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Geospatial Mapping of Background Ionizing Radiation in an Operational Quarry in Modakeke, Osun State, Nigeria

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Abstract

This study investigates the levels of background ionizing radiation in and around a quarry, focusing on geospatial radiation mapping to highlight "hotspots" within the quarry site. Using a portable FNIRSI GC-01 Geiger counter, ambient radiation dose rates were measured at 30 sampling points within the quarry. The results revealed that annual effective dose rates (AEDR), ranged from 1.23 mSv/year to 3.68 mSv/year, with 40% of the sampling points exceeding 2.5 mSv/year. Geospatial analysis identified distinct hotspots, particularly in the North-Eastern and central regions of the quarry. Compared to the global average of 2.4 mSv/year, approximately 43% of the sampling points exhibited elevated radiation levels, raising concerns about occupational exposure for quarry workers. The findings underscore the importance of regular monitoring and targeted mitigation strategies, such as zoning high-risk areas and implementing rotational work schedules, to minimize health risks. This study highlights the utility of geospatial radiation mapping in quarries to safeguard occupational health.

INTRODUCTION

Mineral ores, rocks, and soil play host to naturally occurring radioactive materials (NORMs) (Ademila and Ugo, 2017; Ademila, 2018). These radionuclides, mainly, uranium (^{235}U, ^{238}U), thorium(^{232}Th), and potassium (^{40}K) are native to various geological formations (ICRP, 2007; AUA and DRET, 2015; Krishnamoorthy *et al.*, 2018; Brusseau and Artiola, 2019; Adebiyi *et al.*, 2021). Quarries are significant sources of natural background ionizing radiation due to the excavation and processing of rocks and soil containing these naturally occurring radioactive materials (Omonokhua, Benedict and Daniel, 2022). When these radionuclides are brought to the surface during quarrying activities, they elevate the exposure levels of ionizing radiation in the surrounding environment (Gbenu *et al.*, 2016; Nduka *et al.*, 2022).

The sources of radiation in quarries, primarily, include NORMs, the emissions of radon gas, and the environmental redistribution of radionuclides (Ningappa, Sannappa and Karunakara, 2008; James *et al.*, 2020; Ononugbo and Anekwe, 2020; Nduka *et al.*, 2022; Waqar *et al.*, 2022). In regions with igneous and metamorphic rock formations, such as granite and basalt, quarries often have elevated uranium and thorium concentrations (Ademila, 2018). Furthermore, radon, a decay product of uranium, can be released into the atmosphere, contributing to elevated ionizing radiation levels in quarries. Additionally, quarrying activities lead to the redistribution of radionuclides through dust, water runoff, and rock processing, potentially contaminating soil, air, and water in its vicinity (Shittu *et al.*, 2015; Ademila and Ugo, 2017; Ademila, 2018; Brusseau and Artiola, 2019).

Studies have shown that radiation levels near quarries are often higher than in non-quarry areas (Brusseau and Artiola, 2019; Ekong *et al.*, 2019; Nduka *et al.*, 2022). Annual effective dose rates in these areas have been found, sometimes, to exceed the global population average of 2.4 mSv/year (ICRP, 1994). Radon emissions can also lead to elevated indoor radiation levels in nearby homes, especially those built with quarry materials (Ononugbo, Avwiri and Tutumeni, 2002; Boumala *et al.*, 2019; Azhdarpoor *et al.*, 2021). Furthermore, leachates from quarried rocks can introduce radionuclides into groundwater and surface water systems, causing increased contamination (Krishnamoorthy *et al.*, 2018; Adebiyi *et al.*, 2021; Molua, 2024).

Although ionizing radiation has practical applications in medicine, industry, and research, its potential health risks cannot be overemphasized. Acute exposure to high radiation levels is a wellknown health hazard, however, chronic exposure to low levels, such as those found near quarries, also poses risks, including an increased likelihood of cancer, particularly in critical organs like the lungs and bone marrow (ICRP, 1991, 2007; Benson and Ugbede, 2018; Penabei *et al.*, 2018). Furthermore, besides radiological risks, uranium and other radionuclides can also be chemically toxic, leading to kidney damage and other health outcomes. Given these risks, international bodies like the International Commission on Radiation Protection (ICRP) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) emphasize the need for regular monitoring and assessment to ensure radiation exposure remains as low as reasonably achievable (ALARA) (ICRP, 1994; UNSCEER, 2000; UNSCEAR, 2008; AUA and DRET, 2015; Chiegwu *et al.*, 2022; Omonokhua, Benedict and Daniel, 2022).

Mitigation efforts include regularly monitoring radiation levels, implementing occupational safety measures, and managing environmental impacts (AUA and DRET, 2015). This includes measuring ambient dose rates, radon concentrations, and radionuclide activity in soil and water. Protective measures for workers, such as ventilation systems and personal protective equipment, are essential. Additionally, environmental management strategies like dust control (AUA and DRET, 2015) can also be employed.

This study investigates background ionizing radiation levels in and around a quarry to evaluate potential health impacts. By assessing dose rates, this research aims to produce a radiation contour map in and around the quarry highlighting hotspots around the quarry.

METHODOLOGY

Ambient radiation dose rates within and surrounding the quarry were assessed using a portable FNIRSI GC-01 Geiger counter, a nuclear radiation detector designed to measure x-rays, gamma (γ) rays, and beta (β) particles. The instrument provides readings in multiple units, including microsieverts per hour (μSv/h), micrograys per hour (μGy/h), milliroentgens per hour (mR/h), counts per second (cps), and counts per minute (cpm). It operates within a gamma energy detection range of 48 keV to 1.5 MeV and exhibits a sensitivity of 80 cpm.

For this study, on-site measurements of average airborne dose rates (AVDR) were recorded in μSv/h. All AVDR values (recorded in μSv/h) were subsequently converted to mSv/h. At each sampling location, data were collected over a five-minute interval to determine mean radiation levels, with GPS coordinates logged to geolocate all points. The measured external dose rates were subsequently converted to annual effective dose rates (AEDR) for whole-body exposure (mSv/year) using the formula (Taskin *et al.*, 2009; Rafique *et al.*, 2014):

$$AEDR(mSvy^{-1}) = 24 \times 365(h/y)AVDR(mSv/h)$$

RESULTS AND DISCUSSION

Results

The geolocation and annual effective dose rates (AEDR) for 30 sampling points within the quarry are presented in Table 1. The AEDR values ranged from 1.23 mSv/year (Point 7) to 3.68 mSv/year (Point 11), indicating significant spatial variability. Notably, 40% of the sampling points (e.g., Points 11, 13, 17, 19, and 24) exhibited AEDR values exceeding 2.5 mSv/year, while 33% fell below 2.0 mSv/year. Geospatial analysis revealed clusters of elevated AEDR in the North-Eastern and central regions of the quarry (e.g., Points 11–13 and 16–17), whereas lower values were concentrated in the South-Western areas (e.g., Points 6–7 and 28–30).

Table 1: Showing the geolocation of the sampling points and the annual effective dose rates (AEDR).

Points	long	lat	AEDR(mSv/y)
1	4.53830	7.46773	1.84
2	4.53830	7.46751	2.01
3	4.53790	7.46676	1.75
4	4.53734	7.46718	2.28
5	4.53726	7.46701	2.28
6	4.53720	7.46701	1.40
7	4.53818	7.46708	1.23
8	4.53852	7.46690	2.28
9	4.53833	7.46674	2.45
10	4.53860	7.46707	2.28
11	4.53868	7.46671	3.68
12	4.53885	7.46668	3.24
13	4.53890	7.46676	3.50
14	4.53910	7.46713	1.84
15	4.53893	7.46742	2.01
16	4.53919	7.46734	2.45
17	4.53920	7.46738	3.15
18	4.53910	7.46751	2.72
19	4.53914	7.46753	3.07
20	4.53911	7.46757	2.19
21	4.53932	7.46766	2.19
22	4.53949	7.46753	2.19
23	4.53948	7.46755	2.72
24	4.53955	7.46768	2.54
25	4.53929	7.46781	2.80
26	4.53932	7.46774	2.19
27	4.53909	7.46775	2.54
28	4.53886	7.46778	1.84
29	4.53877	7.46786	2.01
30	4.53873	7.46783	1.84

Figure 1 compares measured AEDR values and the world average (2.4 mSv/y) (UNSCEAR, 2008; CNSC, 2020). Approximately 43% of the sampling points surpassed the 2.4 mSv/y mark, highlighting localized zones of heightened radiation exposure. Figure 2, the radiation contour map, further visualizes these disparities, identifying distinct “hotspots” in the North Eastern quadrant of the quarry site.

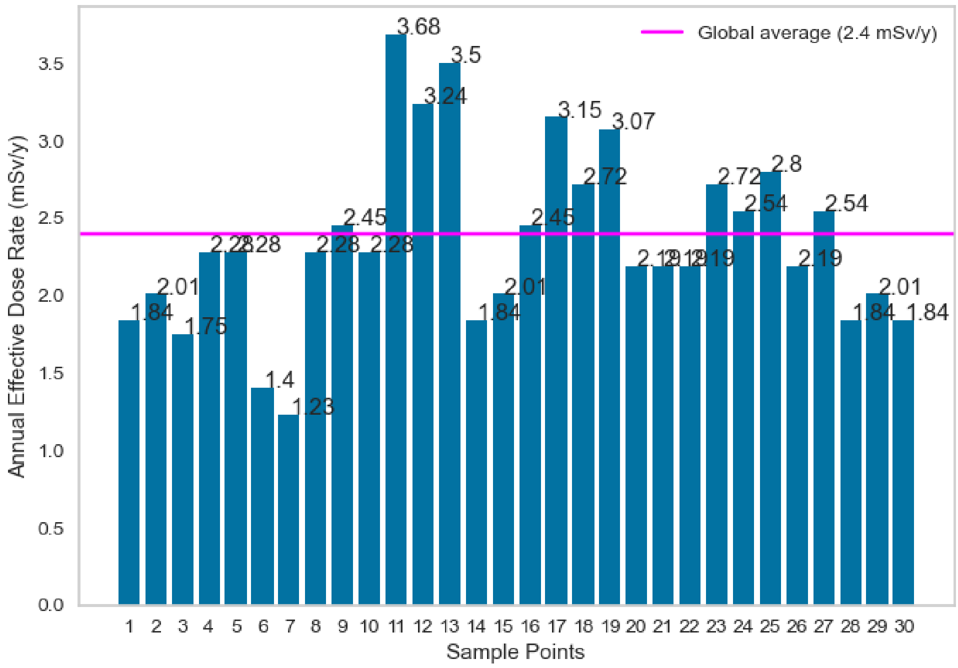

Figure 1: The annual effective dose rates at the sampling points compared with the world average (2.4 mSv/y)

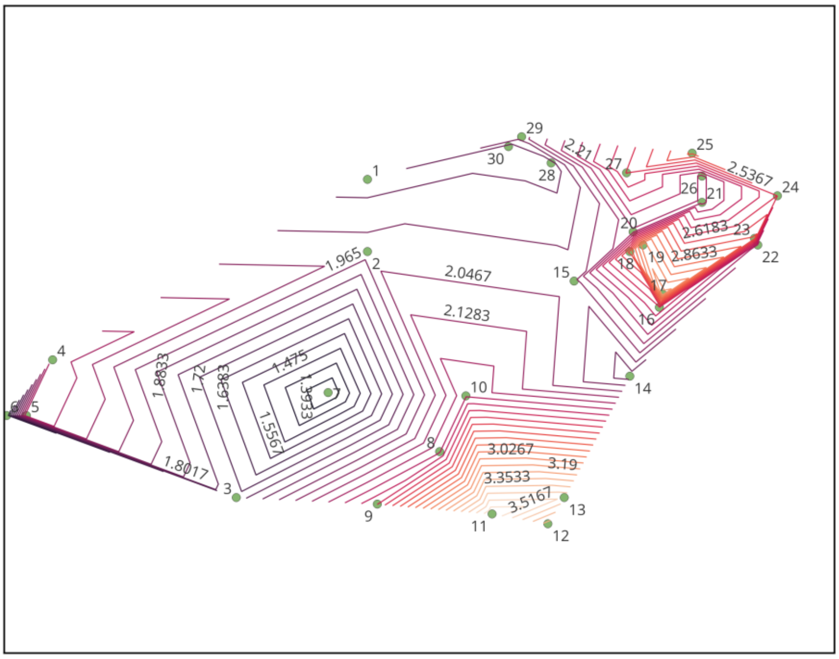

Figure 2: Radiation contour map of the quarry, showing the sampling points and the radiation contours.

DISCUSSION

The observed variability in AEDR across the quarry underscores the influence of localized geological and anthropogenic factors. Elevated radiation levels, particularly in the North-Eastern regions of the quarry (Points 11–13, 16–17), may stem from naturally occurring radioactive materials (NORM), such as uranium- or thorium-bearing minerals, which are often mobilized during quarrying activities. The abrupt drop in AEDR at adjacent points (e.g., Point 6 vs. Point 5) suggests micro-scale

heterogeneity in mineral distribution, possibly influenced by sediment deposition or mechanical sorting during excavation.
Compared to global averages, the higher AEDR values at some of the sampling points raise concerns regarding occupational exposure for quarry workers. In summary, while the overall radiation levels at the quarry are comparable to the global average, the identification of localized hot zones underscores the need for targeted monitoring and mitigation strategies.
Mitigation strategies, such as zoning high-risk areas and implementing rotational work schedules, are recommended to minimize health risks for personnel. This study highlights the importance of geospatial radiation mapping in quarries to safeguard occupational health.

CONCLUSION

Further research may be necessary to unravel the interplay between quarrying practices and environmental radioactivity.
Limitations of this study include a single sampling campaign and restricted spatial coverage. Future research could focus on detailed radionuclide characterization in these zones and evaluating the long-term exposure risks to inform effective environmental and public health management practices.
The findings of this study reveal significant spatial variability in background ionizing radiation levels within the quarry, with certain areas exhibiting elevated annual effective dose rates (AEDR) that exceed global averages. The identification of hotspots, particularly in the North-Eastern and central regions, underscores the influence of localized geological factors, such as the presence of uranium- and thorium-bearing minerals, as well as the impact of quarrying activities on the redistribution of radionuclides. The elevated radiation levels in these zones raise concerns about potential health risks for quarry workers, particularly from chronic exposure to low levels of ionizing radiation, which is associated with an increased likelihood of cancer and other health complications.
To mitigate these risks, it is recommended that quarry operators implement targeted monitoring and mitigation strategies, such as zoning high-risk areas, improving ventilation systems, and adopting rotational work schedules to limit prolonged exposure. Additionally, further research is needed to characterize the specific radionuclides present in these "hotspots" and to evaluate the long-term exposure risks for both workers and nearby communities. This study emphasizes the importance of geospatial radiation mapping as a tool for safeguarding occupational health and guiding effective environmental management practices in quarries.

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