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Assessing Ionizing Radiation Exposure Risks to Human Health in Wadi-B, Jere Oil Exploration Areas, Borno State, Nigeria

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Abstract

Ionizing radiation, emanating from decaying nuclides, poses potential biological harm to human organs. Wadi B, a village within the Jere local government area of Borno State, Nigeria, is currently undergoing oil exploration activities. This study was conducted to evaluate the outdoor gamma radiation levels at the Wadi B oil exploration site. Utilizing a portable hand dosimeter (Radiation Alert Inspector), gamma exposure levels (GEL) were measured across sixteen (16) spots within the exploration site. Results revealed that the gamma exposure levels measured in the boreholes FYM (1 to 8), range from 0.17- 0.27 Mr/hr, with an average of 0.21 Mr/hr while, the levels around the wells FYM (9 to 16) vary from 0.14- 0.25 Mr/hr, with an average of 0.18 Mr/hr. The estimated annual effective dose (AED) varied from 0.24528 to 0.47304 µSv/yr, averaging at 0.3460 µSv/yr. Notably, the average values of Total Dissolved Solids (TDS), Conductivity, and Gamma radiation exceeded the recommended limits established by the World Health Organization (WHO, 2006), which are 400 µS/cm for conductivity, (50-150) ppm for TDS, and 0.002 mR/hr for radiation doses, respectively. However, the calculated Excess Lifetime Cancer Risk (ELCR) values were lower than the proposed world average level of 70 µSv/yr by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). This study suggests a heightened risk of exposure to outdoor ionizing radiation among inhabitants residing near the study locations.

Keywords: AED; ELCR; Radionuclides; Radon gas; Ionisation Radiation.

I. INTRODUCTION

The contamination of the environment by radioactivity refers to an increase in natural background radiation due to human activities involving the use of naturally occurring or artificially produced radioactive substances [1]. This contamination can be sporadic, unintentional, or continuous. Ionizing radiation can cause mutations in the germ cells of various organisms, including fruit flies and mice [2–4]. However, there is currently no clear evidence of the trans-generational effects of radiation in humans. Radionuclides can be harmful to living organisms if they enter the body, as they can damage cells and cause mutations. Therefore, it is important to handle and dispose of them carefully to minimize potential risks to human health and the environment [4–7].

Ionizing radiation produced by decaying nuclides causes biological damage to human organs [8]. The U.S. Environmental Protection Agency (USEPA) is responsible for advising the government on radiation hazards and regulating certain sources of radioactivity in the environment [9]. Radiation is an unavoidable part of everyday life [10]. It is the energy that emits particles from a source or substance and travels through some material or space [11]. Excessive radiation exposure could result in adverse health effects such as cataracts of eye lenses, leukaemia, bone necrosis, bone cancer, and gene mutations.

Radon (^{222}Rn) is a radioactive gas naturally produced in rock, soil, and groundwater. It can cause radiation exposure to the stomach and lung tissues through ingestion and inhalation. Radon is a radioactive gas found in soil and rocks due to the decay of uranium. It can easily be emitted from the soil into water and is present everywhere [10]. The presence of radon in drinking water, combined with other sources of radon exposure, poses a significant hazard to human health [12]. Radon is a noble gas that occurs naturally in soil, rocks, water, and air. It comes from the breakdown of elements like uranium and is radioactive. Despite being colourless and odourless, it can form certain compounds, such as clathrates and complex fluorides, despite being chemically inert [13]. Radon is a radioactive gas that can cause cancer through ingestion and inhalation [14]. Radon gas is produced by the natural radioactive decay of uranium and other elements in bedrocks and soils. The three natural isotopes of radon are Radon-222, Radon-220, and Radon-219. Radon-222 is the most significant because it has a longer half-life of 3.8 days [15].

Residues are a mixture of various impurities and organic materials of different origins [16]. Residues around glaciers are highly enriched with radionuclides, which affect the levels of radioactivity in the surrounding ice caps8. Exposure to natural radionuclides and heavy metals through water sources can lead to deteriorating health. Radionuclides (^{238}U, ^{232}Th, ^{40}K) and heavy metals (Pb, Cr, Cd, As) in both surface and groundwater pose a threat to human health. Radioactive forms of elements, known as radionuclides, are atoms with unstable nuclei that emit energy in the form of radiation as they decay. Some radionuclides occur naturally in the environment, such as potassium-40, carbon-14, and uranium-238, while others are artificially produced through nuclear reactions, such as technetium-99m used in medical imaging and plutonium-239 used in nuclear weapons [1], [17], [18].

Numerous research has been conducted on exploring Gamma Radiation Limits (GEL) and contaminants present in potable water, alongside the assessment of associated annual effective cancer risks, both within Nigeria. Notably amongst these include determination of the concentrations of radionuclides and heavy metals and their transfer factor from soil to crops/vegetables in some agricultural soils in Barkin Ladi Area, Plateau State, Nigeria [19], estimation of excess life cancer risk and annual effective dose for boreholes and well water in Dutse, Jigawa State Nigeria [20], the assessment of radiation levels and radiological health hazards in Keffi dumpsite, Nasarawa State, Nigeria [21] and the study on the determination of heavy metals and radon concentration in soil and water samples from Wadi-B Jere oil exploration sites, Northeast Nigeria [1] where heavy metals and radon concentration was assessed emphasizing environmental contaminants rather than direct health risk from radiation, in contrast to this study which assesses the health risks associated with ionizing radiation exposure in the Wadi B Jere oil exploration areas and focusing on its potential impact on human health.

II. MATERIALS AND METHODS

A. *Study Area*

Wadi B is a remote and scarcely populated region, encompassing an area of around 13 square kilometres (sq km). The region's population is less than five hundred (500), and they have been compelled to leave their homes due to insurgency. Wadi B is situated on a flat terrain with no visible rocks, and the land is covered with dense forestation and dark brown clay soil. The coordinates of Wadi B are latitude N 12°9'30.001" to N 12°9'40.001" and longitude E 13°10'27.732" to E 13°10'30.341". Additionally, the region experiences an average temperature of about 26.9°C, which remains relatively constant throughout the summer and winter seasons [1].

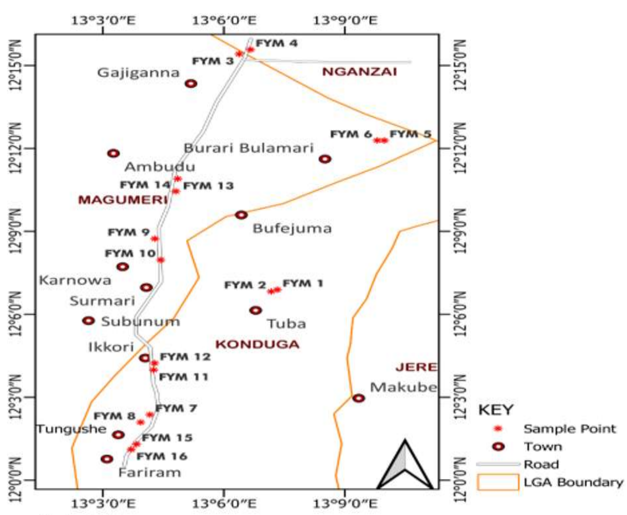

Fig. 1. Map of the study area showing sampling points [1].

The primary socio-economic activity of the area is agriculture, with most of the locals engaged in farming crops and livestock, as well as fishing and trading activities. It has three seasons: dry, winter, and wet season. The rainy season is from April to July, with high rainfall in June, July, and August.

The warmest months are October and November, while December and early February are the coldest. The area features tall trees and short grasses in the coastal savannah zone.

B. Materials

Materials used for this study include the radiation alert inspector (RAI), pH meter, temperature detector and a smartphone with GPS tracking capability.

1) Working principle of the Radiation Alert Inspector (RAI)

A Geiger-Muller (GM) counter is a device used to measure background radiation. It's included in the RAI meter. The counter works by using the principle of ionization of gases caused by radiation. The tube has a wire at the centre, connected to a direct current source, and the metal cylinder is connected to the other terminal [22]. When ionizing radiation generates ions and electrons, it creates an electric current. The incoming radiation produces ions between the wire and the metal cylinder, creating a current pulse. The counter amplifies these pulses, counts them, and displays the measured background radiation amount on a digital screen [21].

Plate 1. Radiation Alert Inspector (RAI).

The Radiation Alert Inspector (RAI) meter (see Plate 1) is a handheld, microprocessor-based radiation detector designed to detect potentially harmful ionizing alpha and beta particles and gamma and x-ray radiation. It has the following key features and specifications:

- Detection Capabilities: Alpha, beta, gamma, and x-ray radiation.
- Display: Four-digit LCD digital display showing millirem (mR) per hour and function indicators.
- Sensitivity: High sensitivity to many common radionuclides, optimized to detect small changes in radiation levels.
- Detector: Uses a 2” halogen-quenched, uncompensated Geiger-Mueller (GM) tube with a thin mica end window.
- Energy Sensitivity: Detects alpha particles down to 2.0 MeV, beta particles at 0.16 MeV with 25% detection efficiency at 1 MeV, and gamma and x-rays down to 10 keV through the end window and 40 keV minimum through the sidewall.
- Dimensions: 145 mm x 72 mm x 38 mm (5.7” x 2.8” x 1.5”).
- Weight: 327.4 g (11.55 oz).
- Power Source: 9-volt alkaline battery, providing approximately 2,160 hours of operation with continuous use in a normal background.

C. Methods

1) Sampling and data collection

Gamma exposure levels were measured using the Radiation Alert Inspector (RAI) meter. The meter was calibrated, with the calibration conducted in Wadi B to ensure the indices accurately reflected the local radiation conditions of the area and placed at one meter ($1\,m$) above the designated spots during the measurement process, and the gamma exposure level of each chosen point was recorded. The coordinates (latitude and longitude) of the sampling site have been accurately captured using a smartphone equipped with a GPS meter to ensure precise location tracking.

2) Radiation Hazard Indices

Various gamma radiation doses are calculated to evaluate potential health risks to the public. The Gamma Exposure Levels (GEL) are utilized to determine the Absorbed Dose (D) and Annual Effective Dose (AED), while the Excess Lifetime Cancer Risk (ELCR) estimates the probability of developing cancer over a lifetime. These values are derived using the following equations [1, 20]

$$1\frac{\mu Sv}{hr} = 10Mr/hr\ (GA) \qquad (1)$$

Annual Effective Dose Rate (AEDR) can be computed using (2).

$$AEDR(mSvy^{-1}) = EDR(\mu Sv/hr) \times T \times OF/1000 \qquad (2)$$

Where EDR is the effective dose rate in $\frac{\mu Sv}{hr}$, T is the time of exposure per year (8760 hours), OF = outdoor occupancy factor (0.2) and 1000 is the conversion coefficient factor.

Excess lifetime cancer risk is determined from (3).

$$ELCR = AEDE \times DL \times RF \qquad (3)$$

Where AEDE($mSvy^{-1}$) is the annual effective dose rate given in (2), DL is the average duration of life by an individual (70 years) and RF = risk factor ($0.05\ Sv^{-1}$)

While the Absorbed dose by organ D_{organ} is given by (4).

$$D_{organ} = AEDE \times OF \qquad (4)$$

Where AEDE($mSvy^{-1}$) is the annual effective dose rate given in (2) and OF is the outdoor occupancy factor (0.2) [1], [17], [18].

Tables I and II depict the sample ID and their corresponding geo coordinates, and the values of the Total Dissolved Solids (TDS), Gamma exposure level (GEL) and conductivity across the oil mining sites in the study area, respectively, while Fig.

2 shows the variation of conductivity ($\mu S/cm$), TDS, and Radiation (Mr/hr).

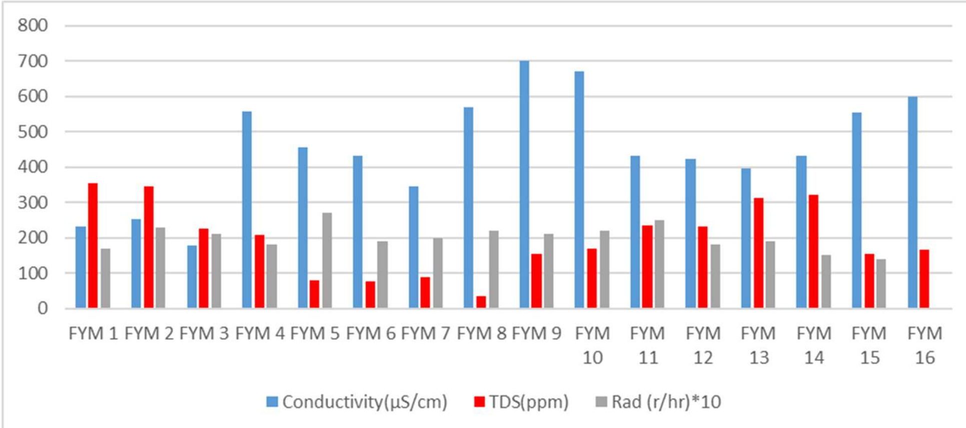

Fig. 2. Variation of Conductivity (μS/cm), TDS, and Radiation (r/hr).

Table I. Sample ID and Geo Coordinates

Sample ID	Geo coordinates
FYM 1	12°6'53.25085"N, 13°7'19.61945"E
FYM 2	12°6'49.47802"N, 13°7'10.60079"E
FYM 3	12°15'25.04001"N, 13°6'22.834"E
FYM 4	12°15'34.57371"N, 13°6'39.65708"E
FYM 5	12°12'17.35898"N, 13°9'58.80748"E
FYM 6	12°12'17.46279"N, 13°9'48.3356"E
FYM 7	12°2'22.13124"N, 13°4'10.10448"E
FYM 8	12°2'5.*56946"N*, 13°3'56.27113"E
FYM 9	12°8'44.06416"N, 13°4'17.42732"E
FYM 10	12°7'58.13364"N, 13°4'26.22148"E
FYM 11	12°3'59.2829"N, 13°4'15.55527"E
FYM 12	12°4'13.90231"N, 13°4'16.87572"E
FYM 13	12°10'54.10177"N, 13°4'51.49955"E
FYM 14	12°10'27.00926"N, 13°4'48.56776"E
FYM 15	12°1'18.0522"N, 13°3'50.21564"E
FYM 16	12°1'6.52432"N, 13°3'42.30862"E

Table II. TDS, conductivity, and Gamma exposure level (GEL) across oil mining sites in the study area.

Sample ID	TDS (ppm)	GEL (Mr/hr)	Conductivity (μS/cm)
FYM 1	354	0.017	233
FYM 2	345	0.023	253
FYM 3	225	0.021	178
FYM 4	209	0.018	559
FYM 5	79	0.027	456
FYM 6	76	0.019	433
FYM 7	87	0.020	345
FYM 8	33	0.022	570
FYM 9	153	0.021	701
FYM 10	168	0.022	670
FYM 11	234	0.025	432
FYM 12	233	0.018	423
FYM 13	312	0.019	396
FYM 14	322	0.015	432
FYM 15	154	0.014	556
FYM 16	165	0.015	600

The water sample's conductivity was measured using a conductivity meter to observe its relationship with radiation and total dissolved solids. The minimum conductivity value of 178 ($\mu S/cm$) was recorded at FYM 3 and the maximum value of 701 (μS/cm) was observed at FYM 9 with the mean value of conductivity 452.31 ($\mu S/cm$). Also, the gamma radiation dose of Wadi B was detected using a radiation alert meter, and the dose varied from 0.027 Mr/hr to 0.014 Mr/hr with an average value of 0.0195 Mr/hr. The total Dissolved Solids of the water samples ranged from 354 to 33 with an average of 196.81. The average values of TDS, Conductivity, and Gamma radiation all surpass the recommended limits set by the World Health Organization (WHO) which are 400 $\mu S/cm$ for conductivity, $(50-150)$ ppm for TDS, and 0.002 Mr/hr for radiation doses, respectively [10].

The experimental results for Temperature and pH values obtained from water samples across the oil mining sites within the study area are presented in Table III.

Table III. Result of the pH and Temperature values obtained from water samples obtained from the study area.

Sample ID	pH	Temperature(^{0}C)
FYM 1	10.00	23.62
FYM 2	10.01	23.50
FYM 3	9.60	22.00
FYM 4	10.50	28.31
FYM 5	6.40	26.76
FYM 6	6.22	26.00
FYM 7	5.33	27.42
FYM 8	6.23	33.98
FYM 9	12.76	35.78
FYM 10	13.21	34.56
FYM 11	13.08	24.32
FYM 12	13.65	25.12
FYM 13	7.87	23.00
FYM 14	7.54	23.11
FYM 15	10.45	27.67
FYM 16	10.65	28.00

Fig. 3 displays the temperature and pH variation from the water samples in the study area. To determine the temperature of the oil exploration site, a portable temperature detector was used. At points FYM 12 and FYM 7, the temperature was found to be in the range of 35.78 to 22.00, respectively, with an average temperature of 27.07. The pH meter was utilized to analyze the power of hydrogen in the water sample. At points FYM 12 and FYM 7, the pH values ranged from 13.65 to 5.33, respectively, with an average pH value of 9.59, which can be seen in Table III. These values exceeded the recommended limit of 8.00 set by WHO for effective disinfection with chlorine and were above the value of 6.5 to 8.5 recommended by the Environmental Protection Agency (EPA) for all living organisms [21].

Fig. 4 above shows the values for Dose, GEL, AEDE, and ELCR. The dose value ranges from 0.014 to 0.027 with a mean value of 0.01975, while the GEL values range from 0.14 to 0.27 with a mean value of 0.1975. Also, the AEDE values range from 0.245 to 0.473 with a mean value of 0.3460, and the ELCR values range from 0.86 to 1.66 with a mean value of 1.04244 (see Table IV). These values exceed the recommended limit of the world average value of 1.45×10^{-3} and the standard value of 0.29×10^{-3}(by factors not less than 1.97 units) [23]. However, none of the samples had an AED of up to the 1mSv/y recommended dose limit for members of the public [21].

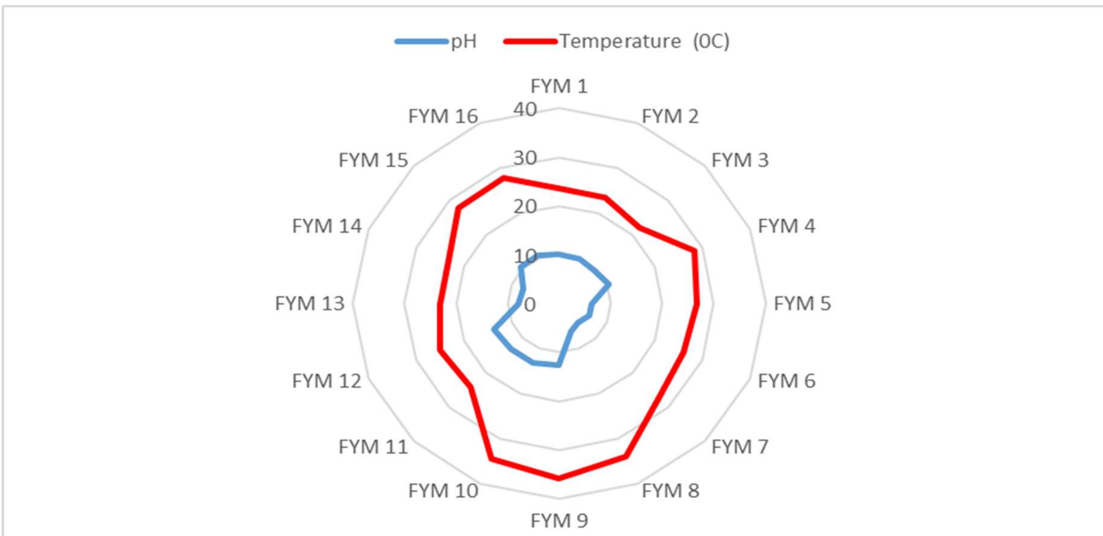

Fig. 3 Results of Temperature and pH values from water samples obtained from the study area.

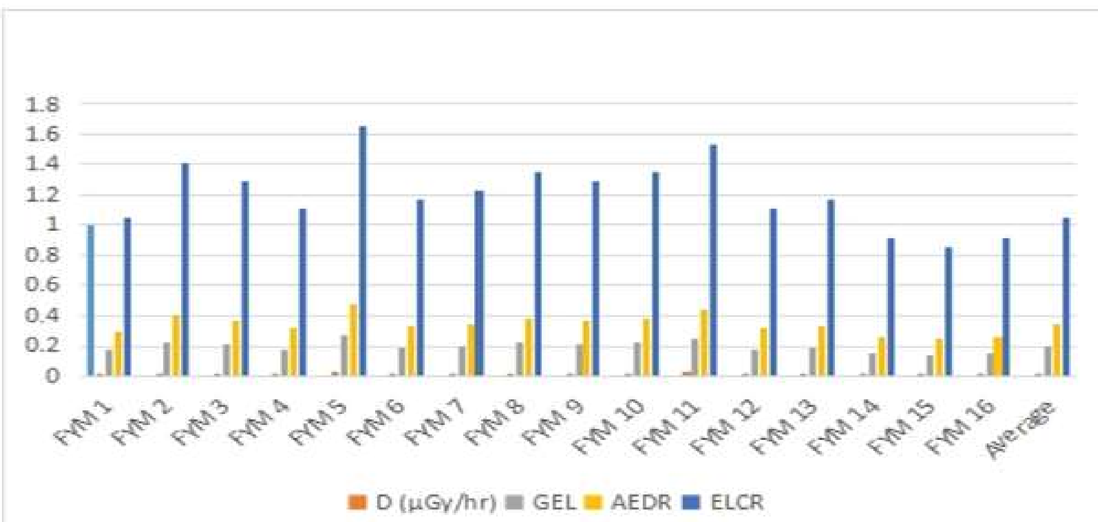

Fig. 4. Gamma exposure levels (GEL), Absorb Dose (D), Annual Effective Dose (AED), and Excess Lifetime Cancer Risk (ELCR).

Table IV. Gamma exposure levels (GEL), Absorb Dose (D), Annual Effective Dose (AED), and Excess Lifetime Cancer Risk (ELCR) were measured across oil mining sites in the study area.

Sample ID	D (µGy/hr)	GEL	AEDR	ELCR
FYM 1	0.017	0.17	0.29784	1.04244
FYM 2	0.023	0.23	0.40296	1.41036
FYM 3	0.021	0.21	0.36792	1.28772
FYM 4	0.018	0.18	0.31536	1.10376
FYM 5	0.027	0.27	0.47304	1.65564
FYM 6	0.019	0.19	0.33288	1.16508
FYM 7	0.020	0.20	0.35040	1.22640
FYM 8	0.022	0.22	0.38544	1.34904
FYM 9	0.021	0.21	0.36792	1.28772
FYM 10	0.022	0.22	0.38544	1.34904
FYM 11	0.025	0.25	0.43800	1.53300
FYM 12	0.018	0.18	0.31536	1.10376
FYM 13	0.019	0.19	0.33288	1.16508
FYM 14	0.015	0.15	0.26280	0.91980
FYM 15	0.014	0.14	0.24528	0.85848
FYM 16	0.015	0.15	0.26280	0.91980
min	0.014	0.14	0.24528	0.85848
max	0.027	0.27	0.47304	1.65564
Average	0.01975	0.1975	0.3460	1.04244

III. Conclusion

The gamma exposure levels measured in the boreholes FYM (1 to 8), range from 0.17- 0.27 Mr/hr, with an average of 0.21 Mr/hr, while the levels around the wells FYM (9 to 16) vary from 0.14-0.25 Mr/hr, with an average value of 0.18 Mr/hr which is slightly below the borehole average value. No notable correlation has been identified between gamma exposure levels and site altitudes. Based on estimated annual effective dose values, individuals who reside within or visit the sampling areas for water collection and household purposes are at risk of outdoor gamma radiation exposure. However, the Excess Lifetime Cancer Risk values for all sampling points are significantly below the WHO-proposed world average reference level and well below the UNSCEAR proposed reference limit of 70 µSv/yr. It is recommended that future research with larger sample sizes and varied sampling techniques be conducted to gain a more comprehensive understanding of the potential health hazards posed by background gamma radiation exposure in this region. The implications of this study are multifaceted and can be summarized as follows:

1) Public Health Assessment: While the gamma radiation exposure levels are relatively low and fall below international safety thresholds, the study highlights the need for ongoing monitoring of environmental radiation, especially for communities that may be exposed regularly.
2) Regulatory Framework: The findings can inform local health authorities and policymakers about the radiation exposure levels in the region. Although current levels are considered safe, understanding the local environment helps in developing guidelines or recommendations for public health safety.
3) Community Awareness: The study underscores the importance of informing residents about the radiation levels in their environment. Increased awareness can empower communities to make informed decisions regarding their water collection and outdoor activities.
4) Research Directions: The recommendation for further research indicates gaps in the current understanding of gamma radiation exposure and its health impacts. Future studies could explore long-term exposure effects, dose-response relationships, and include diverse geographic and demographic factors.
5) Environmental Monitoring: The study suggests that establishing a regular monitoring program could provide valuable data to track changes in radiation levels over time and assess potential risks, especially in the context of environmental changes or industrial activities.
6) Risk Communication: The findings can guide how risks are communicated to the public. Emphasizing that the risks are below significant thresholds can help alleviate community concerns while still advocating for continued vigilance.

Overall, the study serves as a foundation for enhancing knowledge about background gamma radiation exposure and its potential health implications while advocating for informed public health practices and future research initiatives.

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