean results of medical facilities are presented in Table 5. The mean radiological results of Private clinics ranges from 0.010mR/hr to 0.20mR/hr with mean value of 0.015 mR/hr, General Hospitals ranges from 0.008 mR/hr to 0.020 mR/h with mean value of 0.012 mR/hr and Health Centres ranges from 0.011mR/hr to 0.015 mR/hr with mean value of 0.013 mR/hr. The results are within the threshold of 0.013 mR/hr (ICRP, 2007; Omogunloye *et al.*, 2021; Esi *et al.*, 2024; Jwanbot *et al.*, 2012; Karan *et al.*, 2007) as presented in Figures 1. It was observed that the private clinics radiology and X-ray units have the highest values. These high values could be ascribed to the radiation sources presence in X-ray machines, CT scan, mammogram and other medical equipments used for scanning of patients in the private clinics. This imply that both the occupational staffs and patients may be expose to scattered radiation and hence call for constant monitoring for purpose of safety of health workers, patients and the public. The obtained mean results are in agreement with reported values of studied hospital and clinics by scientists across Nigeria as presented in Table 6. However, the measured medical facilities are relatively safe radiological as there is no immediate health implication to both occupational staffs and patients.

Absorbed Dose Rate (ADR)

The ADR evaluates radiation quantity received by occupational staffs and patients that are been potentially exposed to dose rate. It is also used to evaluate biological effects due to doses absorption during medical examination. The ADR was computed using mathematical equation 1 below (Agbalagba 2017; Esi *et al.*, 2024).

$$1\mu\text{Rh}^{-1} = \frac{8.7 \times 10^{-3}}{114.2 \times 10^{-6}} \mu\text{Gyy}^{-1} \quad (1)$$

1mRhr⁻¹ can be converted to nGyh⁻¹.

$$1\text{mRhr}^{-1} = 8.7 \times 10^{-3} \text{nGyh}^{-1} \quad (2)$$

The mean computed ADR radiological results of the three medical facilities ranges from 87.0 to 165.3 with mean value of 130.5 nGy/hr, 69.6 to 174.1 with mean value of 104.4 nGy/hr and 95.7 to 130.5 with mean value of 113.1 nGy/hr respectively. These ADR radiological results exceeded the world permissible dose value of 84 nGy/hr (UNSCEAR, 2006) as presented in Figures 2. The obtained values are in agreement the values of hospitals radiological studied reported in literatures across Nigeria as presented in Table 6.

Annual Effective Dose Equivalent (AEDE)

The indoor AEDE radiological results were obtained using calculated ADR as given the equation 3 (Avwiri *et al.*, 2016; Ijabor *et al.*, 2022)

$$\text{AEDE} = \text{ADR} (\eta\text{Gy}h^{-1}) \times 8760 \times 0.7 \text{ Sv/Gy} \times 0.8 \quad (3)$$

Where ADR, 8760, 0.7 Sv/Gy and 0.8 are absorbed dose rate, total hour per year (24×365), dose conversion factor and occupancy factor of exposure respectively (UNSCEAR, 2008). The results of the three medical facilities ranges from 0.427 to 0.854 with mean value of 0.642 mSv/yr, 0.341 to 0.854 with mean value of 0.512 mSv/yr and 0.472 to 0.644 with mean value of 0.561 mSv/yr respectively. The AEDE computed results of the three medical facilities are below recommended world limit for the patients and occupational staffs 1 mSv/yr and 20 mSv/yr respectively (ICRP, 1990) as presented in

Figures 3. This is a clear indication that the obtained values are radiologically friendly and therefore there are no instant radiological health risk on the life of both patients and occupational staffs. The values obtained also align with scientific reported values across Nigeria as presented in Table 6.

Excess Lifetime Cancer Risk (ELCR)

The ELCR can be express as the possibility of developing cancer such as skin cancer, prostate cancer, breast cancer or blood cancer during the period of living on earth due to exposure to radiation over time. The ELCR radiological results due to medical facilities were computed using equation 4 with symbols as shown in table 1.

$$\text{ELCR} = \text{AEDE} \times \text{AL} \times \text{RF} \quad (4)$$

Table 1: Parameter, Symbols and Factor for Computing Excess Lifetime Cancer Risk (ICRP, 2007: UNSCEAR, 2008; Taskin et al., 2009)

S/No	Parameters	Symbols	Factor
1	Annual Effective Dose Equivalent	AEDE	AEDE Values
2	Average lifespan	AL	70 years
3	Risk Factor	RF	0.057

The ELCR results of the three medical facilities studied ranges between 0.150 to 0.299 with average value of 0.224, 0.119 to 0.299 with average value of 0.179 and 0.165 to 0.224 with average value of 0.196 respectively. The computed obtained results of the three medical facilities are within recommended world limit of 0.29×10^{-3} (Esi *et al.*, 2024; Taskin *et al.*, 2009;

UNSCEAR, 2000; Aliyu *et al.*, 2015; Agbalagba, 2017; Haghparast *et al.*, 2020). Therefore, the ELCR estimate value does not indicates possibility of both patients and occupational staffs developing cancer at the moment. The overall results indicate that the studied medical facilities do not constitute an immediate radiological health hazard to both patients and occupational staffs.

Table 2: Mean Background Ionizing Radiation Levels with Radiation Health Indices in Private Clinics

S/No	Location	Exposure Rate (mR/hr)	Absorbed Dose (nGy/hr)	AEDE Indoor (mSv/yr)	ELCR $\times 10^{-3}$
1	Entrance	0.015	130.5	0.641	0.224
2	Consultation Unit	0.014	121.8	0.598	0.213
3	Radiology Unit	0.020	174.0	0.854	0.299
4	Nursing Unit	0.014	121.8	0.598	0.210
5	Pharmacy Unit	0.010	87.0	0.427	0.150
6	Health	0.013	113.1	0.555	0.194
7	Wards	0.017	147.9	0.726	0.254
8	Walkway	0.017	147.9	0.726	0.254
9	X-Ray Room	0.015	130.5	0.642	0.224
10	X-Ray Unit	0.019	165.3	0.811	0.284
	Mean	0.015	130.5	0.642	0.224

Table 3: Mean Background Ionizing Radiation Levels with Radiation Health INDICES in General Hospital

S/No	Location	Exposure Rate (mR/hr)	Absorbed Dose (nGy/hr)	AEDE Indoor (mSv/yr)	ELCR $\times 10^{-3}$
1	Pharmacy	0.014	121.8	0.598	0.211
2	Consultation	0.011	95.7	0.470	0.165
3	Out-Patient	0.011	95.7	0.471	0.165
4	Theatre	0.011	95.7	0.471	0.165
5	Records Room	0.010	87.0	0.427	0.151
6	Male Ward	0.011	95.7	0.470	0.165

7	Female Ward	0.014	121.8	0.598	0.210
8	Children Ward	0.014	121.8	0.598	0.211
9	Maternity Ward	0.020	174.1	0.854	0.299
10	Labour Room	0.014	121.8	0.598	0.210
11	Isolation Room	0.014	121.8	0.598	0.211
12	Admin Block	0.012	104.4	0.512	0.179
13	Entrance	0.013	113.1	0.055	0.194
14	Consulting Room	0.008	69.6	0.341	0.119
15	Store Room	0.017	147.9	0.726	0.254
	Mean	0.012	104.4	0.512	0.179

Table 4: Mean Background Ionizing Radiation Levels with Radiation Health Indices in Health Centres

S/No	Location	Exposure Rate(mR/hr)	Absorbed Dose (nGy/hr)	AEDE Indoor (mSv/yr)	ELCR $\times 10^{-3}$
1	Entrance	0.015	130.5	0.644	0.224
2	Admin Block	0.012	104.4	0.512	0.179
3	Examination	0.013	113.1	0.551	0.194
4	Main Ward	0.012	104.4	0.512	0.179
5	Delivery Ward	0.014	121.8	0.598	0.212
6	Cold Chain	0.011	95.7	0.472	0.165
7	HoD Office	0.013	113.1	0.572	0.194
8	Pharmacy	0.014	121.8	0.598	0.214
9	Matron's Office	0.015	130.5	0.641	0.224
10	Reception Unit	0.012	104.4	0.512	0.179
	Mean	0.013	113.1	0.561	0.196

Table 5: The Radiological mean Results of Medical Centres in the Coastal Region

S/No	Medical Facilities	Exposure Rate (mR/hr)	Absorbed Dose (nGy/hr)	AEDE (mSv/yr)	ELCR $\times 10^{-3}$
1	Private Clinics	0.015	130.5	0.642	0.224
2	General Hospitals	0.012	104.4	0.512	0.179
3	Health Centres	0.013	113.1	0.561	0.196
	Mean	0.013	116.0	0.572	0.199

Table 6: Comparison of Scientific Reported Radiological Values of Studied Hospital and Clinics across Nigeria with Present Study

Authors	Exposure Rate Range mRh ⁻¹	ADR μ Gyh ⁻¹	Indoor AEDE mSv/yr	ELCR $\times 10^{-3}$	Country
Ononugbo and Nwokeoji, 2017	0.015 - 0.015	111.8 - 139.2	0.18 - 0.60	0.65 - 2.09	Nigeria
Nwokeoji and Avwiri, 2017	0.010 - 0.017	226.2 - 78.3	0.15 - 1.05	0.53 - 3.68	Nigeria
Rilwan <i>et al.</i> , 2022	0.17 - 0.47	24.00	0.17	0.60	Nigeria
Robinson E. & Gbaraton O. (2023).	0.0046	8.7 - 130		0.047 - 0.070	Nigeria
Idris <i>et al.</i> , 2022	0.012 to 0.47	143.3 - 1653	0.66 - 8.11	2.46 - 28.38	Nigeria
Omogunloye <i>et al.</i> , 2025	0.006 - 0.017	60.60 - 147.90	0.107-0.756	0.261 - 2.39	Nigeria
Omogunloye <i>et al.</i> , 2021	0.0013 - 0.0025	11.31 - 20.88	0.055 - 0.107	0.194 - 0.373	Nigeria
Present Study	0.012 - 0.015	116	0.572	0.199	Nigeria

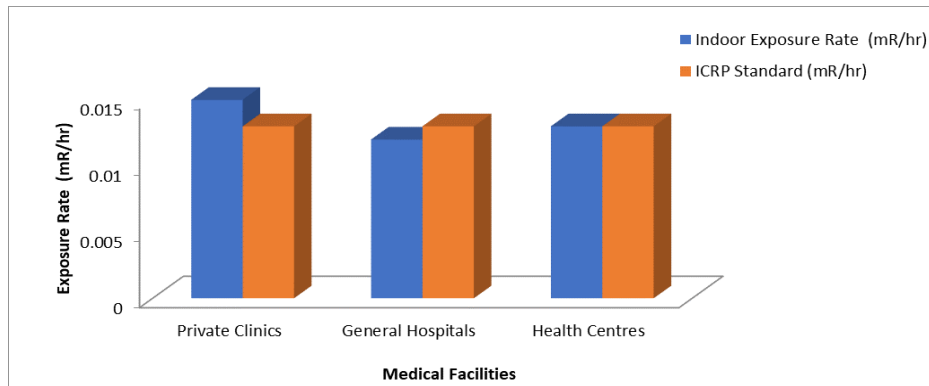


Figure 1: Relationship Graph of mean Estimated Exposure Rate (mR/hr) Results with ICRP Standard

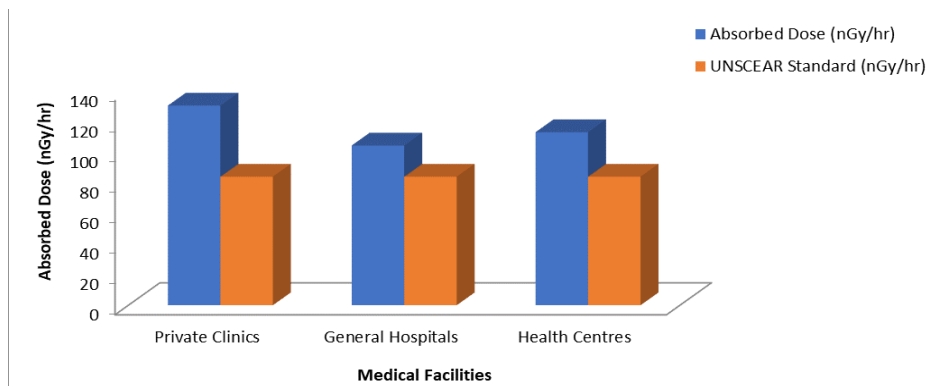


Figure 2: Relationship Graph of Estimated Absorbed Dose (nGy/hr) with UNSCEAR Standard

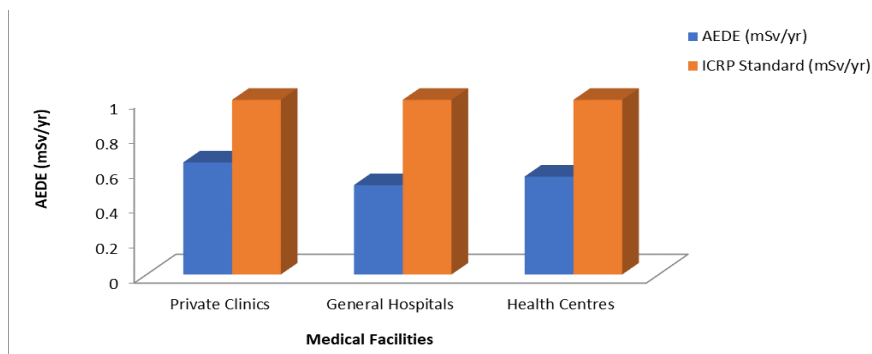


Figure 3: Relationship Graph of Estimated AEDE (mSv/yr) with ICRP Standard

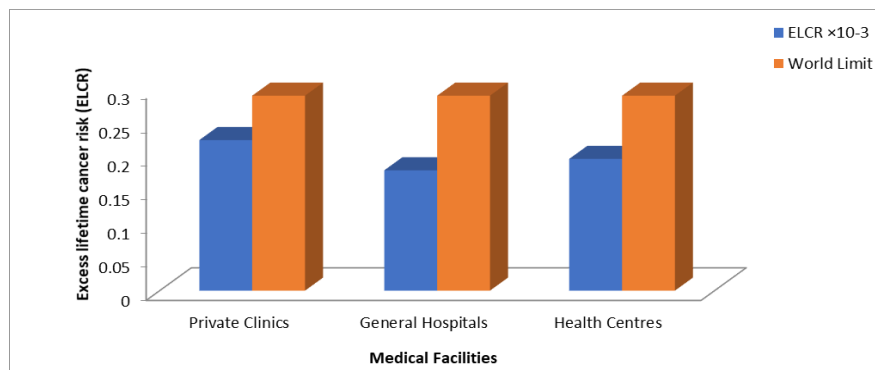


Figure 4: Relationship Graph of Estimated ELCR with World Limit

Different Exposed Body Organ (BD_{organ}) Effective Dose

The body organ (BD_{organ}) effective dose is the amount of radiation dose accumulated in the different body organ and tissue as a result of exposure through inhalation (Esi *et al.*, 2024; Darwish *et al.*, 2015). The BD_{organ} effective

dose of both patients and occupational staffs were computed using equation 5.

$$BD_{organ} \text{ (mSv}^{-1}\text{)} = AEDE \times F \quad (5)$$

Where F and AEDE are the conversion factor of body organs and computed values of annual effective dose equivalent respectively.

Table 7: The Body Organ/Tissue Conversion Factor and Computed Accumulated Dose to Organs/Tissue

Organ	Lungs	Ovaries	Bone Marrow	Testes	Kidney	Liver	Whole Body
Conversion Factor	0.67	0.58	0.69	0.82	0.62	0.46	0.68
Private Clinics	0.4301	0.3724	0.4430	0.5264	0.3980	0.2953	0.4366
General Hospitals	0.3430	0.2970	0.3533	0.4198	0.3174	0.2355	0.3482
Health Centres	0.3759	0.3254	0.3871	0.4600	0.3478	0.2581	0.3815
Mean	0.3830	0.3316	0.3945	0.4687	0.3544	0.2630	0.3888

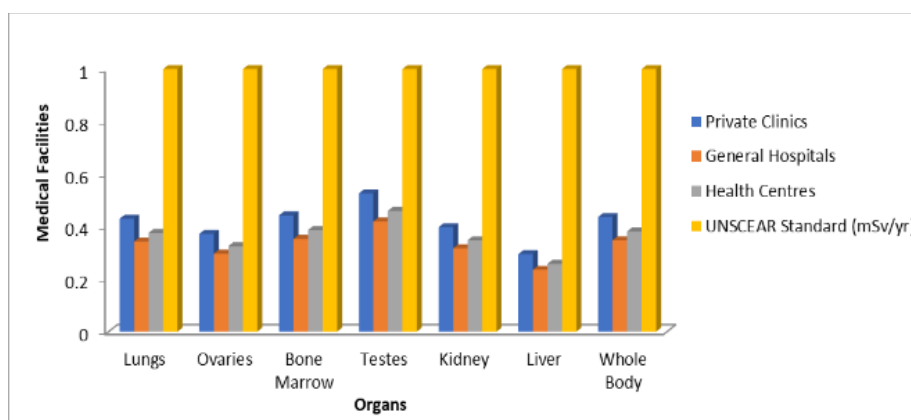


Figure 5: Chart of Accumulated Dose of Different Body Organs of Patients and Occupational Staffs with UNSCEAR Standard

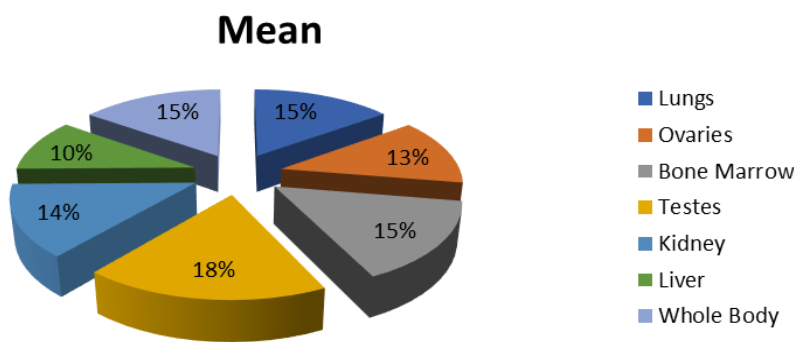


Figure 6: Pie Chart of Accumulated Dose of Body organs Percentage of Patients and Occupational Staffs

The mean computed body organ (BD_{organ}) effective dose results of the three medical facilities studied are 0.3830 (15%), 0.3316 (13%), 0.3945 (15%), 0.4687 (18%), 0.3544 (14%), 0.2630 (10%) and 0.3888 (15%) mSv/yr for lungs, ovaries, bone marrow, testes, kidney, liver and whole body respectively as shown in Table 7 and Figure 5. The computed obtained results of the three medical facilities are all below recommended world limit of 1.0 mSv/yr (UNSCEAR, 2000; Darwish *et al.*, 2015; Agbalagba, 2017) as presented in Figures 4. The computed obtained results indicates that the testes have

18% (maximum) radiation sensitivity and liver have 10% (minimum) radiation sensitivity due to organs exposure and inhalation of patients and occupational staffs in the studied medical facilities. Therefore, the computed body organ (BD_{organ}) effective dose values does not indicates immediate possibility of both patients and occupational staffs developing cancer. The overall results indicates that the studied medical facilities are radiologically safe for both patients and occupational staffs, but there should be constant monitoring of the medical facilities most especially the X-Ray Unit and its surrounding.

CONCLUSION

The occupational and public potential radiological risk and the health implications of medical facilities of southern Niger Delta, Nigeria on patients, health workers and the general public was conducted using a well calibrated Red-Alert 200 nuclear meter with Geiger-Muller tube. This was done to determine the radiation level of the medical facilities and ascertain the possibility of patients, health workers and the general public being exposed to radiation and its health implications. The measured and computed results showed that the medical facilities studied does not pose any instant radiological health risk on patients, health workers and the general public and as a results the chances of cancer or other radiological sickness is insignificant. However, there should be constant monitoring of background ionizing radiation to avoid accumulation radiations in the medical facilities. Also, medical equipments used for examinations of patients should be frequently check to avoid leakage and the use of radiation personal protective equipments should be encourage to minimize radiation exposure during imaging measures in all medical facilities.

Ethics

The study investigated occupational and Public Health potential radiological risk assessment and health implications of medical facilities in Southern Niger Delta, Nigeria. The study applied in-situ measurement of background radiation on medical facilities and in-silico modeling of its health potential implications. It did not apply any human subject and participation. The study was approved by the Faculty of Science, research and ethical committee of Dennis Osadebay University, Asaba with the number DOU/FOS/2022-OPH22/045.

REFERENCES

ICRP (2007) International Commission on Radiological Protection The 2007 Recommendations of the International Commission on Radiological Protection: Annals of the ICRP Publication Elsevier. 103:2-4.

Omogunloye O. Y., Adepoju A. T., and Kururimam P. (2021) Assessment of Radiation Risk from Background Radiation Exposures in Selected Hospitals within Makurdi Metropolis, North-Central, Nigeria, *European Journal of Applied Physics* Vol 3 (4): 43 - 47

Ononugbo C. P. and Nwokeoji I. E. (2017) Radiation Risk Assessment from Background Radiation Exposures in Selected Hospitals in South –South Nigeria, *Current Journal of Applied Science and Technology* Vol. 22 (2): 1-13

Nwokeoji I. E. and Avwiri G. O. (2017) Radiological Risk Estimates Due to Background Exposures in Selected

Hospitals in South – East Nigeria, *Archives of Current Research International* 8(1): 1-12

Chukwuemeka, O.P. and Avwiri G.O (2013) Evaluation of background ionising radiation levels of Braithwaite memorial specialist hospital Port Harcourt, Rivers State. *Am. J. Sci. Ind. Res.*, 4: 359-365.

Abdullahi, A.G., A.K.M.F. Haque, M.G. Abdullahi, M.A. Hajara and S.G. Abdullahi, (2018) Measurement of radiation dose on medical workers in selected hospitals in Dhaka Bangladesh. *CPQ Med.*, Vol. 1.

Blessing, O.B. and Muyiwa A.A (2018) Assessment of background radiation levels in selected diagnostic radiology department across Ondo state, Nigeria. *Niger. J. Pure Appl. Phys.*, 8: 16-19

Md Mostafizur R, Mohammad S .R, Md Harunor R. K and Selina Yeasmin (2023) Assessment of radiation level and potential risk to public living around major hospitals in central and western Bangladesh, *Heliyon* Vol. 9 (9) e19774

Esi E.O, Nwabuoku A.O., Oduah E.C., Ugbede F.O., Okpilike J.C. (2024). Evaluation of Indoor and Outdoor Radiation Levels and its Health Hazard at Dennis Osadebay University, Asaba, Delta State, Nigeria. *Dutse Journal of Pure and Applied Sciences* 10(1c):1 – 9

Salama K.F, AlObireed A, AlBagawi M, AlSufayan Y, AlSerheed M. (2016) Assessment of occupational radiation exposure among medical staff in health-care facilities in the Eastern Province, Kingdom of Saudi Arabia. *Indian J Occup Environ Med* Vol. 20: 21-5.

Agbalagba O.E (2017) Assessment of Excess lifetime cancer risk from gamma levels in Effurun and Warri city of Delta State, Nigeria, *Journal of Taibah University for Science* 11: 307-370

UNSCEAR, (2006) United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), Sources and Effects of Ionizing Radiation, Report Vol.1 to the General Assembly, with scientific annexes, United Nations Sales Publication, United Nations, New York.

Achuka J. A., Usikalu M. R., Aweda M. A., Onumojor C. A. and Babarimisa I. O. (2019) Background Radiation Dose in Selected X-Ray Facilities in Southwest Nigeria. 3rd International Conference on Science and Sustainable Development. *Journal of Physics: Conf. Series* 1299

Avwiri, G.O., Nwaka, B.U. and Ononugbo, C.P. (2016). Radiological health risk due to gamma dose rates around Okposi Okwu and Uburu salt lakes, Ebonyi

- State. *International J. Emerg. Res. in Manage. Technol.* 5(9):36-46.
- Ijabor B. O., Nwabuoku A. O., Ozakpor A. F., Azesi D., Nwaebise I. C., Ikechukwu O. and Nwankwo I. P. (2022). Assessment of Indoor and Outdoor Radiation Dose Levels in Delta State Polytechnic, Ogwashi-Uku, Delta State, Nigeria. *Open Journal of Physical Science.* 3(2): 35 – 46
- Jwanbot, D. I; Izam, M. M; Nyam G. G; Agada, I. S (2012). Evaluation of Indoor background ionising radiation profile in some hospitals in Jos Plateau state Nigeria. *Journal of Natural Sciences Research* 2 (7): 35-40.
- Karan, G; Dhiraj, G; Krishna M. V (2007). Radiation Measurement at X-Ray centres of a few Hospitals in Kathmandu City, Nepal. *Kathmandu University Journal of Science, Engineering and Technology* 1 (4):1-4.
- Taskin, H., M. Karavus, P. Ay, A. Topuzoglu, S. Hindiroglu and G. Karahan, (2009) Radionuclide concentrations in soil and lifetime cancer risk due to the gamma radioactivity in Kirklareli, Turkey, *Journal of Environmental Radioactivity* 100: 49-53.
- Aliyu, A.S., U. Ibrahim, C.T. Akpa, N.N. Garba and A.T. Ramli, 2015. Health and ecological hazards due to natural radioactivity in soil from mining Areas of Nasarawa State, Nigeria. *Isot. Environ. Health Stud.*, 51: 448-468
- UNSCEAR, (2000) United Nations Committee on the Effects of Atomic Radiation, Source and Effects of Ionizing Radiation, United Nation, New York.
- Haghparsat M, Afkhani Ardekani M, Navaser M, Refahi S, Najafzadeh M, Ghaffari H, Masoumbeigi M. (2020) Assessment of background radiation levels in the southeast of Iran. *Med J Islam Repub Iran.* 34 (1) :56.
- UNSCEAR, (2008). United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionizing radiation: Report to the General Assembly with scientific annexes. United Nations Publications.
- Darwish DA, Abul-Nesr KTM, EL-Khayath AW (2015). The Assessment of Natural Radioactivity and its associated radiation hazard and dose parameter in granite sample from south Sinai Egypt. *Journal of Radiation research and applied sciences.* 8:17-25.
- Osimobi, J. C., Agbalagba, E.O., Avwiri, G.O., and Ononugbo, C.P. (2015). GIS mapping and background ionizing radiation (BIR) assessment of solid mineral mining sites in Enugu State, Nigeria. *Open Acc. Lib. J.* 2:1–9.
- Anekwe, U.L. (2024). Assessment of Background Ionizing Radiation and Radiological Health Risks in Federal Government Girls' College, Imiringi, Nigeria. *Communication in Physical Sciences*, 2024, 11(2): 207-220
- Ugbede, F. O., and Echeweozo, E. O. (2017). Estimation of annual effective dose and excess lifetime cancer risk from background ionizing radiation levels within and around quarry site in Okpoto-Ezillo, Ebonyi State, Nigeria. *Journal of Environment and Earth Science* 7(12):74-79.
- Esi O.E, Edomi O and Odedede PO (2019) Assessment of Indoor and Outdoor Background Ionizing Radiation Level in School of Marine Technology, Burutu, Delta State, Nigeria, *Asian Journal of Research and Reviews in Physics* 2 (3), 1 – 8
- Avwiri Gregory O and Esi Oghenevovwero .E. (2015) Survey of Background Ionization Radiation Level in Some Selected Automobile Mechanic Workshops in Uvwie LGA Delta State, Nigeria, *Journal of Environment and Earth Science* 5 (3) 12- 23
- Valuckas KP, Atkocius V, Samerdokiene V (2007) Occupational exposure of medical radiation workers in Lithuania, 1991-2003. *Acta Med Lituanica*, 14:155-9.
- Jabeen A, Munir M, Khalil A, Masood M, Akhter P (2010) Occupational exposure from external radiation used in medical practices in Pakistan by film badge dosimetry. *Radiat Prot Dosimetry*, 140:396-401
- Okedayo Mosunmola O., Yakubu H Ngadda, Alhamdu S. Moi, Flavious B. Nkubli and Geoffrey Luntsi (2015) Ambient Ionizing Radiation Assessment And Its Public Health Implication at Radiology Department, University Of Maiduguri Teaching Hospital, Borno State, Nigeria. *Research journal's Journal of Public Health*, Vol. 1(1): 1- 11
- Sivakumara, A. Chandrasekaran, R. Ravisankar, S.M. Ravikumar, J. Prince Prakash Jebakumar, P. Vijayagopal, I. Vijayalakshmi, M.T. Jose (2014) Measurement of natural radioactivity and evaluation of radiation hazards in coastal sediments of east coast of Tamilnadu using statistical approach, *J. Taibah Univ. Sci.* 8: 375–384
- Agbalagba Ezekiel O. and Esi Oghenevovwero E. (2023) Occupational and public risk assessment of NORMs in soil of the Niger Delta region of Nigeria after six decades of hydrocarbon exploitation, *Arabian J. Geosci.* <https://doi.org/10.1007/s12517-022-11151-w>

- Chad-Umoren Yehuwadah E and Briggs-Kamara Margaret A. (2010) Environmental ionizing radiation Distribution In rivers state, Nigeria, *J. Environ. Eng. Landsc. Manag.* 18 (2) 154-161
- Esi Oghenevovwero E., Avwiri Gregory O., Onjefu A. Sylvanus and Damian C. Onwuodiwe (2024) Radiometric survey of sediments and health risk assessments from the southern coastal area of Delta State, Nigeria. *Heliyon* 10; e26805
- Mokobia, C. E. Nwabuoku, A. O., and Igbeka, C. (2020). Indoor radon concentration measurements in houses of selected communities in Delta Central of Delta State. *Nigerian Journal of Science and Environment*, 18 (2) (2020)
- Osimobi, J.C., Agbalagba, E.O., Avwiri, G.O., and Ononugbo, C.P. (2015). GIS mapping and background ionizing radiation (BIR) assessment of solid mineral mining sites in Enugu State, Nigeria. *Open Acc. Lib. J.* 2:1-9.
- Avwiri, G.O., Nwaka, B.U. and Ononugbo, C.P. (2016). Radiological health risk due to gamma dose rates around Okposi Okwu and Uburu salt lakes, Ebonyi State. *International J. Emerg. Res. in Manage. Technol.* 5(9):36-46.
- Mora, P. and M. Acuña, 2011. Assessment of medical occupational radiation doses in Costa Rica. *Radiat. Prot. Dosim.*, 147: 230-232.
- Adhikari, K. P., Jha, L. N., Galan, M. P. (2012). Status of radiation protection at different hospitals in Nepal. *Journal of Medical Physics*, 37 (4): 240-244
- Panicker, T.M. R., Tina-Angelina, J.T., Korath, M.K., Mohandas, K. and Jagadeesan, K. (2013). Entrance skin dose estimation in X-ray lumbar spine lateral procedure: Conventional vs digital X-ray units: A pilot study. *JIMSA*, 26 (4): 219-220.
- Salama KF, AlObireed A, AlBagawi M, AlSufayan Y, AlSerheed M. Assessment of occupational radiation exposure among medical staff in health-care facilities in the Eastern Province, Kingdom of Saudi Arabia. *Indian J Occup Environ Med*, 20:21-5
- Teghware A.O, Avwiri G.O and Agbalagba E.O. (2023) Radiological Risk Assessment Among Occupational Health Workers in Selected Radiological Centres in Warri City, Nigeria. *Trends Social Sci.*, 1 (1): 1-9
- Rafique, M., S.U. Rahman, M. Basharat, W. Aziz and I. Ahmad et al., 2014. Evaluation of excess life time cancer risk from gamma dose rates in Jhelum Valley. *J. Radiat. Res. Appl. Sci.*, 7: 29-35.
- Kathmann, W. (2017). Optimization of radiation dose performance. *Diagnostic Imaging*, 33 (2): 48-50.
- Abu-Zer, S. S., Khadoura, K. J., Yassin, S. S., Agha, M. R. (2016). Ionizing radiation leakage in radiodiagnostic centers at Gaza Strip hospitals, Palestine. *Asian Review of Environmental and Earth Sciences*, 3 (1): 18-26.
- Avwiri Gregory O and Esi Oghenevovwero .E. (2015) Survey of Background Ionization Radiation Level in Burutu L.G.A, Coastal Area of Delta State, Nigeria, *Journal of Applied Physical Science International* 2 (2) 21- 34
- Dehaghi, B. F., Ghavamabadiz, L. I., Bozar M., Mohamadi, A., Angali, K. A. (2017). Evaluation of X-ray radiation levels in radiology departments of two educational hospitals in Ahvaz, Iran. *Iran Journal of Medical Physics*, 14 (2): 87-91.
- Avwiri Gregory O, Nte Felix U and Esi Oghenevovwero .E. (2014) Assessment of Background Ionization Radiation of Oil Spillage Site at Obodo Creek in Gokana LGA of River State, Nigeria, *British Journal of Applied Science & Technology* 4 (36), 5072-5079
- Omogunloye O. Y., Adepoju A. T. and Kururimam P. (2021) Assessment of Radiation Risk from Background Radiation Exposures in Selected Hospitals within Makurdi Metropolis, North-Central, Nigeria. *European Journal of Applied Physics* 3 (4) 43 - 47
- Omogunloye, O. Y., Ilori, A. O., Isaiyah, O. T. and Adiukwu, K. C. (2025) Analysis of Background Radiation Doses and Their Potential Radiological Effects In Hospitals Across Southwestern Nigeria. *Coast, J. Sch. Sci.* 7 (2): 1427 - 1441
- Idris M. Mustapha, Arogundade U. Fanny, Musa Adamu, Sulayman M. Bello, and Ismail W. Oaniyi (2022) Work Place Assessment of Ambient Background Gamma Exposure Level of Some Radiological Facilities in FCT Abuja, Nigeria. *J. Rad. Nucl. Appl.* 7 No. 3, 27- 32
- Rilwan U., Galadima O.O., Yahaya I and Rufai A.M. (2022) Background Radiation Exposure in Keffi General Hospital, Keffi, Nasarawa State, Nigeria. *J. Rad. Nucl. Appl.* 7, No. 1, 79-83
- Robinson, E., & Gbaraton, O. (2023). Evaluation And Estimation Of Environmental Background Exposure And Associated Risk In A Radiologic Facility. *African Journal of Research in Medical and Health Sciences*, 1(1), 30-37. <https://doi.org/10.60787/AJRMHS-11>