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Evaluation of Ambient Gamma Radiation Levels and Associated Radiological Health Risks in Selected Block Industries of Dutsin-Ma Local Government Area, Katsina State, Nigeria

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ABSTRACT
Ambient gamma radiation arising from naturally occurring radioactive materials (NORM) in geological formations and construction materials contributes to occupational radiation exposure in block-manufacturing industries. This study evaluated ambient gamma radiation levels and associated radiological health risks in seventeen selected block industries in Dutsin-Ma Local Government Area, Katsina State, Nigeria. Indoor and outdoor ambient gamma dose rates were measured in situ using a calibrated Bosean F-S 5000 Geiger-Müller radiation survey meter, while the geographical coordinates of each sampling location were recorded using a handheld Global Positioning System (GPS). Annual Effective Dose (AED) and Excess Lifetime Cancer Risk (ELCR) were estimated following the recommendations of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the International Commission on Radiological Protection (ICRP). Statistical analyses, including descriptive statistics, Shapiro–Wilk normality tests, paired-samples *t*-tests, and Pearson correlation analysis, were performed using IBM SPSS Statistics 26.0. The measured indoor and outdoor ambient gamma dose rates ranged from 0.1467–0.1900 $\mu Sv\ h^{-1}$ and 0.1067–0.1967 $\mu Sv\ h^{-1}$, with mean values of 0.165 ± 0.013 $\mu Sv\ h^{-1}$ and 0.162 ± 0.027 $\mu Sv\ h^{-1}$, respectively. Although these values exceeded the UNSCEAR worldwide average external terrestrial gamma dose rate, no statistically significant difference was observed between indoor and outdoor measurements ($p > 0.05$). The estimated annual effective doses remained well below the ICRP occupational dose limit of 20 $mSv\ y^{-1}$, while the corresponding ELCR values indicated low long-term radiological risk. The observed radiation levels are primarily attributable to naturally occurring radionuclides in construction materials rather than anthropogenic sources. Overall, the investigated block industries are radiologically safe under current operating conditions, providing valuable baseline data for environmental radiation monitoring, occupational health surveillance, and regulatory decision-making in Nigeria.

Keywords: Ambient gamma radiation, Background ionizing radiation, Block-manufacturing industries, Annual effective dose, Excess lifetime cancer risk, Occupational exposure

1.0 INTRODUCTION

Naturally occurring ionizing radiation remains the predominant source of human radiation exposure, contributing approximately 80% of the average annual dose received by the global population. It arises mainly from primordial radionuclides such as uranium-238 (^{238}U), thorium-232 (^{232}Th), potassium-40 (^{40}K) and their decay products, which are ubiquitously distributed in rocks, soils, building materials, air and groundwater (UNSCEAR, 2008, 2020). Gamma photons emitted by these radionuclides produce ambient background radiation whose intensity varies with geological formation, mineralogical composition, altitude, climate and anthropogenic activities (IAEA, 2018).

Background radiation comprises natural sources (terrestrial gamma radiation, cosmic rays, internal radionuclides and radon) and artificial sources (medical procedures, industrial applications, nuclear power generation and research) (UNSCEAR, 2020). Although natural background radiation is an unavoidable environmental component, prolonged exposure to elevated levels elevates the probability of stochastic health effects, particularly cancer induction from cumulative DNA damage (ICRP, 2007). Continuous monitoring of ambient gamma radiation is therefore a core element of environmental radiation-protection programmes worldwide.

1.1 Physics of Ambient Gamma Radiation and Naturally Occurring Radioactive Materials (NORM)

Ambient gamma radiation constitutes the penetrating electromagnetic component of the natural radiation field that reaches the Earth's surface. Primordial radionuclides belonging to the ^{238}U and ^{232}Th decay series, together with the singly occurring ^{40}K, emit gamma photons with energies typically ranging from a few tens of keV to approximately 2.6 MeV (the 2.614 MeV line of ^{208}Tl being the most energetic and highly penetrating). These photons interact with matter principally through the photoelectric effect, Compton scattering and, at higher energies, pair production. The resulting energy deposition in tissue is quantified as absorbed dose (Gy). Because gamma rays travel many metres in air, outdoor ambient dose rates reflect both the local radionuclide inventory in soil and rock and any contributions from building materials or industrial stockpiles.

Naturally occurring radioactive materials (NORM) are defined as materials that contain radionuclides of natural origin at concentrations elevated above typical background levels as a result of human activities (IAEA, 2013). In the construction sector the principal NORM carriers are cement, sand, gravel, laterite, clay, granite aggregates and crushed rock. Activity concentrations of ^{226}Ra (proxy for ^{238}U), ^{232}Th and ^{40}K in these materials commonly range from a few Bq kg^{-1} to several hundred Bq kg^{-1}, depending on the parent geology. Materials derived from granitic terrains or phosphate-rich deposits tend to exhibit the highest activities. Once incorporated into concrete blocks, the radionuclides continue to emit gamma radiation, contributing to both outdoor and indoor exposure fields. In addition, the decay of ^{226}Ra produces radon-222, which may accumulate indoors if ventilation is limited, although the present study focuses exclusively on external gamma exposure.

1.2 Occupational Exposure Pathways in Block Manufacturing Industries

Block manufacturing involves the continuous handling, storage and processing of large volumes of the above-mentioned aggregates. Workers are therefore exposed through several concurrent pathways:

i. External gamma irradiation from bulk stockpiles of sand, gravel, laterite and cement, and from freshly moulded and curing concrete blocks. Dose rates are highest in the immediate vicinity of the materials and decrease with distance according to the inverse-square law and attenuation in air (IAEA, 2013; Mubarak & Khalifa, 2021; Olarinoye et al., 2023; UNSCEAR, 2000).
ii. Prolonged occupancy within production sheds and outdoor yards. Typical working shifts of 8–10 hours per day, five or six days per week, result in occupancy factors substantially higher than those assumed for members of the public (ICRP, 2007; UNSCEAR, 2000).
iii. Secondary contributions from resuspended dust (though internal exposure via inhalation is outside the scope of external gamma monitoring) and from residual moisture that can affect the emanation and transport of radon progeny (Nazaroff & Nero, 1988; IAEA, 2013).

Because the spatial distribution of materials changes daily and because workers move among mixing, moulding, stacking and curing zones, in-situ measurements of ambient dose rate provide the most realistic estimate of occupational external exposure. Recent studies in

Nigerian block industries and related construction settings have demonstrated that dose rates can locally exceed the global outdoor average of 59 nGy h^{-1}, particularly where granitic aggregates or tin-mine tailings are used (Olarinoye et al., 2023; Aladeniyi et al., 2021).

1.3 Theoretical Basis of Annual Effective Dose (AED) and Excess Lifetime Cancer Risk (ELCR)

Radiation dose measurements expressed in microsieverts per hour provide an instantaneous indication of environmental radiation intensity but do not adequately represent the cumulative biological effects experienced by exposed individuals. Therefore, measured ambient dose rates are converted into Annual Effective Dose (AED), which estimates the radiation dose received by an individual over one year while accounting for occupancy patterns and the biological effectiveness of gamma radiation.

The effective dose is based on the concept introduced by the International Commission on Radiological Protection (ICRP), which incorporates tissue-weighting factors representing the relative radiosensitivity of different organs. For environmental gamma radiation, the annual effective dose is calculated using the measured dose rate, annual exposure time, occupancy factor, and the dose conversion coefficient of 0.7 Sv Gy^{-1} recommended by UNSCEAR (2020).

The annual effective dose for outdoor exposure is calculated as

$$\mathrm{AED}_{out} = D \times 8760 \times OF_{out} \times 0.7 \times 10^{-3} \quad (1)$$

Similarly, the indoor annual effective dose is given by

$$\mathrm{AED}_{in} = D \times 8760 \times OF_{in} \times 0.7 \times 10^{-3} \quad (2)$$

where, D= absorbed dose rate (nGy h^{-1}), 8760 = number of hours in one year, OF= occupancy factor, 0.7 Sv Gy^{-1} = conversion coefficient from absorbed dose in air to effective dose.

UNSCEAR recommends occupancy factors of approximately 0.2 for outdoor exposure and 0.8 for indoor exposure for the general population. Occupational studies may modify these factors according to actual working hours.

Annual effective dose provides a standardized metric for comparing environmental radiation exposure with internationally recommended public and occupational dose limits established by the ICRP and IAEA.

The conversion of measured absorbed dose rate in air (D, nGy h^{-1}) into quantities that express potential health detriment follows internationally standardised models.

Annual Effective Dose (AED) accounts for the relative biological effectiveness of gamma radiation and for the fraction of time an individual spends in the radiation field. It is calculated as:

$$\mathrm{AED}\ (\mathrm{mSv\ y}^{-1}) = D \times 8760 \times OF \times CF \times 10^{-6} \quad (3)$$

where, D is the absorbed dose rate in air (nGy h^{-1}), 8760 is the number of hours in a year, OF is the occupancy factor (commonly 0.2 for outdoor and 0.8 for indoor exposure for members of the public; occupational factors may be higher), CF = 0.7Sv Gy^{-1} is the conversion coefficient from absorbed dose in air to effective dose for adults recommended by UNSCEAR (2000, 2020).

The resulting AED is compared with the ICRP recommended public limit of 1 mSv y^{-1} (excluding natural background and medical exposures) and the occupational limit of 20 mSv y^{-1} averaged over five years.

Excess Lifetime Cancer Risk (ELCR) quantifies the additional probability of fatal cancer arising from continuous exposure over a lifetime. It is obtained from:

$$\mathrm{ELCR} = \mathrm{AED} \times DL \times RF \quad (4)$$

where, $DL$is the average duration of life (taken as 70 years in most African studies), $RF$is the risk factor (0.05 Sv^{-1} or 5 × 10^{-2} Sv^{-1} for fatal cancer for the whole population, as recommended by ICRP Publication 103). The world average outdoor ELCR is approximately 0.29 × 10^{-3}. Values significantly above this benchmark indicate an elevated lifetime cancer risk attributable to the measured radiation field.

These two indices therefore translate physical dose-rate measurements into quantities that are directly relevant to radiological protection decision-making and public-health risk communication.

1.4 Regional Context and Rationale for the Present Study

In Nigeria, environmental gamma-radiation investigations have expanded considerably between 2021 and 2025. Studies have documented spatially variable background levels across diverse geological terrains. In Minna, mean background gamma radiation reached 0.126 μSv h^{-1}, more than twice the world average, with corresponding annual effective dose and elevated ELCR values (Sadiq et al., 2024). Terrestrial gamma dose rates in Taraba State averaged 108 nGy h^{-1}, yielding outdoor AED and ELCR values above global means, particularly in areas underlain by uranium-enriched formations (Odoh et al., 2025). Comparable elevations have been reported in the Niger Delta cities of Sapele, Oghara and Koko (Agbalagba et al., 2025), Jimeta–Yola in Adamawa State (Mohammed et al., 2024), and selected campuses and industrial sites in Zaria and Katsina (Usman et al., 2025; Igwe et al., 2025). Assessments of building materials and quarry products further confirm that activity concentrations of primordial radionuclides frequently approach or exceed world averages (Aladeniyi et al., 2021; Garba et al., 2025; Olarinoye et al., 2023).

Parallel investigations across Africa reinforce the regional importance of site-specific monitoring. Ambient gamma dose rates measured in Cotonou, Benin, remained generally low but were elevated in indoor markets and near a cement plant (Houndetoungan et al., 2025). Elevated absorbed dose rates and ELCR values have been recorded around Lake Monoun in Cameroon (Haman et al., 2024), while beach sands and mining-related soils in Ghana and Kenya have yielded radiological indices that, although often below regulatory limits, still warrant continued surveillance (Baafi et al., 2025). Collectively, these recent African studies demonstrate that terrestrial gamma radiation and associated health risks vary markedly with local geology and land-use practices, underscoring the need for localised baseline data.

Northern Nigeria lies within the Precambrian Basement Complex, characterised by granites, migmatites, schists and gneisses naturally enriched in uranium, thorium and potassium. Katsina State, situated in this geological province, has experienced rapid urban expansion and a corresponding proliferation of block-manufacturing industries. Despite this growth and the availability of recent radiological data from other Nigerian and African settings, systematic measurements of ambient gamma radiation and associated health risks within block industries of Dutsin-Ma Local Government Area remain scarce. Because block production relies on locally sourced cement, sand, gravel and crushed rock, workers may be exposed to spatially variable terrestrial gamma radiation during routine operations.

Environmental radiation monitoring establishes baseline data for regulatory agencies, supports long-term surveillance, informs epidemiological investigations and underpins radiation-protection policy (IAEA, 2018). Baseline measurements are especially valuable in rapidly developing communities, enabling future comparisons should industrial or mining activities alter existing conditions. International reference values provide objective benchmarks: the worldwide average outdoor absorbed gamma dose rate is approximately 59 nGy h^{-1}, corresponding to an annual effective dose from terrestrial external radiation of about 0.48 mSv y^{-1} (UNSCEAR, 2020). The ICRP occupational dose limit is 20 mSv y^{-1} averaged over five years (not exceeding 50 mSv in any single year), while the public limit is 1 mSv y^{-1} excluding medical and natural background exposures (ICRP, 2007).

In view of the limited information on occupational radiation exposure in block-manufacturing facilities of Katsina State and the growing body of recent regional evidence, the present study evaluated ambient gamma radiation levels in seventeen selected block industries within Dutsin-Ma Local Government Area. Indoor and outdoor dose rates were measured in situ with an F-S 5000 radiation survey meter, and the corresponding annual effective doses and excess lifetime cancer risks were estimated using the theoretical framework outlined above. The findings provide baseline radiological data for the study area, permit comparison with international protection standards and recent Nigerian and African studies, and contribute to the expanding national and continental database on environmental radiation exposure. The results also supply practical information for regulatory bodies, public-health authorities and industry stakeholders concerned with occupational radiation safety and sustainable environmental management.

2.0 MATERIALS AND METHODS

2.1 Study Area

The study was conducted in Dutsin-Ma Local Government Area (LGA), Katsina State, northwestern Nigeria. Dutsin-Ma LGA lies approximately between latitudes 12°25′ N and 12°35′ N and longitudes 7°28′ E and 7°31′ E. It is bounded by Kurfi LGA to the north, Safana and Dan-Musa LGAs to the west, Charanchi and Kankia LGAs to the east, and Matazu LGA to the south. The sample locations are presented in Figure 1. The study area forms part of the Nigerian Precambrian Basement Complex, which is predominantly composed of granites, migmatites, gneisses, schists, and pegmatites. These crystalline rocks are naturally enriched in primordial radionuclides, particularly uranium (^{238}U), thorium (^{232}Th), and potassium (^{40}K), making them important contributors to terrestrial gamma radiation (Obaje, 2009; Rahaman, 1988; United Nations Scientific Committee on the Effects of Atomic Radiation [UNSCEAR], 2020). The climate is classified as tropical wet-and-dry (Aw) according to the Köppen climate classification, with a rainy season extending from May to October and a dry season from November to April. Mean annual rainfall ranges from approximately 700 to 1000 mm, while temperatures are generally high throughout the year, reflecting the Sudan Savanna ecological zone of northwestern Nigeria (Nigerian Meteorological Agency [NiMet], 2023; Peel et al., 2007). The landscape is characterized by gently undulating plains interspersed with granitic inselbergs, rocky outcrops, and weathered lateritic soils typical of the Basement Complex terrain (Obaje, 2009). In recent years, rapid urbanization, population growth, and infrastructural development have stimulated the expansion of small- and medium-scale block-manufacturing industries within the area. These industries rely predominantly on locally sourced sand, gravel, laterite, Portland cement, and crushed granite for concrete block production, materials that may contain varying concentrations of naturally occurring radioactive materials (NORM) depending on their geological origin (International Atomic Energy Agency [IAEA], 2013; Ravisankar et al., 2014).

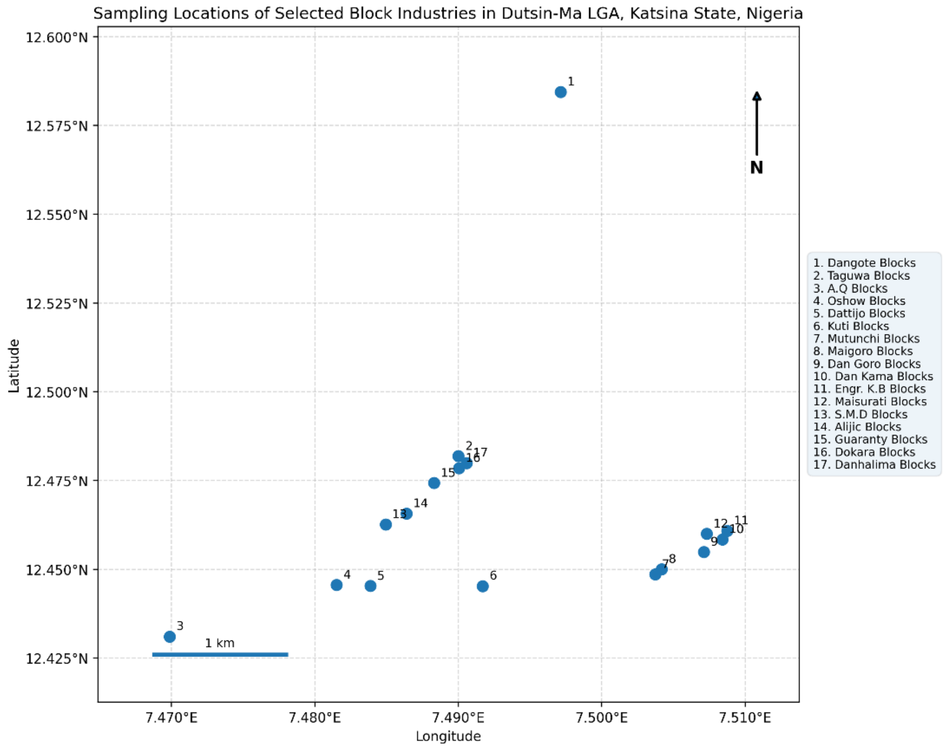

Figure 1: Location of selected sample block industries for the study

2.2 Selection of Study Sites

Seventeen (17) operational block-manufacturing industries were purposively selected across Dutsin-Ma LGA to ensure spatial coverage of the major production clusters (Table 1). Purposive sampling was considered appropriate because only active industries with continuous production activities and unrestricted access could provide representative occupational exposure conditions (Creswell & Creswell, 2018). Selection criteria included continuous production activity, accessibility for in-situ measurements, and representation of different scales of operation (small, medium and relatively larger facilities). The geographic coordinates of each industry were recorded using a handheld Global Positioning System (GPS) receiver.

2.3 Instrumentation

Ambient gamma radiation dose rates were measured using a portable F-S 5000 (or Bosean FS-5000) radiation survey meter. The instrument is equipped with a Geiger-Müller (GM) tube detector sensitive to beta, gamma and X-radiation. Key specifications include:

i. Energy response range: 48 keV – 1.5 MeV
ii. Dose-rate measuring range: 0.01 $\mu Sv\ h^{-1}$ – 50 $mSv\ h^{-1}$
iii. Relative intrinsic error: ≤ ±10%
iv. Sensitivity: approximately 80 cpm/µSv (relative to ^{60}Co)

The meter was factory-calibrated and periodically checked against a known reference source before and after each field campaign to ensure measurement reliability. A handheld GPS device was used concurrently to log the precise location of every measurement point.

2.4 Radiation Measurement Procedure

Ambient gamma radiation measurements were conducted in situ under normal operating conditions within each of the selected block industries following standard environmental radiation monitoring procedures recommended by the International Atomic Energy Agency and the United Nations Scientific Committee on the Effects of Atomic Radiation (IAEA, 2018; UNSCEAR, 2020).

Measurements were performed in two exposure environments:

i. Indoor: production sheds, moulding areas, curing sections, cement storage rooms, and block stacking areas.
ii. Outdoor: production yards, aggregate stockpiles, curing grounds, and finished block storage locations.

The following standardized protocol was adopted:

i. the survey meter was positioned at 1.0 m above ground level, representing the approximate height of the human gonads and internal organs during occupational exposure (UNSCEAR, 2020);
ii. measurements were conducted away from metallic structures and electrical installations that could influence detector response;
iii. the detector was allowed to stabilize for approximately 30–60 s before recording each reading;
iv. between three and five replicate measurements were obtained at each location;
v. the arithmetic mean of the replicate measurements was considered the representative ambient dose rate for the sampling point;
vi. measurements were conducted between 09:00 and 16:00 h under stable weather conditions.

We ensured that for each location, site identification, GPS coordinates, date, time, indoor dose rate, outdoor dose rate, and field observations were documented.

2.5 Estimation of Radiological Health Risk Indices

The measured ambient dose rates (D) in μSv h^{-1} were converted and used to estimate two primary radiological indices following internationally recommended models (UNSCEAR, 2000, 2020; ICRP, 2007).

2.6 Ethical Considerations

Permission to conduct radiation measurements was obtained from the owners and managers of all selected block-manufacturing industries before commencement of the survey. The study involved only non-destructive in-situ environmental radiation measurements, and no physical samples or personal information were collected. Consequently, the investigation posed no risk to workers or the surrounding communities and complied with internationally accepted ethical principles governing environmental field investigations (IAEA, 2018).

3.0 RESULTS AND DISCUSSION

3.1 Ambient Gamma Dose Rates

The mean indoor and outdoor ambient gamma dose rates measured at the seventeen selected block industries in Dutsin-Ma Local Government Area are presented in Table 1. Indoor dose rates ranged from 0.1467 μSv h^{-1} (Engr. K.B Blocks and Guaranty Blocks) to 0.1900 μSv h^{-1} (Kuti Blocks), with an overall mean of 0.1653 ± 0.0132 μSv h^{-1}. Outdoor dose rates varied from 0.1067 μSv h^{-1} (Dangote Blocks) to 0.1967 μSv h^{-1} (Maisurati Blocks), with a mean of 0.1623 ± 0.0272 μSv h^{-1} (see Table 1).

When converted to conventional units used by UNSCEAR, the mean indoor and outdoor absorbed dose rates correspond to approximately 165.3 nGy h^{-1} and 162.3 nGy h^{-1}, respectively. Both values are substantially higher than the worldwide average outdoor terrestrial gamma dose rate of 59 nGy h^{-1} reported by UNSCEAR (2020) (see Figure 2). The observed indoor values also exceed the typical global indoor average of about 84 nGy h^{-1}.

The relatively small difference between mean indoor and outdoor dose rates suggests that the primary contribution to the radiation field arises from the bulk stockpiles of sand, gravel, laterite, cement and curing concrete blocks rather than from building structures alone. This pattern is consistent with findings from other Nigerian studies on construction-related environments, where proximity to NORM-bearing aggregates elevates external gamma exposure (Olarinoye et al., 2023; Aladeniyi et al., 2021).

Table 1: **Geographic locations (GPS coordinates) and corresponding mean indoor and outdoor ambient gamma dose rates measured at selected block industries in Dutsin-Ma Local Government Area, Katsina State, Nigeria**

S/N	Sample Area	Location (GPS Coordinates)	Mean Indoor Radiation (μSv/h)	Mean Outdoor Radiation (μSv/h)
1	Dangote Blocks	N12°35′06694, E7°29′82816	0.1533	0.1067
2	Taguwa Blocks	N12°28′90842, E7°29′40108	0.1833	0.1933
3	A.Q Blocks	N12°25′86012, E7°28′19265	0.1733	0.1433
4	Oshow Blocks	N12°26′73558, E7°28′89095	0.1733	0.1300
5	Dattijo Blocks	N12°26′71704, E7°29′03220	0.1500	0.1900
6	Kuti Blocks	N12°26′71284, E7°29′50263	0.1900	0.1733
7	Mutunchi Blocks	N12°26′91300, E7°30′22456	0.1733	0.1900
8	Maigoro Blocks	N12°26′99628, E7°30′25152	0.1567	0.1600
9	Dan Goro Blocks	N12°27′28998, E7°30′42696	0.1733	0.1733
10	Dan Kama Blocks	N12°27′50022, E7°30′50562	0.1667	0.1833
11	Engr. K.B Blocks	N12°27′64674, E7°30′52560	0.1467	0.1433
12	Maisurati Blocks	N12°27′59562, E7°30′43966	0.1733	0.1967
13	S.M.D Blocks	N12°27′75271, E7°29′09622	0.1533	0.1833
14	Alijic Blocks	N12°27′93681, E7°29′18388	0.1533	0.1700
15	Guaranty Blocks	N12°28′45434, E7°29′29842	0.1467	0.1267
16	Dokara Blocks	N12°28′70448, E7°29′40288	0.1733	0.1633
17	Danhalima Blocks	N12°28′79196, E7°29′43456	0.1700	0.1333

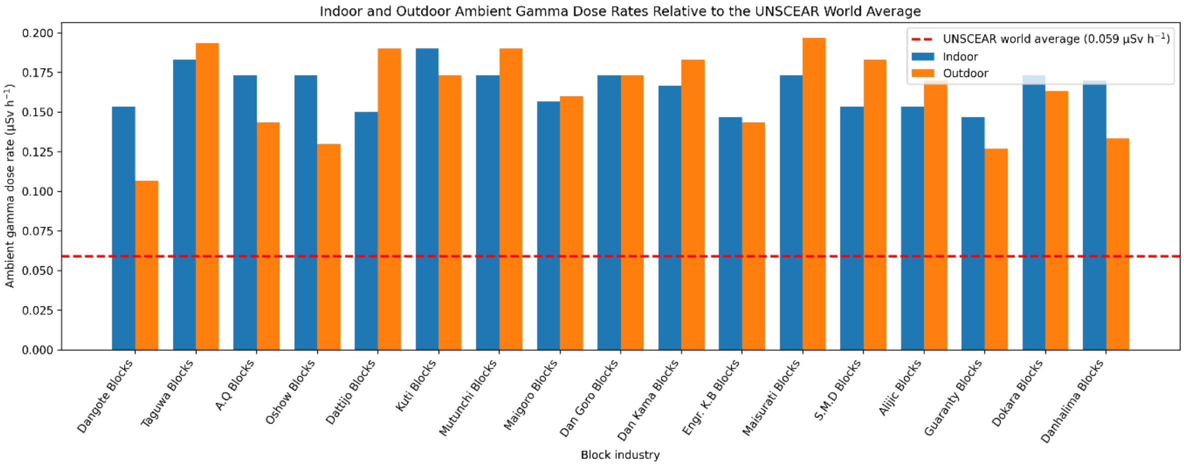

Figure 2: Indoor and Outdoor Ambient Gamma Dose Rates Measured at Selected Block-Manufacturing Industries in Dutsin-Ma Local Government Area, Katsina State, Nigeria

The horizontal dashed line (Figure 2) represents the UNSCEAR worldwide average external terrestrial gamma dose rate (0.059 µSv h^{-1}), providing a reference for comparison with the measured values (UNSCEAR, 2020). As illustrated in Figure 2, all measured indoor and outdoor ambient gamma dose rates exceeded the UNSCEAR worldwide average external terrestrial gamma dose rate of 0.059 µSv h^{-1} (UNSCEAR, 2020). Nevertheless, although the measured dose rates were higher than the global average natural background level, the estimated annual effective doses remained well below the occupational dose limit of 20 mSv y^{-1} recommended by the International Commission on Radiological Protection (ICRP, 2007). This suggests that the investigated block industries do not presently pose significant radiological health risks to workers under normal operating conditions.

It should be noted that the generally higher indoor annual effective doses arise primarily from prolonged occupancy and the close proximity of workers to large quantities of construction materials stored within production sheds. Indoor environments often contain stacked concrete blocks, cement bags, freshly mixed concrete, and aggregate stockpiles, which collectively contribute to the external gamma radiation field. Furthermore, partial enclosure may increase the contribution of scattered gamma photons, although gamma attenuation by lightweight industrial structures is generally minimal. Consequently, occupational exposure within indoor production areas tends to exceed outdoor exposure despite comparable ambient dose rates.

3.2 Spatial Variation

Notable spatial variation was observed across the study sites. Higher outdoor dose rates were recorded at Maisurati Blocks (0.1967 µSv h^{-1}), Taguwa Blocks (0.1933 µSv h^{-1}), Dattijo Blocks and Mutunchi Blocks (both 0.1900 µSv h^{-1}) (Figure 2). These elevated values may be linked to differences in the mineralogical composition of locally sourced aggregates, particularly materials derived from the uranium- and thorium-enriched Precambrian Basement Complex rocks that underlie the region (Odoh et al., 2025; Usman et al., 2025). Lower outdoor readings at Dangote Blocks and Guaranty Blocks may reflect differences in raw-material sourcing or greater spatial separation between measurement points and large stockpiles.

3.3 Annual Effective Dose (AED)

Using the standard UNSCEAR conversion model with occupancy factors of 0.8 (indoor) and 0.2 (outdoor) for members of the public, the mean indoor AED was estimated at 0.811 mSv y^{-1} and the mean outdoor AED at 0.199 mSv y^{-1}, giving a combined total of approximately 1.01 mSv y^{-1}. When a more realistic occupational occupancy scenario is considered (approximately 0.4 indoor and 0.2 outdoor, corresponding to 8–10 hour work shifts), the estimated total AED for workers is about 0.60 mSv y^{-1}. Both public and occupational estimates remain below the ICRP recommended annual limit of 1 mSv y^{-1} for members of the public and well below the occupational limit of 20 mSv y^{-1} averaged over five years (ICRP, 2007). Nevertheless, the values are higher than the world average outdoor terrestrial effective dose of 0.48 mSv y^{-1} (UNSCEAR, 2020).

Figure 3 further shows that the estimated indoor annual effective doses at all investigated block industries exceeded the UNSCEAR worldwide average annual effective dose of 0.48 mSv y^{-1}, indicating enhanced terrestrial gamma radiation within indoor production environments. In contrast, the outdoor annual effective doses remained below the worldwide average. Despite this observation, both indoor and outdoor annual effective doses were substantially lower than the occupational dose limit of 20 mSv y^{-1} recommended by the International Commission on Radiological Protection (ICRP, 2007), indicating that workers are not exposed to levels that constitute significant radiological health hazards under current operating conditions.

These results are comparable to recent findings from other Nigerian locations. Elevated background levels and corresponding AED values have been reported in Minna (Sadiq et al., 2024), Taraba State (Odoh et al., 2025), parts of the Niger Delta (Agbalagba et al., 2025), and industrial/campus environments in Zaria and Katsina (Usman et al., 2025; Igwe et al., 2025). Similar patterns of moderately elevated gamma dose rates have also been documented in selected African settings, including parts of Cameroon and Ghana (Haman et al., 2024; Baafi et al., 2025).

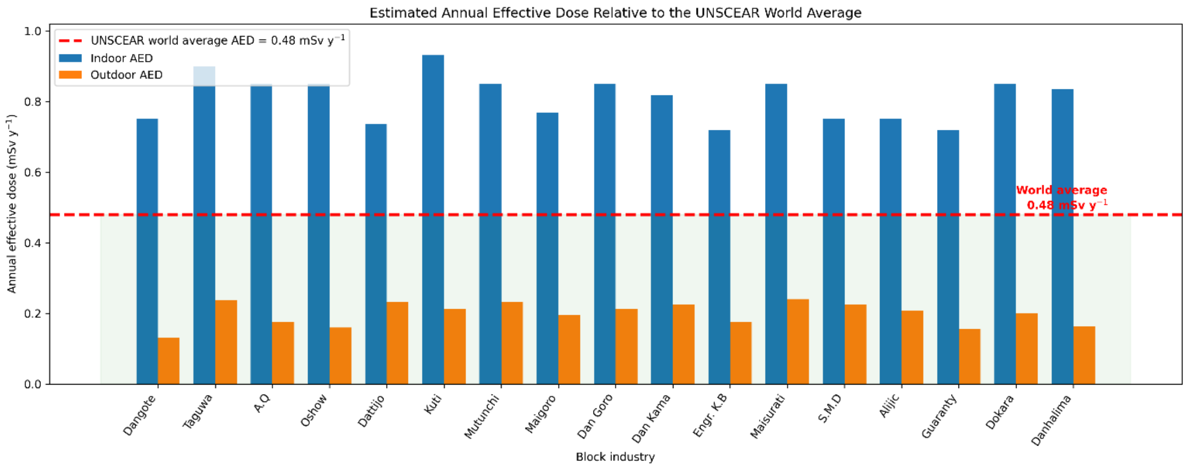

Figure 3: Estimated indoor and outdoor annual effective doses (AED) for the selected block-manufacturing industries in Dutsin-Ma Local Government Area, Katsina State, Nigeria.

3.4 Excess Lifetime Cancer Risk (ELCR)

The estimated excess lifetime cancer risk (ELCR) values varied among the investigated block-manufacturing industries according to the measured ambient gamma radiation levels. The mean ELCR calculated from the total annual effective dose (1.01 mSv y^{-1}) was 3.53×10^{-3}, whereas the mean outdoor ELCR was approximately 0.70×10^{-3}. The outdoor ELCR exceeded the world-average outdoor ELCR of approximately 0.29×10^{-3} derived from the worldwide outdoor annual effective dose reported by UNSCEAR (2020), indicating that outdoor occupational exposure within the investigated industries is higher than the global average natural background level. Nevertheless, the estimated ELCR values remain relatively low and are characteristic of chronic exposure to naturally occurring terrestrial gamma radiation rather than enhanced exposure from artificial radiation sources.

As illustrated in Figure 4, the indoor ELCR values were consistently higher than the corresponding outdoor values because of the greater indoor occupancy factor adopted in the annual effective dose calculations. Although the indoor ELCR values also exceeded the benchmark derived from the worldwide average annual effective dose (1.68×10^{-3}), this comparison should be interpreted cautiously because it represents a reference calculated from the total annual effective dose rather than outdoor exposure alone. Despite the relatively elevated indoor values, the estimated annual effective doses remain far below the occupational dose limit of 20 mSv y^{-1} recommended by the International Commission on Radiological Protection (ICRP, 2007). Consequently, the investigated block-manufacturing industries do not present significant radiological health hazards to workers under current operating conditions, although periodic environmental radiation monitoring and occupational surveillance are recommended to ensure continued compliance with international radiation protection standards.

Although the calculated risks remain within the range considered acceptable for chronic low-level environmental exposure in many regulatory frameworks, the elevated ELCR relative to the global average indicates a modestly increased lifetime probability of stochastic effects for individuals with long-term residence or occupational exposure in these environments. Similar exceedances of the world-average ELCR have been reported in several recent Nigerian studies of background radiation in urban, industrial and construction-related settings (Sadiq et al., 2024; Agbalagba et al., 2025; Mohammed et al., 2024).

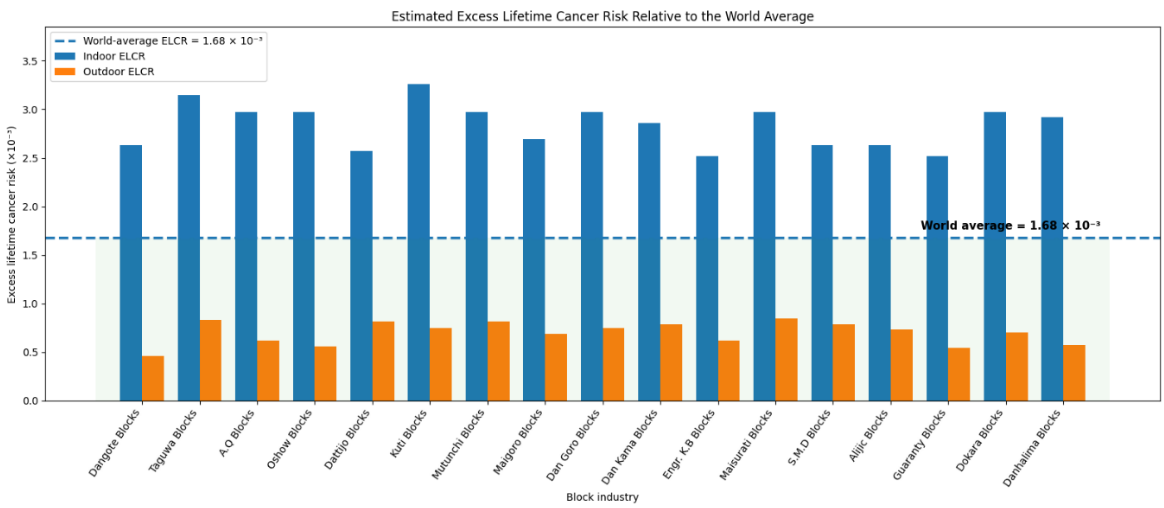

Figure 4: Estimated indoor and outdoor excess lifetime cancer risk for workers at selected block-manufacturing industries in Dutsin-Ma Local Government Area, Katsina State, Nigeria.

3.5 Occupational Implications and Comparison with International Standards

The measured dose rates and derived indices confirm that workers in the surveyed block industries are exposed to external gamma radiation levels above the global average, primarily due to continuous proximity to NORM-containing construction aggregates. This finding aligns with the broader literature on occupational exposure in industries handling building materials and quarry products (IAEA, 2013; Mubarak & Khalifa, 2021; Olarinoye et al., 2023). Nevertheless, the estimated annual effective doses remain comfortably below the ICRP occupational dose limit. The results therefore do not indicate an immediate regulatory breach, but they do highlight the need for routine monitoring, particularly in facilities that use aggregates sourced from geologically enriched terrains. Simple administrative measures—such as increasing the distance between work stations and large stockpiles, rotating work locations, and improving ventilation in curing sheds—could further reduce cumulative exposure.

3.6 Statistical Interpretation of Indoor and Outdoor Radiation Levels

The paired comparison of indoor and outdoor ambient gamma dose rates revealed no statistically significant difference ($p > 0.05$), indicating that the radiation environment within the investigated block-manufacturing industries is relatively homogeneous. This finding suggests that the primary source of external gamma radiation is not the production sheds themselves but the widespread distribution of naturally occurring radioactive materials (NORM) in construction aggregates used throughout the production environment. Cement, sand, laterite, gravel, crushed granite, and curing concrete blocks are present in both indoor and outdoor working areas, resulting in comparable external exposure irrespective of work location. Similar observations have been reported for construction material industries in southwestern Nigeria and in studies involving concrete blocks manufactured from mine tailings, where naturally occurring radionuclides contributed uniformly to indoor and outdoor dose rates (Aladeniyi et al., 2021; Olarinoye et al., 2023). The relatively low standard deviations obtained further indicate that radiation levels are spatially stable across the investigated industries, supporting the reliability of the sampling strategy.

3.7 Geological Influence on Ambient Gamma Radiation

The elevated ambient gamma dose rates observed in the study area are closely associated with the geological characteristics of the Nigerian Precambrian Basement Complex. Granitic rocks, migmatites, gneisses, pegmatites, and associated lateritic soils are naturally enriched in primordial radionuclides, particularly ^{238}U, ^{232}Th, and ^{40}K (Obaje, 2009; Rahaman, 1988). Weathering of these crystalline rocks supplies radioactive minerals into the sand, gravel, and lateritic materials used for concrete block production. Granitic aggregates are especially rich in potassium-bearing feldspars and accessory minerals such as zircon, monazite, allanite, and uraninite, which contain appreciable concentrations of uranium and thorium. Consequently, variations in the geological origin of construction materials likely explain the observed spatial differences in ambient gamma dose rates among the investigated industries.

3.8 Influence of Construction Materials on Radiation Levels

The measured radiation levels are consistent with the known radiological characteristics of common construction materials. Portland cement, crushed granite, river sand, gravel, and laterite naturally contain varying concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, the principal contributors to terrestrial gamma radiation (Ravisankar et al., 2014; Aladeniyi et al., 2021). Although the present study did not directly determine radionuclide activity concentrations, the measured ambient dose rates strongly suggest that naturally occurring radionuclides within these materials constitute the dominant source of external exposure. Differences in aggregate source locations, mineral composition, and particle size distribution may further contribute to the observed variability among block industries.

3.9 Comparison with International Studies

The measured ambient gamma dose rates fall within the range reported for construction and industrial environments worldwide. Studies conducted in Turkey (Taskin et al., 2009), India (Ravisankar et al., 2014), Cameroon (Haman et al., 2024), Benin (Houndetoungan et al., 2025), Ghana (Baafi et al., 2025), and Kenya (Pkemoi et al., 2025) similarly attributed elevated terrestrial gamma radiation to geological formations enriched in naturally occurring radionuclides. Compared with these investigations, the Dutsin-Ma block industries exhibit moderate radiation levels that exceed the global average but remain substantially below internationally accepted occupational exposure limits. This consistency indicates that the observed radiation environment is characteristic of construction industries operating within granitic terrains rather than an indication of abnormal radiological contamination.

3.10 Occupational Radiation Protection Implications

Although the calculated annual effective doses remain well below the ICRP occupational dose limit of 20 mSv y^{-1}, the elevated ambient gamma dose rates relative to global background values emphasize the importance of maintaining sound radiation protection practices. In accordance with the ALARA (As Low As Reasonably Achievable) principle, workers should minimize unnecessary exposure by optimizing workplace layout, limiting prolonged occupancy near aggregate stockpiles, rotating personnel where feasible, and ensuring adequate ventilation within enclosed production areas (IAEA, 2018; ICRP, 2007). Routine environmental monitoring and periodic awareness programmes would further strengthen occupational radiation safety and facilitate early detection of any future increases associated with changes in construction material sources.

3.11 GIS Interpretation of Spatial Distribution

The GIS distribution map demonstrates that ambient gamma radiation is relatively uniform across the investigated block industries, with only localized areas exhibiting moderately elevated dose rates. The absence of pronounced radiological hotspots suggests that the measured radiation field reflects regional geological characteristics rather than isolated contamination events. Industries exhibiting comparatively higher dose rates are likely utilizing aggregates obtained from quarry sites underlain by uranium- and thorium-bearing granitic formations. Such spatial information is valuable for environmental planning and provides a baseline for future radiological surveillance within Dutsin-Ma Local Government Area.

4.0 CONCLUSION

This study evaluated ambient gamma radiation levels and the associated radiological health risks in seventeen selected block-manufacturing industries located in Dutsin-Ma Local Government Area, Katsina State, Nigeria. Indoor and outdoor ambient gamma dose rates were measured using a Bosean F-S 5000 radiation survey meter, while the corresponding annual effective dose (AED) and excess lifetime cancer risk (ELCR) were estimated following the recommendations of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the International Commission on Radiological Protection (ICRP). The results showed slight spatial variations in ambient gamma radiation across the investigated industries, reflecting the relatively uniform geological characteristics of the area and the widespread use of similar locally sourced construction materials, including sand, laterite, gravel, crushed granite, and cement. Although the measured ambient dose rates generally exceeded the worldwide average terrestrial background radiation reported by UNSCEAR, the observed radiation levels are attributable to naturally occurring radionuclides in the geological materials rather than anthropogenic radioactive contamination. The estimated annual effective doses indicated that indoor exposure was consistently higher than outdoor exposure, primarily because of longer occupancy periods within production environments. Statistical analysis further revealed no significant difference between indoor and outdoor ambient gamma dose rates, indicating comparable radiological conditions across the selected block industries. While the estimated excess lifetime cancer risks were higher than the corresponding worldwide outdoor reference values, the calculated annual effective doses remained well below the occupational dose limit of 20 mSv y^{-1} recommended by the ICRP. Consequently, the investigated block industries do not pose significant radiological health hazards to workers under current operating conditions. The study provides valuable baseline radiological data for Dutsin-Ma Local Government Area and contributes to the growing database on occupational exposure to natural background radiation in Nigeria. These findings are important for environmental radiation monitoring, regulatory decision-making, and occupational health management within the construction industry. To ensure sustained radiation safety, periodic environmental radiation monitoring is recommended, together with the radiological characterization of construction materials obtained from different sources. Future investigations should incorporate high-resolution gamma-ray spectrometry for determining the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, indoor ^{222}Rn measurements, seasonal variation studies, and GIS-based spatial modelling of radiation distribution. In addition, future occupational dose assessments should adopt occupancy factors based on actual working hours to provide more realistic estimates of worker exposure and associated lifetime cancer risk. These measures will strengthen occupational radiation protection and support sustainable industrial development in the study area.

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