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# Assessment of Natural Radioactivity and Radiological Hazards from Ingestion of Well Water in Selected Communities of Rumuekpe, Rivers State

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**Abstract**
Natural radioactivity refers to the spontaneous emission of ionizing radiations from naturally occurring radioactive materials in the earth’s crust. This study focuses on assessment of radiological hazards associated with intake of radionuclides in well water samples from some randomly selected communities in Rumuekpe, Emohua Local Government Area, Rivers State, using Sodium Iodide gamma-rays spectrometer. The radionuclides present in the water samples are 40K, 232Th and 238U, their mean activity concentrations are 71.51, 2.73 and 9.67 Bql-1 respectively. Mean total annual effective dose in infants (0-1 and 1-2)y, children (1-2 and 2-7)y and adults (12-17 and >17)y are (3.70 and 1.95) mSvy-1, (1.17 and 0.86) mSvy-1, and (1.37 and 1.09) mSvy-1 respectively. Mean absorbed dose, annual effective dose equivalent and annual gonad dose equivalent are 8.94 nGyh-1, 10.96 mSvy-1 and 62.73 Bql-1 respectively. Mean radium equivalent and excess lifetime cancer risk are 19.11 Bql-1 and 37.88 E-3 respectively. All mean radiological hazards are above their respective recommended safe limits, except 238U.This indicates that the water samples are radiologically polluted and harmful for human consumption. Provision of clean, alternative and safe source of water, as well as medical check-ups and treatment are recommended for the inhabitants.

**Keywords:** Harmful, Concentration, Equivalent, Alternative, Recommended

## Introduction

Ground water such as wells and boreholes, is water that exists beneath the earth's surface in aquifers, reservoirs, or soil layers. Groundwater is a crucial water resource for cooking, drinking and bathing, irrigation, and industrial uses (Irunkwor et al., 2022). It accumulates through the process of precipitation, which infiltrates the soil and percolates downward to fill porous rock formations. It is the highest reservoir of water for domestic purposes and is less contaminated than the surface water due to the process of natural filtration through layer of soil underground (Aiyesammi et al., 2004).

Generally, water helps to maintain hydrological balance of ecosystems as well in survival and well-being of all living organisms (Igbudu & Briggs-Kamara, 2023). Its importance cuts across various biological, ecological, and environmental functions (Orosun et al., 2022). In humans, water is very vital for hydration, health, digestion, and even social (swimming) and cultural (fishing) activities. It helps to dissolve nutrients, gases, and waste products, as well as in facilitating important processes such as digestion, metabolism, and cellular respiration (Akinloye, 2008). Water plays a central role in maintaining body temperature through processes like sweating and evaporation in humans and other animals, as well as regulating the internal temperature of plants through transpiration.

The contamination of water can have serious health effects on human beings as well as other living organisms (Ajayi et al., 2012), hence the need for sustainable water management is very vital. The quality and safety of groundwater are critical for human health, and various natural and anthropogenic factors can influence its quality. One of such factors is the presence of radionuclides, which are radioactive isotopes that contaminate groundwater (Irunkwor et al., 2022; Ononugbo & Anyalebechi, 2017). Contamination of groundwater is caused by presence of radionuclides which are present in the soil and rocks beneath the earth (Ajayi, 2008). Some of these radionuclides can also be present in underground water from anthropogenic sources such as mining, industrial discharge, improper nuclear waste management, illegal bunkering activities, oil spillage due to equipment failure, N-P-K fertilizer application (Ononugbo & Anyaleechi 2017; Igbudu & Briggs-Kamara, 2023). These sources can introduce harmful levels of radiation into groundwater through weathering process and dissolution of minerals, thereby potentially posing health risks to humans, as well as the environment. Some of the naturally occurring radioactive materials in groundwater such as Radon, Uranium, Thorium, and their decay products which include Radium and Polonium (Ononugbo & Tutumeni, 2016) are typically present in granitic, sedimentary, or metamorphic rock formations. Monitoring and proper management of groundwater are essential in areas where radionuclides are naturally abundant or where anthropogenic contamination may occur. This highlight of this study is to assess the natural radioactivity and radiation hazards which are associated with intake of well water from some randomly selected locations in Rumuekpe, a Niger Delta community in Emohua Local Government Area, Rivers State, Nigeria.

The presence of natural radioactivity in groundwater such as hand dug well constitutes a major environmental problem worldwide, with implications on human health and ecological balance. In Rumuekpe communities, the contamination of water sources with naturally occurring radioactive materials (NORMs) remains largely unexplored despite the increasing reliance on groundwater for drinking, irrigation, and industrial purposes. This region is known for its complex geology, which includes sedimentary formations rich in uranium, thorium, and radium, all of which are potential sources of radionuclides in water. The amount of natural radioactivity in well water and its radiologically induced hazards have not been adequately assessed in Rumuekpe communities. There is a growing concern about the potential health risks posed by the consumption of well water contaminated with these radioactive elements. Studies revealed that exposure of natural radionuclides such as radon, uranium, and radium for a long time leads to acute health challenges such as cancer, kidney damage, and bone disorders (Ononugbo & Anyalebechi, 2017). Furthermore, the lack of data on the assessment of levels of radioactivity in underground water from this region implies that the local population may be exposed unknowingly to these hazardous substances.

This study aims to assess the natural radioactivity in well water from some communities in Rumuekpe, as well as to evaluate the potential radiological hazards associated with its consumption. The findings in this study will contribute to understanding the level of radioactive contamination of water sources within the study area, as well as provide crucial data for public health policy, water safety standards, and recommendations for mitigating exposure to radionuclides. The study area is noted for its high oil and gas exploration and exploitation activities as well as activities of illegal refining of crude oil (Osuagwu & Olaifa, 2018). Oil pollution arising from activities of oil thieves as well as equipment failure have reportedly resulted to serious damage to the environmental media (air, soil and water), loss of aquatic lives and natural ecosystem as well as increase in the level or concentration of radionuclides (Igbudu et al., 2025a). These had impacted negatively on human health (Nriagu et al., 2016; Ordinioha & Brisibe, 2013). Amnesty International Nigeria (2009), also reported that constant oil pollution within the study area have resulted in serious environmental degradation which also affected mostly the surface water sources, groundwater sources (well water) became their only source of water (Igbudu et al., 2025a) for domestic uses the communities.

Furthermore, research study on the quality of water resources in Rumuekpe communities have been difficult due to its internal violent crisis that lasted between 2005 and 2008. The crisis resulted in killings and destruction of infrastructure hence, there are no available literature on study of natural radioactivity in the study area, except a research on assessment of ingested radionuclide dose from groundwater sources in Rumuekpe, Rivers State, Nigeria, conducted by Igbudu et al. (2025a). However, there are similar studies on surface and ground water within Niger Delta


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region. These include the study conducted by: Woke and Bolaji (2015) to assess ground water quality in Emohua Local Government Area, Rivers State, Nigeria; Ononugbo and Tutumeni (2016) on natural radioactivity and radiation dose estimation in various water samples in Abua/Odual Local Government Area, Rivers State, Nigeria. Other are assessment of radiological hazards associated with $^{40}$K, $^{232}$Th and $^{232}$U in waters samples from Emohua section of the New Calabar River, Rivers State, Nigeria (Igbudu et al., 2025b); radiological risk assessment of adult exposure to radionuclides from the New Calabar River, Nigeria (Igbudu & Ogan, 2025); risk assessment of natural radionuclides in surface and ground water of oil and gas producing communities, Rivers State, Nigeria (Irunkwor et al., 2022); radioactivity assessment of shallow aquifers and Warri River in Udu Area of the Western Niger Delta, Nigeria (Ohwoghere-Asuma et al., 2021); investigating the concentration of radionuclides in wells used as drinking water in Northern Nigeria: A Case study of Jos metropolis (Godwin et al., 2021) and assessment of natural radioactivity in sediments and groundwater from selected areas in Funtua town, Katsina State, Nigeria (Tyongiga et al., 2024). The above studies reported high level of concentration of radionuclides in the underground water samples above the internationally recommended safe limits. The studies further highlighted that the water resources (surface and ground water) are radiologically harmful and unsafe for human consumption. The only exception to this is the study by Tyongiga et al. (2024), which reported that all radiological parameters considered were below internationally recommended safe limits. The study further highlighted that the groundwater samples were safe and fit for human consumption, with no serious health risk.

## Materials and Methods

### Study Area

Rumuekpe is one of the Ikwerre speaking communities located in the Niger Delta Region, South-South Nigeria. It lies in latitude 4° 58′ 59″ N and longitude 6° 45′ 0″ E, and comprises of eight villages which include: Rumuegwu, Omoviri, Mgbodo, Ovelle-Odouha, Mgbuhie, Ekwutche, Imogu and Ovelle. Rumuekpe, known for its wetlands, rivers, and rich natural resources, with its geography consisting mainly of tropical rainforests, swamps, and riverine have fishing, farming and small-scale trading as their major occupations. Rumuekpe is one of major oil-producing communities in Niger Delta, and plays host to some multinational and international oil companies such as Shell Petroleum Development Company (SPDC), Total E&P Nigeria Limited (TNL), Nigeria Liquified Natural Gas Limited (NNLNG), Nigeria Agip Oil Company (NAOC) and Niger Delta Petroleum Resources (NDPR). Despite the presence of multinationals in the area, the people suffer serious challenges in social, economic and infrastructural developments. Oil and gas operations by the multinationals, oil spillage due to pipeline vandalization and equipment failure, illegal refining of crude (bunkering activity) by oil thieves within the study area had resulted in severe environmental degradation. This had affected domestic water supplies, agricultural productivity, and overall health condition of the inhabitants.


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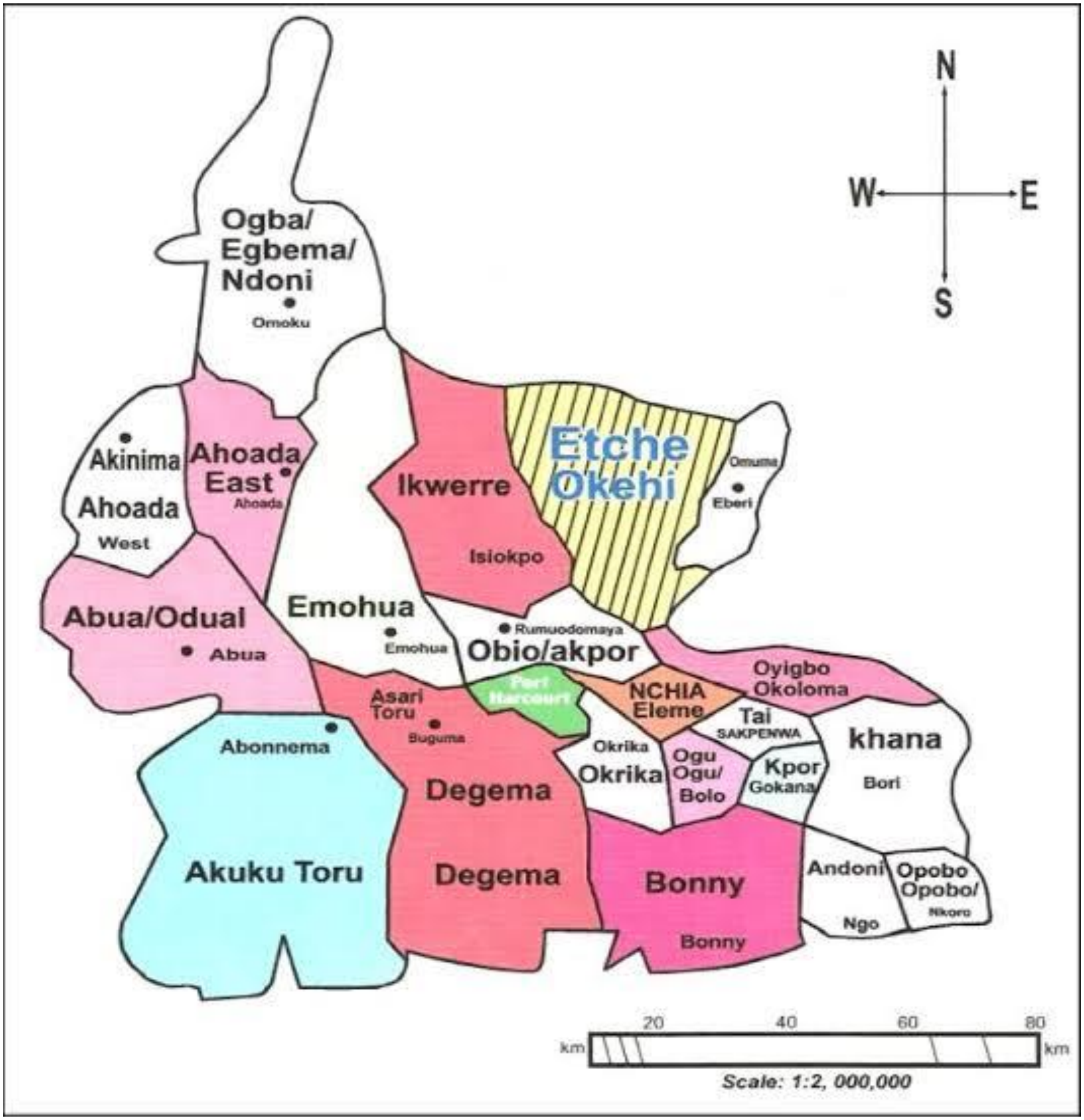

Fig. 1: Map of Rivers State showing the Local Government Area of study.


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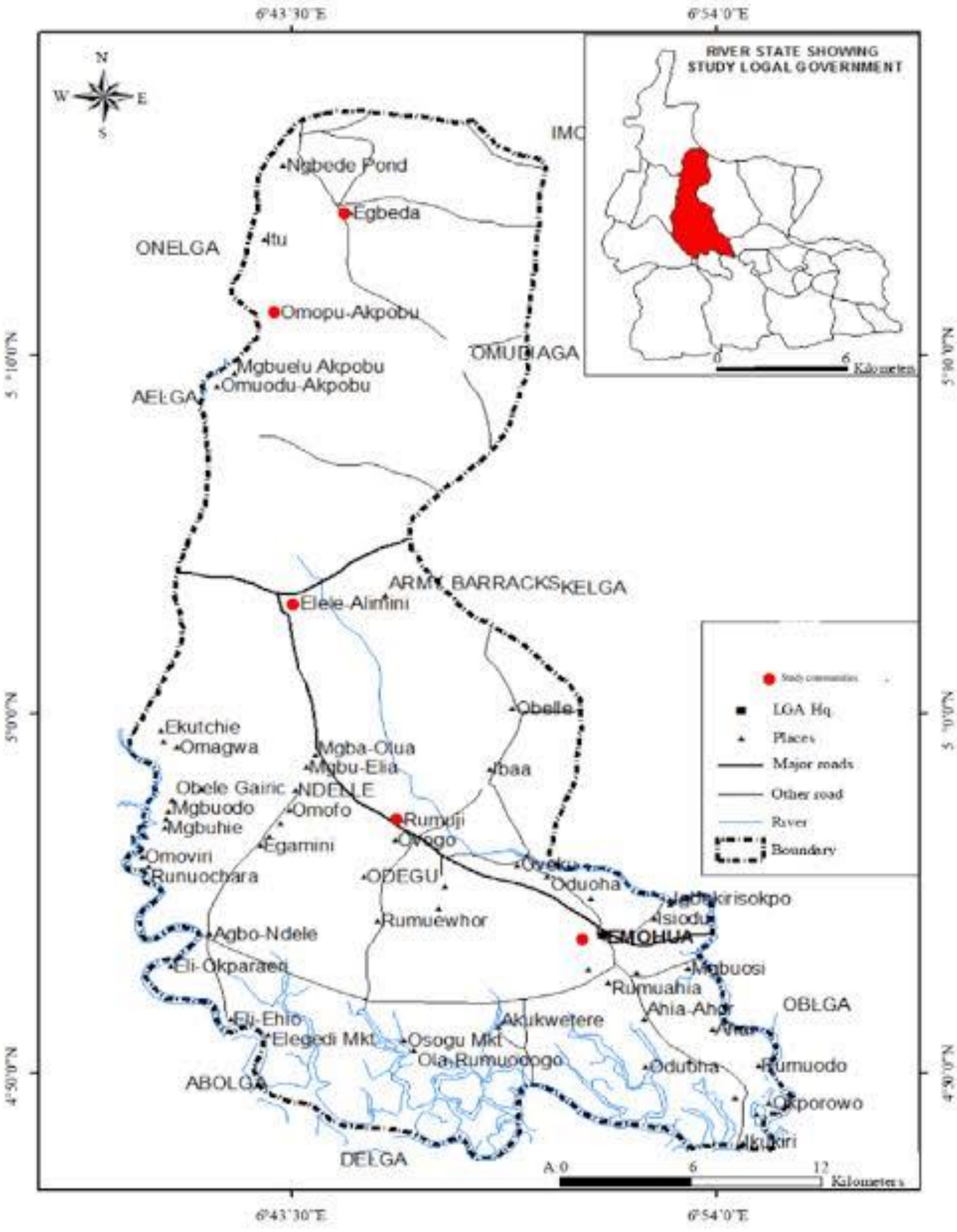


**Fig. 2: Map of Emohua Local Government Area Showing the study area**


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## Materials

The following materials were used in this study: 50 cl sterilized plastic bottle for sample collection, sterilizing agents (bleach or alcohol) to ensure containers are free of contaminants, sample collection labels for proper identification of location, Sodium Iodide (TI) scintillation gamma-ray spectrometer to detect gamma radiation from radioactive isotopes in the water samples, chemical reagents ($HNO_3$ or HCl) for lowering the pH of water samples. Others are filters to remove suspended particles from the water sample before measurement, radiation sources or standards for calibrating radiation detection instruments (e.g., Cesium-137, Cobalt-60), personal protective equipment (PPE) such as gloves, laboratory coat, and safety goggles used for handling samples and hazardous materials, logbooks and data sheets used to record sample collection details, equipment calibration, and measurement data.

## Methods

Twenty (20) pieces of sterilized 50 cl containers were thoroughly washed with the help of detergents, and were later rinsed thrice with the aid of distilled water. Well water samples were collected into the containers and acidified with $HNO_3$ solution. This is to enable the pH of well water samples to be lowered below 2, and to allow for secular equilibrium to be achieved before analysis (Orosun et al., 2022; Igbudu & Briggs-Kamara, 2023). The sample containers were properly labelled, ice cooled, and conveyed to the laboratory for analysis, with the aid of Sodium Iodide (NaI) gamma-ray spectrometer. Activity concentration of radionuclides in the well water was determined with the help of computer program connected to the detector, and calculated after subtracting decay corrections.

## Estimation of Radiological Hazards

Study of radiological hazard indices in well water samples helps to assess the potential health effects caused by the presence of natural radionuclides such as uranium, radium, thorium, and their decay products. These indices help in determining the radiological safety of water consumed by humans. The common indices used to estimate radiological risks are:

### Activity Concentration

Activity concentration of well water samples refers to the amount of radioactive element present in a given volume of water sample, and was estimated using Eq. (1): (Avwiri et al., 2014; Igbudu et al., 2023)**:**

$$A_c(Bql^{-1}) = \frac{C_a}{P_\gamma (M_S/V_S)\varepsilon_\gamma \, t_c} \quad (1)$$

where**:**

$A_c$ = Activity Concentration.
$C_a$ = Net peak area of a peak at energy.
$\varepsilon_\gamma$ = Efficiency of the detector for a $\gamma$-energy of interest.
$V_s$ = Sample volume
$t_c$ = Total counting time.
$P_\gamma$ = Abundance of the $\gamma$-line in a radionuclide

### Total Annual Effective Dose (TAED)

This refers to the total radiation exposure an received by an individual as a result of presence of radionuclides in a given water sample over the course of a year. Its value varies with the type of radionuclides present, as well as age group of the individuals consuming the water (Igbudu & Briggs-Kamara, 2023). The TAED was obtained summation of AED of each of the radioelements present in a given water sample for infants, children and adults population that who consumes the water, using Eq. (2): (Ajayi & Adesida, 2009; Ononugbo & Anyalebechi, 2017):

$$\text{TAED } (mSvy^{-1}) = \sum A_c I_A C_F \quad (2)$$

where:

$A_c$ = Activity concentration ($Bql^{-1}$) of the radionuclide in the water sample.
$I_A$ = Daily water consumption ($Ld^{-1}$).
$C_F$ = Dose conversion factor ($mSvBq^{-1}$)


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**Absorbed Dose (AD)**
The absorbed dose refers to the amount of energy deposited by ionizing radiation per unit mass of water. It is used to measure the potency of biological damage to certain organs of human body. The type of radiation, duration of exposure, and individual sensitivity can affect the overall value of absorbed dose. The absorbed dose in water sample was estimated using Eq. (3): (Eke & Emelue, 2019; Mbonu & Ben, 2021; Samaila & Tampul, 2021):

$$AD\ (nGyh^{-1}) = 0.462\ A_U + 0.604\ A_{Th} + 0.0417\ A_K \quad (3)$$

where:
$A_K$, $A_{Th}$ and $A_U$ are activity concentrations of $^{40}K$, $^{232}Th$ and $^{232}U$ respectively while 0.0417, 0.604, 0.462 are conversion factor for $^{40}K$, $^{232}Th$ and $^{232}U$ respectively.

**Annual Effective Dose Equivalent (AEDE)**
This refers to estimated radiation dose received by an individual due to intake of well water samples over a period of one year. It helps to determine the strength of future effect on humans due to exposure to radiation (Ugbede & Benson, 2018). The AEDE was estimated using Eq. (4): (Ereh & Zhang, 2018; Sowole & Egunjobi, 2019):

$$AEDE\ (mSvy^{-1}) = D\ (nGyh^{-1}) \times 8760\ hr \times 0.2 \times 0.7\ (Sv/Gy) \times 10^{-6} \quad (4)$$

where**:**
$D\ (nGyh^{-1})$ = Absorbed dose
$8760 =$ Total hour per year.
0.7 (Sv/Gy) = Dose conversion factor
$0.2 =$ Occupancy factor for outdoor measurement.

**Annual Gonad Dose Equivalent (AGDE)**
This is a measure of the quantity of radiation absorbed by the gonad cells over a period of one year. Several factors such as concentration of radionuclides, amount of water consumed, ingestion pathway and dose conversion factor affect the amount of AGDE. It is used to measure potential threat to sensitive cells (UNSCEAR, 2000) due to radiation exposure to a certain level. It was estimated using Eq. (5): (Eke & Emelue, 2019):

$$AGDE = 3.09A_U + 4.18A_{Th} + 0.314A_K \quad (5)$$

where:
$A_U, A_{Th}\ and\ A_K\ are$ activity concentrations of $^{232}U$, $^{232}Th$ and $^{40}K$ respectively and 3.09; 4.18 and 0.314 are their respective radionuclides conversion factor.

**Radium Equivalent (Raeq)**
This is a measure of total radioactivity present in a given water sample, and is expressed in terms of equivalent activity of radium. It is a summation of the radioactivity of uranium, thorium, and radium, and presenting a singular value for the overall radiological risk in a given water sample. It was estimated using Eqs. (6) and (7): (Avwiri et al., 2014; Eke & Emelue, 2019):

$$Raeq = \left[\frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810}\right] \times 370 \quad (6)$$

$$Raeq = A_U + 1.43A + 0.077A_K \quad (7)$$

where:
$A_U, CA_{Th}\ and\ CA_K\ are$ activity concentrations of radioelements: $^{232}U$, $^{232}Th$ and $^{40}K$ respectively while 1, 1.43 and 0.077 are the conversion factors for the respective radionuclides.

**Excess Lifetime Cancer Risk (ELCR)**
This is a measure of increased risk of developing cancer in a lifetime as a result of exposure to radioactive contaminants in a given water sample. It was estimated using Eq. (8): (Avwiri et al., 2014; Samaila & Tampul, 2021):

$$ELCR = AEDE \times DL \times RF \quad (8)$$

where:
$AEDE =$ Annual effective dose equivalent.
$DL =$ Duration of life (approximately 70 years).
$RF =$ Fatal risk factor per Sievert ($Sv^{-1}$), approximately 0.05 for stochastic effect for general public.

**Results**
Activity concentration of radionuclides of ($^{40}K$, $^{232}Th$ and $^{238}U$) in well water samples is presented in Table 1. Total annual effective dose for six different age categories (infants, children and adults) as well as estimated radiological hazard indices in well water samples are presented in Tables 2 and 3 respectively. Mean radiological hazard indices and the world average value are presented in Fig.1.

**Table 1: Activity Concentrations of $^{40}K$, $^{232}Th$ and $^{238}U$ present in hand dug Well Water in Rumuekpe Communities**

| Sample Location | | Location | | Activity Concentration (Bql$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | | Latitude N | Longitude E | $^{40}K$ | $^{232}Th$ | $^{238}U$ |
| **Ovelle Community** | | | | | | |
| Emeka's Compound | W1 | 4º 59′ 17.82″ | 6º 41′ 03.79″ | 19.66±1.00 | 3.77±0.22 | BDL |
| Elechi's Compound | W2 | 4º 59′ 27.12″ | 6º 41′ 14.27″ | 20.58±1.03 | 4.36±0.25 | 7.00±0.92 |
| Amadi;s Compound | W3 | 4º 59′ 25.44″ | 6º 41′ 26.31″ | 26.10±1.26 | 3.09±0.17 | 13.93±1.09 |
| Eze's Compound | W4 | 4º 59′ 14.63″ | 6º 41′ 33.58″ | 27.38±1.39 | 1.54±0.09 | 0.20±0.03 |
| Kalu's Compound | W5 | 4º 59′ 21.41″ | 6º 41′ 13.33″ | 32.48±1.66 | 0.64±0.04 | BDL |
| America's Compound | W6 | 4º 59′ 11.48″ | 6º 41′ 34.58″ | 105.04±5.31 | 2.82±0.16 | 14.50±1.82 |
| Buchi's Compound | W7 | 4º 59′ 22.71″ | 6º 41′ 45.54″ | 59.15±2.97 | 0.13±0.01 | 4.94±0.67 |
| Good Luck Compound | W8 | 4º 59′ 11.66″ | 6º 41′ 49.31″ | 83.60±4.22 | 0.99±0.06 | 1.45±0.20 |
| Orlu's Compound | W9 | 4º 59′ 49.61″ | 6º 41′ 36.42″ | 11.69±0.59 | 2.75±0.16 | 3.01±0.42 |
| Obene's Compound | W10 | 4º 59′ 15.66″ | 6º 41′ 51.89″ | 43.07±2.16 | 3.18±0.18 | 7.25±0.88 |
| Adigwe's Compound | W11 | 4º 58′ 10.39″ | 6º 41′ 49.48″ | 119.94±6.03 | 0.17±0.01 | 24.23±2.68 |
| Chigozie's Compound | W12 | 4º 59′ 11.82″ | 6º 41′ 56.91″ | 105.56±5.34 | 5.94±0.34 | 20.68±2.45 |
| Barry's Compound | W13 | 4º 59′ 32.32″ | 6º 41′ 43.89″ | 32.82±1.58 | 2.97±0.17 | 0.65±0.05 |
| Ekwulo's Compound | W14 | 4º 59′ 47.56″ | 6º 41′ 35.58″ | 160.86±8.11 | 3.20±0.19 | 1.07±0.14 |
| Chinweikpe's Compound | W15 | 4º 59′ 10.87″ | 6º 41′ 53.37″ | 134.06±6.75 | 1.39±0.08 | 16.18±1.92 |
| **Mgbodo Community** | | | | | | |
| Power's Compound | W16 | 4º 56′ 27.28″ | 6º 40′ 21.43″ | 22.54±1.14 | 1.15±0.07 | 3.82±0.54 |
| Obisike's Compound | W17 | 4º 56′ 55.76″ | 6º 40′ 52.57″ | 161.91±8.16 | 2.05±0.12 | 0.20±0.02 |
| Chekwa's Compound | W18 | 4º 56′ 46.22″ | 6º 40′ 25.48″ | 30.25±1.53 | 2.24±0.13 | 1.14±0.15 |
| Akachukwu's Compound | W19 | 4º 56′ 39.44″ | 6º 40′ 51.57″ | 129.09±6.52 | 3.82±0.22 | 1.14±0.15 |
| John's Compound | W20 | 4º 56′ 47.49″ | 6º 40′ 56.32″ | 22.93±1.15 | 2.21±0.13 | 12.12±1.47 |
| **Omoviri Community** | | | | | | |
| Elder Uchenna Compound | W21 | 4º 55′ 51.24″ | 6º 40′ 31.31″ | 133.15±6.69 | 3.79±0.22 | 3.07±0.41 |
| Wele's Compound | W22 | 4º 55′ 26.18″ | 6º 40′ 57.89″ | 77.84±3.76 | 3.55±0.20 | 8.79±0.71 |
| **Mgbuhie Community** | | | | | | |
| Chinenye's Compound | W23 | 4º 57′ 09.60″ | 6º 41′ 14.65″ | 71.44±3.61 | 2.57±0.15 | 15.68±1.87 |
| Anyanda's Compound | W24 | 4º 57′ 19.43″ | 6º 41′ 42.19″ | 50.13±2.53 | 2.15±0.12 | 31.91±3.36 |
| Francis' Compound | W25 | 4º 57′ 26.55″ | 6º 41′ 57.65″ | 54.31±2.74 | BDL | 18.43±2.17 |
| Chikweri's Compound | W26 | 4º 57′ 33.39″ | 6º 41′ 10.43″ | 63.85±3.23 | 1.49±0.09 | 3.82±0.48 |
| Wukezie's Compound | W27 | 4º 57′ 49.43″ | 6º 41′ 44.15″ | 125.96±6.31 | 10.06±0.58 | 33.41±3.60 |
| Agbe's Compound | W28 | 4º 57′ 49.87″ | 6º 41′ 52.31″ | 76.93±3.87 | 4.54±0.26 | 22.05±2.46 |
| **Min** | | | | **11.69±0.59** | **0.13±0.01** | **0.20±0.03** |
| **Max** | | | | **161.91±8.16** | **10.06±0.58** | **33.41±3.60** |
| **Mean** | | | | **71.51** | **2.73** | **9.67** |
| **SD** | | | | **46.79** | **2.03** | **9.95** |
| **WAV** | | | | **10** | **0.1** | **10** |

*****World Average Value.
(±) Associated uncertainty error.


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BDL = Below detectable level
SD = Standard Deviation

**Table 2: Total Annual Effective Dose (mSv y$^{-1}$) Due to Ingestion of $^{40}K$, $^{232}Th$ and $^{238}U$ in Well Water Samples from Rumuekpe Communities for the Six Age Groups**

| | Annual Effective Dose (mSv y$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Infant | | Children | | Adult | |
| **Sample Code** | **(0 –1) yr** | **(1-2 )yr** | **(2 – 7) yr** | **(7 – 12) yr** | **(12 – 17) yr** | **> 17 yr** |
| W1 | 3.387 | 0.920 | 0.633 | 0.492 | 0.797 | 0.722 |
| W2 | 4.327 | 1.338 | 0.922 | 0.733 | 1.252 | 1.055 |
| W3 | 3.753 | 1.517 | 1.002 | 0.797 | 1.390 | 1.095 |
| W4 | 1.615 | 0.682 | 0.413 | 0.298 | 0.443 | 0.390 |
| W5 | 0.904 | 0.603 | 0.334 | 0.222 | 0.297 | 0.254 |
| W6 | 4.455 | 2.708 | 1.588 | 1.156 | 1.807 | 1.424 |
| W7 | 1.084 | 1.144 | 0.625 | 0.418 | 0.594 | 0.354 |
| W8 | 1.867 | 1.508 | 0.809 | 0.538 | 0.716 | 0.592 |
| W9 | 2.628 | 0.763 | 0.529 | 0.421 | 0.714 | 0.615 |
| W10 | 3.607 | 1.506 | 0.648 | 0.172 | 1.174 | 0.967 |
| W11 | 3.002 | 2.928 | 1.649 | 1.188 | 1.881 | 1.367 |
| W12 | 7.464 | 3.500 | 2.172 | 1.643 | 2.681 | 2.154 |
| W13 | 2.904 | 1.019 | 0.650 | 0.486 | 0.756 | 0.668 |
| W14 | 4.572 | 3.039 | 1.673 | 1.129 | 1.528 | 1.300 |
| W15 | 3.691 | 2.992 | 1.678 | 1.185 | 1.789 | 1.371 |
| W16 | 1.457 | 0.701 | 0.431 | 0.324 | 0.522 | 0.420 |
| W17 | 3.565 | 2.828 | 1.509 | 0.990 | 1.282 | 1.084 |
| W18 | 2.275 | 0.882 | 0.551 | 0.408 | 0.633 | 0.550 |
| W19 | 4.739 | 2.656 | 1.505 | 1.044 | 1.469 | 1.262 |
| W20 | 2.866 | 1.245 | 0.809 | 0.644 | 1.123 | 0.873 |
| W21 | 4.879 | 2.797 | 1.595 | 1.109 | 1.581 | 1.249 |
| W22 | 4.406 | 2.161 | 1.307 | 0.963 | 1.510 | 1.237 |
| W23 | 3.937 | 2.204 | 1.334 | 1.000 | 1.632 | 1.269 |
| W24 | 4.352 | 2.519 | 1.591 | 1.258 | 2.231 | 1.636 |
| W25 | 1.758 | 1.640 | 0.954 | 0.715 | 1.202 | 0.851 |
| W26 | 2.210 | 0.930 | 0.790 | 0.556 | 0.810 | 0.664 |
| W27 | 11.94 | 5.046 | 3.226 | 2.492 | 4.169 | 3.356 |
| W28 | 6.049 | 2.891 | 1.814 | 1.717 | 2.334 | 1.834 |
| **Min.** | **0.904** | **0.603** | **0.334** | **0.222** | **0.297** | **0.254** |
| **Max** | **11.94** | **5.046** | **3.226** | **2.492** | **4.169** | **3.356** |
| **Mean** | **3.70** | **1.95** | **1.17** | **0.86** | **1.37** | **1.09** |
| **SD** | **2.20** | **1.08** | **0.65** | **0.52** | **0.81** | **0.64** |
| **WAV** | **0.26** | | **0.20** | | **0.10** | |


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Table 3: Estimated Radiological Hazard Due to Ingestion of Radionuclides ($^{40}$K, $^{232}$Th and $^{238}$U) in Well Water Samples from some selected communities in Rumuekpe.

| Sample Code | D (nGyh$^{-1}$) | AEDE (mSvy$^{-1}$) | AGDE (Bql$^{-1}$) | Raeq (Bql$^{-1}$) | ELCR (E-3) |
|---|---|---|---|---|---|
| W1 | 3.10 | 3.80 | 21.93 | 6.91 | 13.29 |
| W2 | 6.73 | 8.25 | 33.88 | 14.82 | 28.87 |
| W3 | 5.21 | 6.39 | 62.27 | 20.36 | 11.87 |
| W4 | 2.16 | 2.65 | 15.65 | 4.51 | 9.29 |
| W5 | 1.74 | 2.10 | 12.87 | 3.42 | 7.36 |
| W6 | 12.78 | 15.68 | 89.58 | 26.62 | 54.87 |
| W7 | 4.83 | 5.92 | 34.38 | 9.68 | 20.72 |
| W8 | 3.50 | 4.30 | 34.87 | 9.30 | 15.04 |
| W9 | 3.54 | 4.34 | 24.47 | 7.84 | 15.19 |
| W10 | 7.07 | 8.67 | 49.22 | 15.11 | 30.33 |
| W11 | 16.3 | 19.99 | 113.24 | 33.71 | 69.96 |
| W12 | 17.54 | 21.52 | 121.88 | 37.30 | 75.31 |
| W13 | 2.48 | 3.04 | 15.62 | 7.42 | 10.64 |
| W14 | 9.14 | 11.20 | 67.19 | 18.03 | 39.21 |
| W15 | 13.91 | 17.05 | 96.96 | 28.49 | 59.69 |
| W16 | 3.40 | 4.17 | 23.69 | 7.20 | 14.59 |
| W17 | 8.08 | 9.91 | 60.03 | 16.24 | 32.17 |
| W18 | 3.14 | 3.85 | 22.28 | 6.67 | 13.48 |
| W19 | 4.05 | 4.96 | 60.02 | 16.54 | 17.37 |
| W20 | 7.89 | 9.68 | 53.89 | 17.05 | 33.87 |
| W21 | 14.13 | 17.33 | 67.14 | 18.74 | 60.64 |
| W22 | 10.70 | 13.12 | 66.57 | 19.87 | 45.92 |
| W23 | 11.78 | 14.44 | 81.63 | 24.86 | 50.54 |
| W24 | 18.13 | 22.24 | 123.33 | 38.84 | 77.83 |
| W25 | 10.78 | 13.22 | 74.00 | 22.61 | 46.27 |
| W26 | 5.33 | 6.53 | 33.61 | 10.87 | 22.86 |
| W27 | 26.73 | 32.78 | 184.84 | 57.50 | 114.72 |
| W28 | 16.01 | 19.64 | 111.28 | 34.47 | 68.73 |
| **Min** | **1.74** | **2.10** | **12.87** | **3.42** | **7.36** |
| **Max** | **26.73** | **32.78** | **184.84** | **57.50** | **114.72** |
| **Mean** | **8.94** | **10.96** | **62.73** | **19.11** | **37.88** |
| **SD** | **6.19** | **7.59** | **41.35** | **12.64** | **26.90** |
| **WAV** | **1.0** | **0.10** | **1.0** | **370.0** | **0.29E-3** |

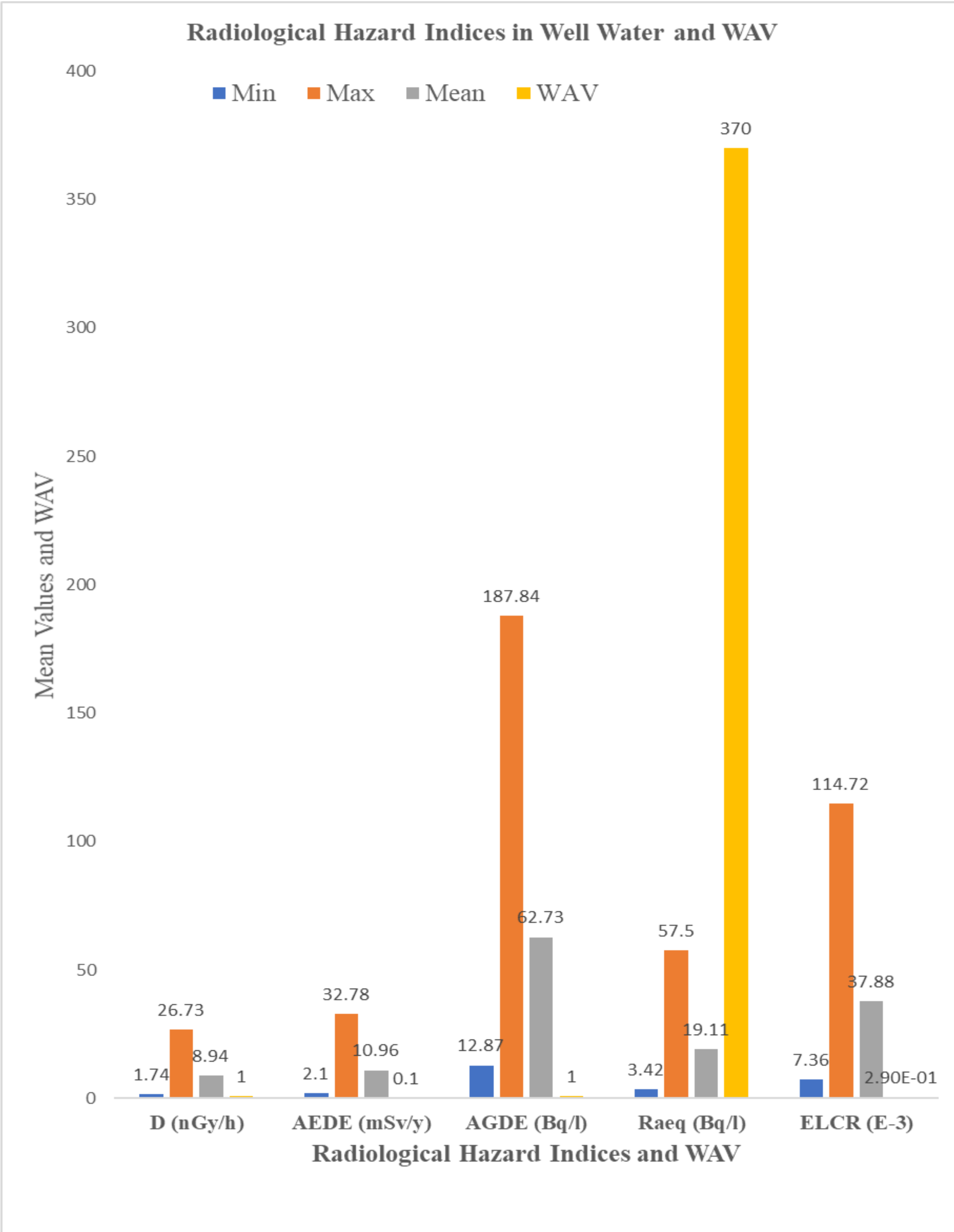


**Fig. 1: Mean Radiological Hazards in Well Water Samples and WAV**


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## Discussion

A study on natural radioactivity and radiological hazard due to intake of well water samples from some randomly selected communities in Rumuekpe, Rivers State, Nigeria, was carried out. The presence of radionuclides ($^{40}K$, $^{232}Th$ and $^{238}U$) was detected with the aid of NaI gamma-ray spectrometry.

### Activity Concentration

Mean activity concentration of radionuclides: $^{40}K$, $^{232}Th$ and $^{238}U$ are 71.51, 2.73 and 9.67 $Bql^{-1}$ respectively. The minimum values of $^{40}K$ (11.69 $Bql^{-1}$), $^{232}Th$ (0.13 $Bql^{-1}$) and $^{238}U$ (0.2 $Bql^{-1}$, were recorded in W9, W7 and W4 respectively while maximum value of the radionuclides ($^{40}K$, $^{232}Th$ and $^{238}U$) of 161.91, 10.06 and 33.41 $Bql^{-1}$ respectively were recorded in W17, W27 and W27, respectively. The $^{232}Th$ was below detectable limit in W25, while $^{238}U$ was below detectable limit in W1 and W5. Mean activity concentration of $^{40}K$ and $^{232}Th$ are above internationally permissible limit of 10.0 and 0.1 $Bql^{-1}$ while that of $^{238}U$ is 3.3% below the recommended safe limit of 10.0$Bql^{-1}$(UNSCEAR, 2010; WHO, 2017). Results indicated that the well water samples are contaminated radiologically, polluted and unfit for human consumption. This might be due to oil and gas activities by multinational and international oil companies operating within the study area as well as illegal mining of crude oil, and bunkering activities (Ononugbo & Anyalebechi, 2017; Igbudu et al., 2023) within the communities.

### Total Annual Effective Dose (TAED)

Results in Table 2 revealed that TAED in infants (0-1and 1-2)y, children (2-7 and 7-12)y, and adults (12-17 and >17)y ranged from (0.904 to 11.94 and 0.603 to 5.046) $mSvy^{-1}$, (0.334 to 3.226 and 0.222 to 2.492) $mSvy^{-1}$, and (0.297 to 4.169 and 0.254 and 3.356) $mSvy^{-1}$ respectively. Minimum and maximum values were recorded in W5 and W27 respectively across the six different age groups. Mean TAED in infants (0-1and 1-2)y, children (2-7 and 7-12)y, and adults (12-17 and >17)y are (3.70 and 1.95) $mSvy^{-1}$, (1.17 and 0.86) $mSvy^{-1}$, and (1.37 and 1.09) $mSvy^{-1}$ respectively. Mean TAED are above the internationally recommended safe limits of 0.26, 0.20 and 0.10 $mSvy^{-1}$ for infants, children and adults respectively (UNSCEAR, 2010; WHO, 2017). The results indicate that the well water samples contain some naturally radioactive substances capable of causing health risks on its consumers.

### Absorbed Dose (AD)

Results in Table 3 revealed that absorbed dose ranged from 1.74 to 26.73 $nGyh^{-1}$, with minimum and maximum values being recorded in W5 and W27 respectively. The mean absorbed dose in this present study (8.94 $nGyh^{-1}$) exceeded the internationally recommended safe limit of 1.0 $nGyh^{-1}$ (UNSCEAR, 2010; WHO, 2017) (Fig.1). This implies that the well water samples are radiologically contaminated, polluted and unfit for human consumption.

### Annual Effective Dose Equivalent (AEDE)

The AEDE ranged from 2.10 to 32.78 $mSvy^{-1}$. The minimum and maximum values were recorded in W5 an W27 respectively while the mean AEDE is 10.96 $mSvy^{-1}$. The mean AEDE in this study exceeded the internationally recommended safe limit of 0.10 $mSvy^{-1}$(UNSCEAR, 2010; WHO, 2017). The results indicated that the well water supplies in this study are radiologically polluted and unsafe for consumption since they contain radiological hazards capable of causing health risks on its consumers.

### Annual Gonad Dose Equivalent (AGDE)

Results (Tab. 3) revealed that the AGDE due to intake of radionuclides in well water samples ranged from 12.87 to 184.84 $Bql^{-1}$, with mean value of 62.73 $Bql^{-1}$. The minimum and maximum values were recorded in W5 and W27 respectively. Results further revealed that the mean AGDE is far higher than the internationally recommended safe limit of 1.0 $Bql^{-1}$ (UNSCEAR, 2010; WHO, 2017). This also implies that the well water samples are unfit for human consumption since they contain radiological hazards that expose the consumers to some form of ionizing radiations with attendant health implications.

### Radium Equivalent (Raeq)

The results in Table 3 revealed that the radium equivalent ranged from 3.42 to 57.50 $Bql^{-1}$, with mean value of 19.11 $Bql^{-1}$. The minimum and maximum values were recorded in W5 and W27 respectively. Results further revealed that


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mean radium equivalent due to ingestion of well water samples is below recommended safe limit of 370.0 $Bql^{-1}$ (UNSCEAR, 2010; WHO, 2017). This means that the water samples do not presently contain radiological substances capable of causing health effects on humans due to radium equivalent. However, there is a possibility of its increased effect on humans due to continuous exposure to radiation (Igbudu et al., 2023).

**Excess Lifetime Cancer Risk (ELCR)**

Results revealed that minimum and maximum values of excess lifetime cancer risk are 7.36 and 114.72 E-3 respectively while the mean value is 37.88 E-3. Again, the minimum and maximum values were obtained from W5 and W27 respectively. The mean excess lifetime cancer risk due to intake of well water sample was found to have exceeded the recommended safe limit of 0.29 E-3 (UNSCEAR, 2010; WHO, 2017). The well water samples are harmful and unsafe for consumption since they contain radioactive substances capable of causing cancer on its consumers.

## Conclusion

A study to assess the natural radioactivity and radiological hazards in hand dug well water samples from some randomly selected communities in Rumuekpe, Emohua Local Government Area, Rivers State, Nigeria, was carried out, using Sodium Iodide (NaI) gamma-rays spectrometry system. The radionuclides ($^{40}K$, $^{232}Th$ and $^{238}U$) in the water samples were identified with the aid of NaI gamma-ray detector, while their activity concentrations were obtained with the aid of relevant mathematical relations stated earlier.

The study revealed that the mean activity concentration of $^{40}K$ and $^{232}Th$ are above the recommended safe limit of 10.0 $Bql^{-1}$ and 0.1 $Bql^{-1}$ respectively while that of $^{238}U$ was slightly below the recommended safe limit of 10.0 $Bql^{-1}$. The mean TAED in infants, children and adults are above the recommended safe limits of 0.26, 0.20 and 0.10 $mSvy^{-1}$ respectively. The mean absorbed dose (AD), annual effective dose equivalent (AEDE), annual gonad dose equivalent (AGDE) and excess lifetime cancer risk (ELCR) are above their recommended safe limits of 1.0 $nGyh^{-1}$, 0.10 $mSvy^{-1}$, 1.0 $Bql^{-1}$ and 0.29 E-3 respectively while the mean radium equivalent (Raeq) is below the recommended safe limit of 370 $Bql^{-1}$. The study generally revealed that the well water supplies from the study area are radiologically contaminated, polluted and unsafe for human consumption. This is because all the radiological parameters under study were found to be higher than the internationally recommended (UNSCEAR, 2010; WHO, 2017) safe limits.

## Recommendations

The authors recommend provision of alternative, clean and safe water supplies to the inhabitants of the area. Regular check-ups and adequate medical treatment of consumers of the well water samples, as well as further research on other sources of water supplies in the study area are also recommended.

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