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ASSESSMENT OF GAMMA DOSE RATE AND POPULATION EXPOSURE IN THE TOWN OF BERAT, ALBANIA

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Abstract. *This study aims to establish the gamma dose rate and accumulated radiation dose in Berat and compare the exposure of inhabitants in the old town district, which has been under UNESCO protection since 2008, with that of those living in other parts of the city. For this purpose, we utilized the Backpack ATOMTEX device and took measurements at various points, following international guidelines for environmental radiation monitoring. To calculate a per-year population dose estimation, the conversion coefficient from absorbed dose in air to effective dose was used. Data were analyzed and processed using the Kriging method of interpolation to address the spatial distribution of values, as well as MATLAB for numerical data processing. The largest gamma dose rate in the city was 0.134 μGy/h. Because two-thirds of people spend time indoors and one-third outdoors, the residents' annual effective dose is approximately 0.087 mSv/year, which is lower than the European Union's limit of 1 mSv/year. The results indicate a uniform and low-level natural background radiation environment across Berat, with no radiological risk for the public. These findings contribute valuable baseline data for environmental radiation monitoring in historically significant urban areas and support future public health planning.*

Keywords: *Backpack ATOMTEX, effective dose, gamma dose rate, IAEA, Kriging interpolation, MATLAB, UNSCEAR*

1. INTRODUCTION

Berat, one of Albania's most historically important cities, stands out for its unusual geography and rich cultural heritage, both of which have shaped its development over the centuries. Positioned between Mount Tomorr and the Osum River, the city's landscape has supported agriculture and offered natural protection throughout different eras. Landmarks like the Berat Castle and the National Museum of Onufri reflect a mix of Byzantine and Ottoman influences, showing how different layers of history have left their mark. Its inclusion on the UNESCO World Heritage list highlights this universal value [16]. That recognition has also helped tourism grow and sparked new efforts to balance preservation with development [15],[17]. What is often overlooked when discussing heritage cities is how environmental factors, like natural background radiation, can affect public health. Measuring ambient gamma dose rates helps us understand this better. Long-term exposure to low levels of ionizing radiation has been linked to higher cancer risks [10],[9]. In some places, natural materials in the ground raise these levels. For example, a study in Sinai found that granite samples contained radionuclides that could increase local dose rates [3]. Similar concerns were raised near coal mines in Nigeria, where elevated radiation levels were found in surrounding soils [7]. To assess the risk accurately, we need good field data and reliable methods. The European Atlas of Natural Radiation provides a harmonized basis for dose-rate mapping at the European scale [1], and a decomposition approach has been proposed to estimate terrestrial gamma dose rates from ambient dose equivalent rate data [2]. Others have applied in-situ gamma spectroscopy in oil-field environments to quantify natural radionuclides and assess radiation hazard indicators [6]. Atmospheric releases of naturally occurring radioactive materials from industrial activities are another concern [8]. Agencies like the IAEA [11] offer clear safety guidelines for radiation protection, and guidance on monitoring programmes [12]. Given its geology and the widespread use of local stone in traditional buildings, Berat is a particularly interesting case. Despite its UNESCO status, the area has never been studied in detail for background radiation. This research aims to fill that gap. By conducting an in-situ survey of gamma radiation across the city, the study will map dose rates, identify potential hotspots, and estimate the annual effective dose for the population. The results will support better radiation protection, inform public health planning, and add a new layer of environmental understanding to heritage site management.

2. MATERIALS AND METHODS

This study was carried out in Berat, a UNESCO World Heritage city in southern Albania, known for its blend of historical architecture and modern urban development. The objective was to assess ambient gamma radiation and estimate the effective dose to which the local population is exposed. A total of 14,761 measurement points were recorded across the city using the ATOMTEX AT6130 Backpack gamma spectrometer, a portable device compliant with international

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standards for environmental radiation monitoring [11]. The spectrometer was worn at approximately 1 meter above ground level to reflect typical human exposure height. Measurement routes were randomly selected to ensure wide spatial coverage and avoid duplicating streets. This approach helped avoid bias from population density or orientation. The device automatically recorded gamma ambient dose equivalent rate H*(10) in μSv/h every 5 seconds, following standard sampling intervals for mobile surveys. Raw data were exported in CSV format and filtered using a custom GNU Octave script based on geographic coordinates, allowing the data to be automatically grouped by zone of interest. Measurements falling outside the area of interest were excluded. For spatial analysis, we used Kriging interpolation, a widely accepted geostatistical method for estimating environmental radiation patterns [5]. This allowed for the construction of high-resolution dose distribution maps. The ATOMTEX AT6130 backpack system measures the ambient dose equivalent rate H*(10) in μSv/h. For terrestrial gamma radiation, H*(10) is numerically close to the absorbed dose rate in air (D), therefore instrument readings in μSv/h were treated as μGy/h when applying Eq. (1). This conversion follows standard practice in environmental gamma surveys. To calculate the annual effective dose (E) received by the public, the following formula was applied:

$$E=D\times T\times F\times CC \qquad (1)$$

where:

- **D** = mean absorbed dose rate in air (μGy/h)
- **T** = annual exposure time (8760 hours)
- **F** = occupancy factor (0.2 for outdoor, 0.8 for indoor)
- **CC** = conversion coefficient (0.7 Sv/Gy) from absorbed dose in air to effective dose, as recommended by UNSCEAR [13].

This calculation assumes that individuals spend 20% of their time outdoors and 80% of their time indoors, consistent with the IAEA [12] recommendations for general population exposure. Reference levels were compared with those set by UNSCEAR [13] and European Union guidance levels [18] to evaluate potential radiological risk. This methodology aligns with international best practices for environmental radiation assessment and population dose estimation [11],[12],[13]. Local geology was additionally considered. Based on published geological maps of Albania, Berat lies on a combination of carbonate formations (limestone), flysch sequences, and Quaternary alluvial deposits. Historical buildings in the elevated parts of the city, particularly near the castle, frequently incorporate limestone and tuff-derived materials containing naturally occurring radionuclides such as K-40 and traces of uranium and thorium series isotopes. These geological characteristics help explain the spatial variations of gamma dose rate observed in the survey.

3. RESULTS AND DISCUSSION

First, we pulled all the measurements collected using the Backpack ATOMTEX device and combined them into a single dataset. During initial checks, some data points were found outside the actual study area, including several with dose values of 0 μSv/h, clearly unrealistic and likely the result of a temporary equipment error. These outliers were removed using a MATLAB script based on geographic filters, so that only the valid readings from within the city limits of Berat were included. In the raw data visualization, gamma dose rates across Berat ranged from around 0.030 μSv/h to 0.134 μSv/h. Areas shown in green and yellow had higher values, while dark blue areas had the lowest. Notably, elevated radiation was observed in the UNESCO-designated historical center, particularly around the main square and the Berat Castle, where values often exceeded 0.070 μSv/h. The local geology and architecture likely influence this pattern. Traditional buildings in this part of the city usually use natural stones, such as limestone and tuff, which can contain naturally occurring radioactive materials (NORM), including uranium, thorium, and potassium-40 [3],[2]. These materials are known to contribute to elevated background radiation in other heritage zones across Europe and North Africa [4]. In contrast, peripheral neighborhoods and lower-elevation areas exhibited more stable and lower values, typically ranging from 0.032 to 0.045 μSv/h. This contrast confirms the influence of both natural rock types and building ambient dose rates. These spatial patterns are not just a scientific curiosity; they matter for public health and planning. Elevated radiation levels in public spaces, even if low, merit long-term attention. To deepen the analysis, the first step involved visualizing the processed data using MATLAB. This visualization is presented in Figure 2 below.

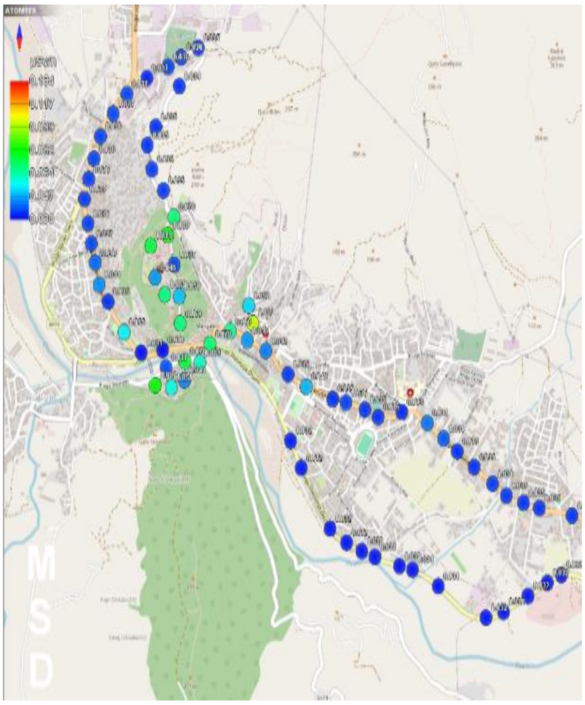

Figure 1. Raw, unfiltered dose rate data. After filtering, the cleaned dataset was used for spatial interpolation, starting with Kriging and then continuing with Inverse Distance Weighting (IDW), both widely used methods for environmental radiation mapping [2] [12].

As shown in Figure 2, in the area where the Berat Castle is located, which includes older buildings and residential structures, there is an increase in the gamma dose rate. This reflects the influence of local geology, with higher concentrations of radionuclides in the underlying rock and in the materials used in older construction.

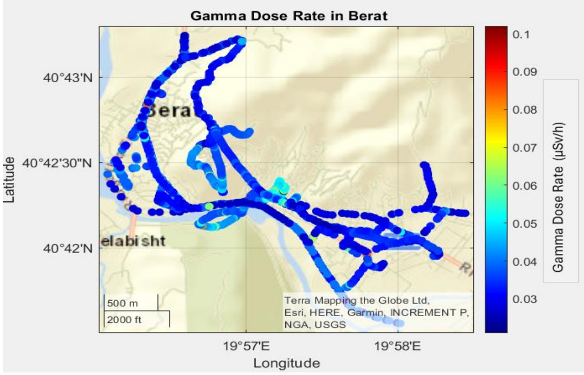

Figure 2. The filtered dataset, mapped over a satellite base layer. The colour gradient here ranges from deep blue (low dose rate) to red (high dose rate), with the most elevated values clustered again in the north, near the castle.

To make this spatial variation more evident, we will use MATLAB to simulate the interpolation of gamma dose rate measurements across the city of Berat, applying the kriging method to generate a representative map of radiation levels. The interpolation helps fill in gaps between measurements, highlighting "hotspots" with dose rates over 0.08 µSv/h. Once again, these are centered near the historical core. The remaining areas display lower values, between 0.035 and 0.055 µSv/h — consistent with the background expected in sedimentary and alluvial terrains [13]. Mapping radiation like this helps authorities and the public visually understand risk — a key step in environmental communication, especially for culturally significant sites [11]. The boxplot confirms that the data is right-skewed and contains several outliers above 0.07 µSv/h. The median value is 0.042 µSv/h, with a standard deviation of 0.022 µSv/h, indicating a relatively tight spread, but with some localized spikes. Statistical tests for normality (Shapiro-Wilk and Kolmogorov-Smirnov) yielded p-values below 0.001, showing the dose rates are not normally distributed.

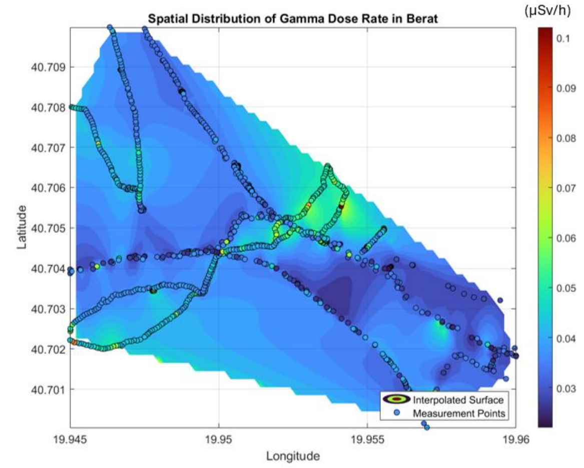

Figure 3. A more detailed, continuous distribution of gamma dose rate using IDW interpolation.

This non-normality supports the idea of distinct sources, like specific types of building materials or soil, rather than a smooth, natural background. The scatter plot, also in Figure 4, shows a weak but statistically significant correlation between dose rate and altitude (r = 0.16, p = 0.000). In simple terms, higher places, such as the castle hill, tend to have slightly higher radiation levels. This trend is consistent with elevation-based gradients observed in other environmental radiation studies [8], where both terrestrial sources and cosmic radiation increase with altitude. Altogether, these findings show that Berat's background radiation is not uniformly distributed. It is shaped by both the land and the layers of history built upon it. That is not unusual in ancient cities, but it serves as a reminder that public health studies in heritage zones must consider both architecture and geology.

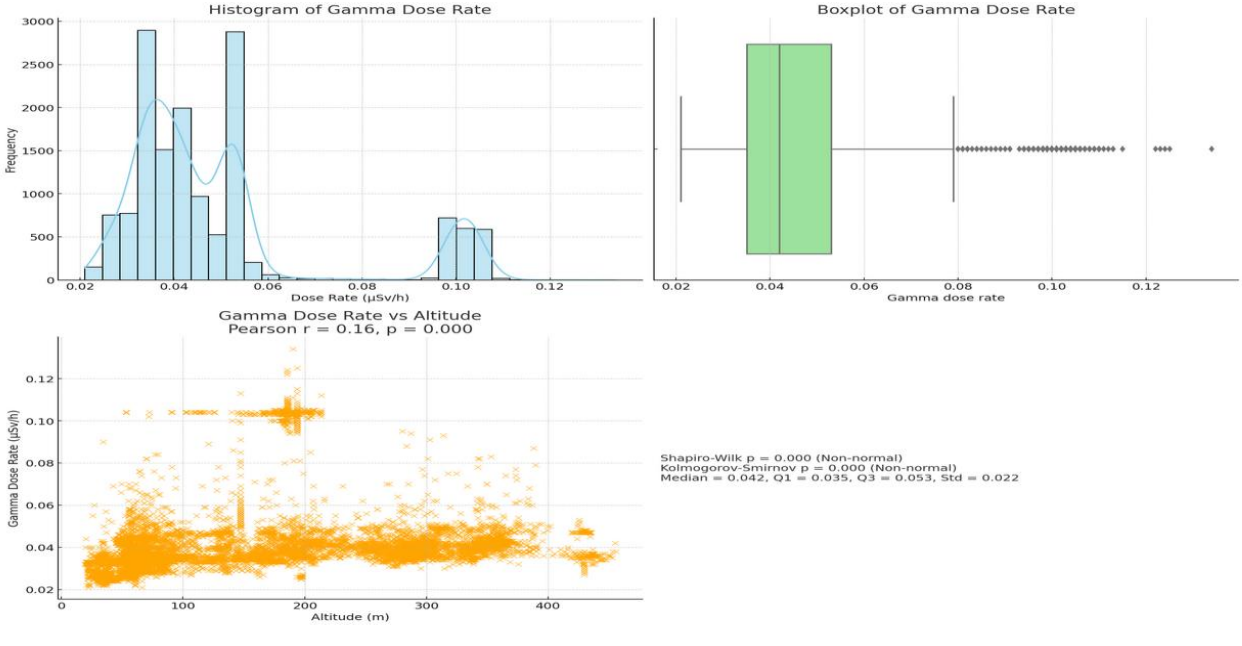

Figure 4. Deeper dive into the statistical picture. The histogram shows that most dose rate values fall between 0.03 and 0.06 µSv/h. There's also a secondary cluster near 0.1 µSv/h, tied to readings from the castle area.

Table 1 provides a summary of all findings and calculations carried out for the historic city of Berat. These values reflect the spatial distribution of the gamma dose rate across the area and serve as a basis for estimating the annual effective dose to the population. distribution. In Figure 5, measurement was conducted using a high-sensitivity portable gamma spectrometer with a 5-second acquisition time. The spectrum reveals a significant continuum in the low-energy region (below ~300 keV), which is characteristic of Compton scattering. Additionally, discrete peaks at higher energies (above 600 keV) may correspond to natural radionuclides, primarily Potassium-40 (K-40): ~1460 keV, Uranium series (e.g., Bi-214, Pb-214): Peaks around 609, 1120, and 1764 keV, Thorium series (e.g., Tl-208): Peaks around 2614 keV.

Table 1. Summary of Statistical
Parameters and Annual Effective Dose

Parameter	Value	Unit
Minimum dose rate	0.021	μGy/h
Maximum dose rate	0.134	μGy/h
Arithmetic mean	0.049	μGy/h
Median	0.042	μGy/h
First quartile (Q1)	0.035	μGy/h
Third quartile (Q3)	0.053	μGy/h
Standard deviation	0.022	μGy/h
Outdoor annual effective dose	0.087	mSv/year

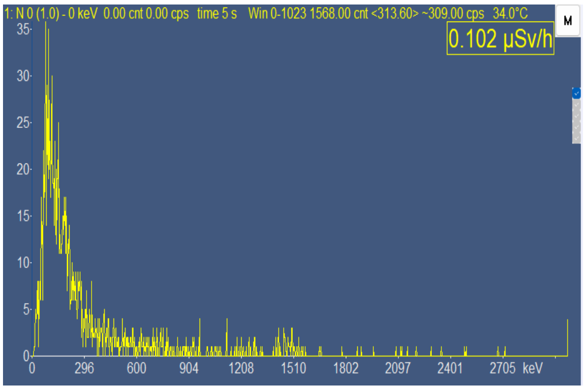

Figure 5. The gamma-ray spectrum obtained at one of the highest dose rate points in Berat (0.102 μSv/h), as previously highlighted in the statistical.

These isotopes are commonly found in natural building materials such as stone, brick, and soil — supporting the hypothesis that the elevated dose rate in Berat is influenced by using local stone materials in historical buildings, particularly near the castle area. The total count rate recorded was ~309 cps, and the environmental temperature was 34°C, indicating typical operating conditions. This spectrum confirms the presence of naturally occurring radioactive materials (NORM). It justifies the local increase in ambient dose rate, contributing to the spatial heterogeneity seen in the dose maps and statistical distributions. These nuclides are widely reported in gamma spectrometric surveys in granite-based and tuff-rich environments, reinforcing the geogenic origin of observed radiation patterns [3],[14].

4. CONCLUSION

The results of this study show a nearly uniform distribution of gamma dose rates across the city of Berat, with values mostly clustered around the average of 0.04 μGy/h. The highest recorded dose rate (0.134 μGy/h) remains well below concerning levels and is associated with areas of historical stone construction. Statistical variation was minimal, as indicated by the narrow interquartile range and low standard deviation. The estimated outdoor annual effective dose of 0.087 mSv/year confirms that population exposure is well below the internationally recommended public dose limit of 1 mSv/year. These findings suggest there are no radiological health risks for residents and provide a strong basis for ongoing environmental radiation monitoring in culturally important urban areas.

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