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Radiological Assessment and Potential Health Implication of Produced Water from Oil facilities Around Oil Mining Lease (OML X), Southern Delta, Nigeria

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ABSTRACT
This study assessed the concentration of naturally occurring radionuclides in produced water from Oil Mining Lease (OML X) and evaluated their potential health implications in the Niger Delta, Nigeria. The totality of produced water collected for measurement were eighteen (18), three from each oil-field facility and analyzed using Gamma-Ray Spectrometer (sodium iodide (NaI(Tl)) . the obtained mean values of ^{40}K, ^{238}U and ^{232}Th are 122.14 BqL^{-1}, 10.58 BqL^{-1} and 4.12 BqL^{-1} respectively. The mean computed potential radiological health implications parameters of Raeq, D_R, $AEDE_{out}$, $AEDE_{in}$, Hex, Hin and Iy are 25.87 BqL^{-1}, 12.47 nGy/h, 0.0153 mSv/y, 0.0612 mSv/y, 0.0699, 0.0985 and 0.0965 respectively. However, the obtained values of radionuclides exceeded the world recommended limits while that of computed potential radiological are below world recommended limits. Therefore, the values may not pose significant radiological health impact as at the time of the research, but it may have potential long-term impact with time. Hence, release oil-field facility produced water ought to be treated appropriately before discharged into the environment. All hydrocarbon operation stakeholders should carry out routine monitoring of the study area environment. This research also provides critical baseline data for environmental radiation management and supports policy development toward sustainable oil production and public health protection in the Niger Delta region.

Keywords:
Radiological,
Produced water,
OML X,
Hydrocarbon,
Health implications,
Niger Delta.

INTRODUCTION

The Niger Delta is one of the world's most prolific hydrocarbon provinces, underlain by thick sedimentary sequences rich in organic matter and trace minerals, making it susceptible to enhanced mobilization of NORMs under dynamic geochemical conditions (Joledo et al., 2025; Ekpo & Udom, 2019). Produced water discharged into aquatic environments without adequate treatment contributes radionuclides directly to surface and groundwater systems, potentially increasing environmental radioactivity and impacting water quality (Meskini et al., 2024). Produced water is the principal waste stream linked with oil and gas extraction from the earth. This principal waste stream is brought to the outer surface along with other hydrocarbons products from the reservoir formation. This produced water is naturally characterized by high dissolved solids, salinity, hydrocarbons, and trace naturally occurring radioactive materials (NORMs) (Esi et al., 2018; Avwiri et al., 2013). The radionuclides presence in produced water can be influenced by geological formations, reservoir characteristics, formation location condition and production techniques (Ononugbo et al., 2011). This produced water has emerged as a significant environmental concern due to its potential toxicity and contamination with various pollutants such as radionuclides. Understanding the radioactivity concentration level in produced water and their health implications is essential for safeguarding community health and environmental integrity (Afolabi et al., 2020). The radiological significance of NORMs stems from their capacity to emit ionizing radiation, which poses health risks upon chronic exposure. Humans and the ecosystem can be exposed to high concentration of environmental radioactivity through direct physical exposure, ingestion or inhalation and can significantly elevate radiogenic diseases and lifetime health risk (Mustapha et al., 2020; Afolabi et al., 2020). Over time, previous scientific studies (Avwiri et al., 2013; Nwankwo et al., 2022) have shown the concentration of environment radioactivity level in environment samples analyzed, but much work has not been carried out on radionuclide concentration in produced water. This research is to evaluate the concentrations of radionuclides in produced water collected from Oil Mining Lease (OML X) in Delta State, Nigeria. Also, to compute the potential health implications as it concern oil field workers and the host communities. The study is conducted in Oil Mining Lease (OML X), a major onshore oil block situated in Delta State, Nigeria. The region lies within the Niger Delta Basin, characterized by flat terrain, high rainfall, and an intricate network of rivers, creeks, and swamps. OML X is located in close proximity to oil wellheads, flow stations, and effluent discharge points (Ekpo & Udom, 2019; Nwilo & Badejo, 2006). The residents of the OML X communities primarily depend on hand-dug wells, boreholes, and surface water bodies for drinking and domestic use. Oil production activities in the area often involve the discharge of untreated or partially treated produced water into the environment, raising concerns about radioactive contamination of water sources.

MATERIALS AND METHODS

Sample Preparation and Analysis

Eighteen (18) produced water samples (three from each oil-field facility) were collected from oil-field facilities discharge points within OML X. Cylindrical containers that were meticulously washed with dilute HNO3, rinsed with treated distilled water and air dried were used to collect produced water samples from the oil-field facilities. Collecting the samples, the containers were rinsed three times with some quantities of the produced water before collecting the samples. Thereafter, samples containers were cover firmly and labeled according to circumvent miss identification and cross contamination. These collected produced water samples were kept for one month in the laboratory to attain secular equilibrium of the radionuclides in the samples (Avwiri et al., 2013; Obasi and Akudinobi., 2012; Hamed et al., 2024). After which radionuclide concentrations in prepared produced water samples were measured using calibrated Gamma-Ray Spectrometer detector System.

The Spectrometer detector System used to evaluate the concentration level of ^{40}K, ^{238}U and ^{232}Th present in prepared produced-water samples is called sodium iodide (NaI(Tl)). This detector was manufactured at Vienna and shielded with 10 cm thickness of lead to ensure accuracy factor of about 95% to 97% from background environment inadequacy, connected to Multi Channel Analyser (MCA). The efficiency calibration was done using 385 reference standards while energy calibration of the detector was done using standard emitters gamma source (Multi-gamma-ray) ^{241}Am, ^{137}Cs, and ^{60}Co. It was ensured that regular check was carry out on the detector, to maintained adequate calibration curve peaks within an energy wide range of 65 keV to 2531.6 keV throughout the analysis. The energies of ^{40}K, ^{238}U and ^{232}Th were given out from ^{40}K, ^{214}Bi and ^{208}Tl, with peaks of 1,460 keV 1764 and 2,614 respectively. The Spectrometer detector System used for this investigate is accessible at Centre for Energy Research and Development (CERD), Obafemi Awolowo University Ile Ife, Nigeria. The below mathematics equation 1 was used to compute specific activity of the radionuclide in each produced water samples (Igwe et al., 2020) and average to six (6) as shown in table 2.

$$C=\frac{A}{V_\gamma\, T E_p} \qquad (1)$$

Where C = radionuclide specific activity in BqL^{-1}, A = radionuclide Net count rate, V_γ= Water sample volume, T = time, E_p= Gamma ray energy efficiency in BqL^{-1}.

Radiological Hazard Parameters

Table 1: Formulas used for Radiological Hazard Computation (Avwiri et al., 2013; Ashraf et al., 2010; UNSCEAR 2010; UNSCEAR, 2000; WHO, 2017; Ehirim et al., 2020)

S/No	Hazard Index	Formulas
1	Radium Equivalent Index	$Ra_{eq}=P_{Ra}+1.43P_{Th}+0.077P_k$ (2)
2	Absorbed Does Rate (D)	$D=0.461P_{Ra}+0.623P_{Th}+0.04144P_k$ (3)
3	Annual Effective Dose Rate (Outdoor)	$AEDR(mSvyr^{-1})=(nGrh^{-1})\times 8760hryr^{-1}\times 0.7\times(10^3 mSv/10^9)nGy\times 0.2$ (4)
4	Annual Effective Dose Rate (Indoor)	$AEDE(mSvyr^{-1})=D(nGrh^{-1})\times 8760hryr^{-1}\times 0.7\times(10^3 mSv/10^9)nGy\times 0.8$
5	External Hazard Index (H_{ex})	$H_{ex}=\frac{P_{Ra}}{370}+\frac{P_{Th}}{259}+\frac{P_k}{480}$ (6)
6	Internal Hazard Index (H_{in})	$H_{in}=\frac{P_{Ra}}{185}+\frac{P_{Th}}{259}+\frac{P}{480}$ (7)
7	Representation Level Index (I_{yr})	$I_{yr}=\frac{P_{Ra}}{150}+\frac{P_{Th}}{100}+\frac{P_k}{1500}$ (8)

RESULTS AND DISCUSSION

The results reveal measurable levels of naturally occurring radionuclides ^{40}K, ^{238}U and ^{232}Th in all analyzed produced water matrices across OML X are as presented in Table 2.

Table 2: Shows the Average Concentration of Radionuclides in OML X Produced Water Samples (Bq L^{-1})

Code	^{40}K (Bq/L)	^{238}U (Bq/L)	^{232}Th (Bq/L)
OMLPW1	97.84	13.13	5.61
OMLPW2	112.99	9.10	4.55
OMLPW3	108.28	11.07	3.84
OMLPW4	110.76	6.15	2.65
OMLPW5	199.97	12.73	4.45
OMLPW6	102.98	11.29	3.59
Mean	122.14	10.58	4.12

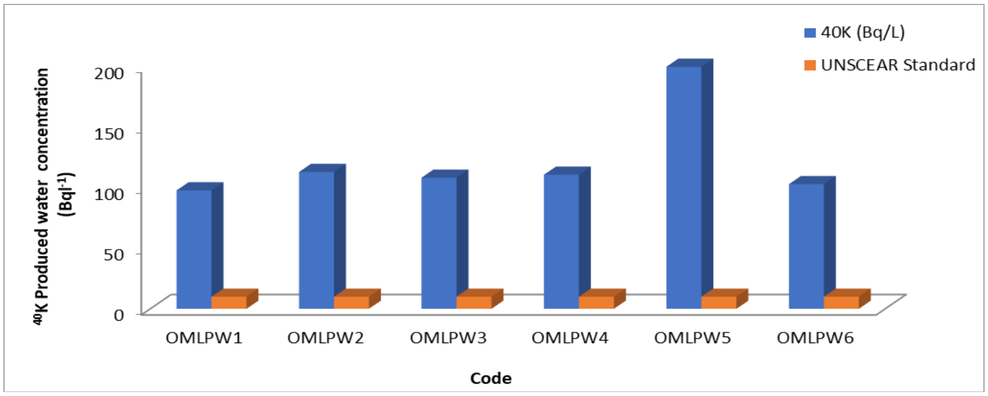

Figure 1: Comparison of ^{40}K (Bql^{-1}) Produced water values with UNSCEAR Standard value

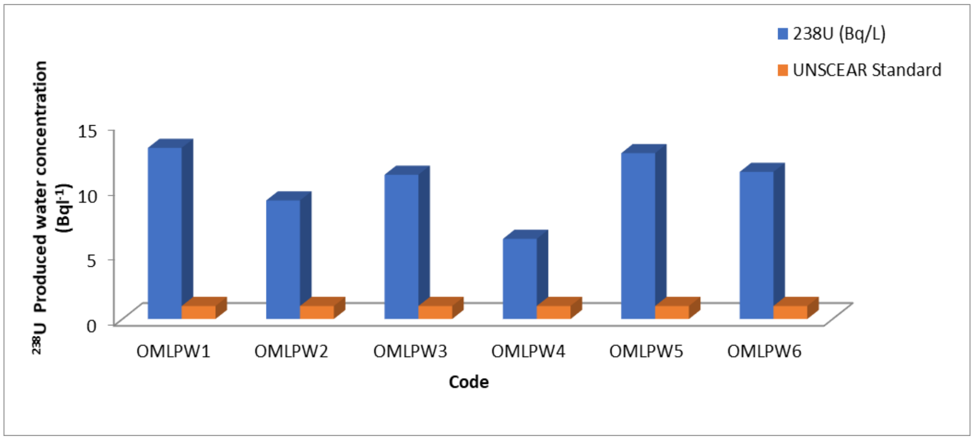

Figure 2: Comparison of ^{238}U (Bql^{-1}) Produced water values with UNSCEAR standard value

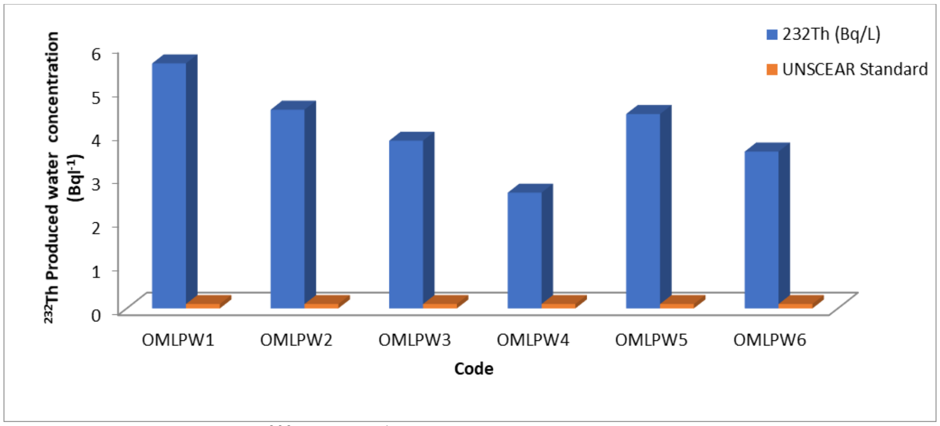

Figure 3: Comparison of ^{232}Th (Bql^{-1}) Produced water with UNSCEAR standard value

Table 3: The Results of the Radiological Risk Assessment of the Produced Water Samples from OML X

Sample	Raeq (BqL⁻¹)	D_R (nGy/h)	$AEDE_{out}$ (mSv/y)	$AEDE_{in}$ (mSv/y)	Hex	Hin	Iγ
OMLPW1	28.69	13.53	0.0166	0.0664	0.0775	0.1130	0.1044
OMLPW2	24.31	11.66	0.0143	0.0572	0.0657	0.0902	0.0907
OMLPW3	24.90	11.95	0.0147	0.0586	0.0673	0.0972	0.0922
OMLPW4	18.47	9.06	0.0111	0.0444	0.0499	0.0665	0.0707
OMLPW5	34.49	16.91	0.0207	0.0829	0.0932	0.1276	0.1313
OMLPW6	24.35	11.68	0.0143	0.0573	0.0658	0.0963	0.0899
MEAN	25.87	12.47	0.0153	0.0612	0.0699	0.0985	0.0965

The measured ^{40}K, ^{238}U and ^{232}Th in produced-water from OML X oil-field facilities that operate in the southern Nigeria have its values ranged from 97.84 at OMLPWM1 to 199.97 at OMLPWM 5 with mean value of 122.14 BqL^{-1} for ^{40}K, 9.10 at OMLPW2 to 12.73 at OMLPWM 5 with mean value of 10.58 BqL^{-1} for ^{238}U and 2.65 at OMLPW4 to 5.61 OMLPWM1 with mean of 4.12 BqL^{-1} for ^{232}Th respectively. These values are higher than the world recommended limit of 10, 1.0 and 0.1 BqL^{-1} as shown in statistical graphic representation in figure 1 to 3 respectively. These values are in agreement with other scientific research works (Avwiri et al., 2013; Esi et al., 2018; Onuoha et al., 2019; Ali et al., 2020; Pankratz & Warner, 2024; Hamed et al., 2024). Also, the values are higher than scientific reported work by (Gafvert et al., 2004; Jerez Vegueira et al., 2002). These high values may be attributed to the area geological formation and drilling mud used during operation that are not properly handled and inadequately treated which may contribute to reservoir contamination and geochemical connections involving reservoir rocks and formation water. The computed radiological risk parameters values of studied produced water from oilfield facilities in OML X are as presented in table 3. The Raeq values ranged from 18.47 at OMLPW4 to 34.49 at OMLPW5 with a mean of 25.87 BqL^{-1}. The D_R values ranged from 9.06 at OMLPW4 to 16.91 at OMLPW5 with mean value of 12.47 nGy/h. These obtained values are below the world recommended limit of 55 - 59 nGy/h (UNSCEAR 2000) and the reported values by (Joledo et al., 2025; Kpeglo et al., 2016; Almog et al., 2024). Also, these high values may be ascribed to geological formation and the production activities of the hydrocarbon companies operating in the area. The computed values of $AEDE_{out}$ and $AEDE_{in}$ ranged from 0.0111 at OMLPW4 to 0.0207 OMLPW5 with mean value of 0.0153 mSv/y and 0.0444 at OMLPW4 to 0.0829 OMLPW5 with mean value of 0.0612 mSv/y respectively. While Hex and Hin values ranged from 0.0499 at OMLPW4to 0.0932 at OMLPW5 with mean value of 0.0699 and 0.0665 at OMLPW4 to 0.1276 at OMLPW5 with mean value of 0.0985 respectively. The Iy computed values ranged from 0.0707at OMLPW4 to 0.1313 at OMLPW5 with mean value of 0.0965. These values of $AEDE_{out}$, $AEDE_{in}$, Hex, Hin and Iy are all below world recommended limits (EC, 1999; UNSCEAR, 2000). These values are in agreement with reported scientific research work by (Massuod et al., 2012; Abdelbary et al., 2019; Elghawi et al., 2017; Schandorf et al., 2010). Generally, these OML X produced water elevated radionuclide values may pose reminiscent environmental and potential health risks on both the oilfield workers and the ecosystem. Chronic exposure in terms of ingestion, inhalation and physical contact can enhance the risk of human having cancer during lifetime. Furthermore, released produced water can lead to resultant contamination of the ecosystems and water quality.

CONCLUSION

This study provides a comprehensive radiological and health risk assessment of produced water from OML X using a well calibrated Gamma-Ray Spectrometer for radionuclides measurement and mathematical models for radiological health implications. This study has ascertained the level of radionuclides in hydrocarbon produced water and potential radiological health implication on both workers and the ecosystem. The mean values of ^{40}K, ^{238}U and ^{232}Th of OML X oil-field facilities produced-water are 122.14 BqL^{-1}, 10.58 BqL^{-1} 4.12 BqL^{-1} respectively. These values are relatively high compared to the world recommended limit and other scientific research report across the world. These high values may be ascribed to geological formation, improper released of used drilling mud during hydrocarbon production operation. However, the computed potential radiological health implications are below world recommended limits, hence it does not pose significant risk burden on both humans and the ecosystem. Therefore, it is our recommendation that produced water should be properly treated before release into the environment and there should be continuous monitoring of produced water radiologically. This research will increase the data base of hydrocarbon produced water radiological study across the Niger Delta. Furthermore, researchers should investigate other oil field produced water and if possible use High Purity Germanium (HPGe) for better resolution.

REFERENCES

Abdelbary, H. M., Elsofany, E. A., Mohamed, Y. T., Abo-Aly, M. M., & Attallah, M. F. (2019). Characterization and radiological impacts assessment of scale TENORM waste produced from oil and natural gas production in Egypt. *Environmental Science and Pollution Research, 26*, 30836–30846. https://doi.org/10.1007/s11356-019-06183-x

Ademola, T. A., Orosun, M. M., & Joledo, A. O. (2025). Potential health risk assessment of sediment and water in some Niger Delta areas of Nigeria. *Nuclear Analysis, 4*(1), 100159. https://doi.org/10.1016/j.nucana.2025.100159

Afolabi, A. A., Olise, F. S., Chukwu, A., &Tchokossa, P. (2020). Radionuclides and heavy metals in produced water from the Niger Delta region of Nigeria: Health implications. *Environmental Monitoring and Assessment, 192*(4), 247. https://doi.org/10.1007/s10661-020-8210-5

Agbalagba, E. O., Avwiri, G. O., and Ononugbo, C. P. (2013). Radiological impact assessment of oil exploration and production activities in selected oil fields in the Niger Delta region of Nigeria. Journal of Environmental Radioactivity, 126, 74–80.

Ali, M.M.M., Zhao, H., Li, Z. and A.A.T. Ayoub A.A.T. (2020) A review about radioactivity in TENORMs of produced water waste from petroleum industry and its environmental and health effects, IOP Conf. Ser. Earth Environ. Sci. 467, 012120, https://doi.org/10.1088/1755-1315/467/1/012120

Almog, M. T., Youshah, B. M., &Abuqarbuah, N. M. (2024). Evaluation of naturally occurring radioactive materials (NORM) in produced water and oil-field equipment stations NA/100 and BD/200. *International Science and Technology Journal*. https://doi.org/10.62341/ghjy2003

Avwiri, G. O., Esi, E. O., & Agbalagba, E. O. (2013). Gamma spectroscopy analysis of produced water from selected flow stations in Delta State, Nigeria. *International Journal of Environmental Monitoring and Analysis, 1*(5), 167–174. https://doi.org/10.11648/j.ijema.20130105.11

Ehirim, C. N., and Nwankwo, M. U. (2020). Environmental radiation and health risk assessment in selected oil and gas facilities in Bayelsa State. Journal of Environmental Health Research, 30(1), 12–23.

Ekpo, I. E., and Udom, G. J. (2019). Assessment of groundwater contamination from oil and gas activities in rural Niger Delta communities, Nigeria. *Environmental Monitoring and Assessment*, 191(12), 764.

Elghawi, U. M., Abutweirat, F. A., & Barka, T. S. (2017). Evaluation of naturally occurring radioactive materials in oilfields of south east of Libya. *International Journal of Low Radiation, 10*(4), 304–313.

Esi, Oghenevovwero, E and O. Avwiri Gregory. 2018. "Radiological Hazards Assessment of Produced Water from Some Oil and Gas Flow Stations in Delta State, Nigeria". *Journal of Scientific Research and Reports* 19 (6):1-10. https://doi.org/10.9734/JSRR/2018/41478.

European Commission. (1999). *Radiological protection principles concerning the natural radioactivity of building materials* (Radiation Protection 112). Office for Official Publications of the European Communities.

European Commission. (1999). *Radiological protection principles concerning the natural radioactivity of building materials* (Radiation Protection 112). Office for Official Publications of the European Communities.

Gafvert.T and Faerevik.I. 2004: Natural Radioactivity in Produced Water from Norwegian Oil and Gas Industry in 2003.

Hamed, Y., Ayadi, Y., Hadji, R., Ben Saad, A., Gentilucci, M., &Elaloui, E. (2024). Environmental radioactivity, ecotoxicology (^{238}U, ^{232}Th and ^{40}K) and potentially toxic elements in water and sediments from North Africa dams. *Sustainability, 16*(2), 490. https://doi.org/10.3390/su16020490

Ibrahim, S. I., Ahmed, B. A., and Sulaiman, S. A. (2020). Comparative radiological assessment of treated and untreated produced water from oilfields in Nigeria. Journal of Radiation Research and Applied Sciences, 13(1), 134–141.

Igwe, O. C., Alao, M. A., and Uzochukwu, C. E. (2020). Radiological characterization of produced water from oilfields in the Niger Delta region of Nigeria. Radiation Protection Dosimetry, 189(3), 317–325.

International Atomic Energy Agency. (2003). *Radiation protection and the management of radioactive waste in the oil and gas industry* (Safety Reports Series No. 34). IAEA.

Jerez Vegueria SF, Godoy JM, Miekeley N. 2002. Environmental impact studies of barium and radium discharges by produced water from the "Bacia de Campos" oil-field offshore platforms, Brazil. Journal of Environmental Radioactivity 2002; 62: 29-38

Joledo, A. O., Orosun, M. M., & Ademola, T. A. (2025). Radiological impact assessment of produced water from oilfield production facilities in the Niger Delta region. *Nuclear Analysis, 4*, 100174. https://doi.org/10.1016/j.nucana.2025.100174

Kpeglo, D. O., Mantero, J., Darko, E. O., Emi-Reynolds, G., Faanu, A., Manjón, G., Vioque, I., Akaho, E. H. K., & Garcia-Tenorio, R. (2016). Radiochemical characterization of produced water from two production offshore oilfields in Ghana. *Journal of Environmental Radioactivity, 162–163*, 207–215. https://doi.org/10.1016/j.jenvrad.2015.10.026

Massuod, T. S., Abuttweirat, F., &Elghawi, U. M. (2012). Chemical and radioactive content of oilfield produced water in Libya. *Libyan Agriculture Research Center Journal International, 3*(3), 155–159. https://doi.org/10.5829/idosi.larcji.2012.3.3.1211

Mustapha, A. O., Patel, J. P., & Rathore, I. V. S. (2020). Health risks associated with radionuclide contamination in produced water in Nigeria. *International Journal of Environmental Research and Public Health, 17*(5), 1523. https://doi.org/10.3390/ijerph17051523

Nwankwo, K. C., and Ifeadi, C. N. (2018). Institutional challenges in enforcing environmental radiation protection in Nigeria's oil and gas sector. Journal of Environmental Policy and Administration, 4(2), 33–44.

Nwankwo, U. K., Avwiri, G. O., & Egieya, J. M. (2022). A study of the concentration of radionuclides in contaminated water sources in oil fields in Nigeria. *Nigerian Journal of Physics, 33*(1), 85–92.

Obasi, R. A., and Akudinobi, B. E. B. (2021). Awareness and perception of environmental radiation risks in oil-producing communities of the Niger Delta. Journal of Health Education Research & Development, 9(3), 54–61.

Okonkwo, O. A., Avwiri, G. O., & Chad-Umoren, Y. E. (2021). Assessment of radionuclide concentration in the surface water of oil producing areas in Delta State, Nigeria. *Journal of Environmental Radioactivity, 226*, 106493. https://doi.org/10.1016/j.jenvrad.2020.106493

Ononugbo, C. P., Avwiri, G. O., & Chad-Umoren, Y. E. (2011). Impact of Gas Exploitation on the Environmental Radioactivity of Ogba/Egbema/Ndoni Area, Nigeria. Energy and Environment, 22(8), 1017-1028.

Onuoha, J. C., Edeani, F. N., and Okoye, F. I. (2019). Radiological risk assessment of rivers in oil-producing areas of Rivers State. Journal of Environmental Radioactivity, 203, 42–50.

Pankratz K. and Warner N.R. (2024) Radioactivity from oil and gas produced water accumulated in freshwater mussels, Sci. Total Environ. 927, 172151, https://doi.org/10.1016/j.scitotenv.2024.172151.

Schandorf, C., Osei, E. K., & Darko, E. O. (2010). Determination of activity concentration levels of ^{238}U, ^{232}Th, and ^{40}K in drinking water in a gold mining area in Ghana. *Health Physics, 99*(Suppl. 2), S149–S153. https://doi.org/10.1097/HP.0b013e3181f72dcd

Schandorf, C., Osei, E. K., & Darko, E. O. (2010). Natural radioactivity in drinking water from gold mining areas in Ghana. *Journal of Radiation Research and Applied Sciences, 3*(3), 1–10.

U.S. Nuclear Regulatory Commission. (2023). *10 CFR §20.1301: Dose limits for individual members of the public*. https://www.nrc.gov/reading-rm/doc-collections/cfr/part020/part020-1301.html

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). (2000). *Sources and effects of ionizing radiation: UNSCEAR 2000 report to* *the General Assembly, with scientific annexes*. United Nations.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). (2008). *Sources and effects of ionizing radiation: UNSCEAR 2008 report to the General Assembly, with scientific annexes*. United Nations.

World Health Organization. (2017). *Guidelines for drinking-water quality* (4th ed., incorporating the 1st addendum). World Health Organization.