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Research Paper

Examining External Dose Rates in Mamuju Regency, Indonesia: A Personal Radiation Dosimetry Approach

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Abstract

This study aimed to quantify the individual external radiation exposure in Mamuju, Indonesia. A SmartRad portable personal dosimeter was utilized for this purpose, and data was collected over a period of 30 days. The findings indicate that the dose rate varies from 0.152 to 4.200 µSv/h and cumulatively ranges from 0.1 to 8.4 µSv/day based on an average measurement duration of 160 minutes. The average dose rate in areas with mineral deposits is 11.02 mSv per year. In contrast, the average effective dose in areas without radioactive mineral deposits is 2.6493 mSv per year. The annual average effective dose for individuals was measured at 6.8347 mSv. These findings imply that personal exposure to radiation among the public in Mamuju exceeds the threshold recommended by the International Commission of Radiological Protection.

Keywords: *Mamuju; natural radiation; radioactive mineral; radiation protection; radiation exposure.*

Introduction

Mamuju, a region in Indonesia, has been identified as a unique high natural background radiation area (HNBRA). The area is known for its high radiation exposure compared to the average across the country. Massive radioactive mineral deposits contribute to the high levels of natural radiation in the region. The primary radioactive elements in the earth's crust that lead to human exposure are potassium (^{40}K), uranium (^{238}U), thorium (^{232}Th), and their radioactive decay products, e.g., radium (^{226}Ra) and radon (^{222}Rn). ^{226}Ra, a byproduct of the decay process of uranium and thorium, is a radioactive element that can be found in the environment and can potentially lead to adverse effects on human health when existing in drinking water. This element has the potential to infiltrate groundwater from natural deposits present in the earth's crust. When humans consume water contaminated with radium, a significant portion of it, approximately 80%, is expelled from the body through waste products. However, the remaining 20% is absorbed and distributed throughout the body, primarily accumulating in the bones.

The ingestion of radium, particularly through drinking water, is of concern due to the alpha particles it emits, which can cause tissue damage. This damage can result in a range of health complications, such as anemia, cataracts, dental fractures, inhibited bone growth, compromised immunity, and in severe cases cancer. The severity of these health effects is influenced by the level and frequency of radiation exposure as well as the specific type of radium ingested.

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The yearly radiation dose in Mamuju was found to be in a range from 17 to 115 mSv, averaging at 32 mSv. This significantly surpasses the global average annual radiation dose of about 2.4 mSv. Lifetime exposure estimates suggest that Mamuju residents could receive an average dose as high as 2.2 Sv. This is notably higher than the average dose received by atomic bomb survivors, where risks of cancer and other diseases have been established [2]. These results underline the need for thorough radiation exposure assessments in unique high natural background radiation areas (HNBRA) like Mamuju [2-3].

Personal dosimetry is a crucial tool in radiation detection, primarily used to monitor individuals' total accumulation of ionizing radiation exposure. It is predominantly employed in the nuclear industry to ensure worker safety. The device, which comes in various forms, such as stickers, badges, pens, or digital readout devices, not only detects the exposure dose but also pinpoints the exact location of the radiation source. When an individual is exposed to radiation levels exceeding the natural limit, the device promptly signals an alert [1].

Standard techniques used for radiation detection include film dosimeters, thermoluminescent dosimeters (TLD), and, more recently, optically stimulated luminescence and radiophotoluminescence dosimetry. In this context, personal dosimetry can be used to assess the occupational effect on workers' health. In regions with high levels of natural radiation, such as Mamuju Regency, West Sulawesi, Indonesia, personal dosimetry can also be used to monitor the radiation exposure received by local residents. Mamuju Regency is known for its massive radioactive mineral deposits, making it the area with the highest natural radiation in Indonesia [1-2]. Since most of the population works as farmers, personal dosimetry measures the external dose to which residents are naturally exposed [1-2].

This study was conducted in Mamuju Regency, where the primary focus was the occupational dose. This was measured using a SmartRad personal dosimeter worn by a researcher. The study spanned 75 measurement points across 5 sub-districts, providing valuable data for future radiation protection studies and enhancing our understanding of the health effects of chronic low-dose-rate radiation exposure.

Research Method

Over the course of a month-long study, we utilized the SmartRad, a personal dosimeter device developed by Enviro Korea Co., Ltd. This device is specifically engineered to monitor radiation exposure by detecting X-rays, gamma rays, and beta rays. It was consistently worn on the chest of a researcher to monitor the occupational dose during the time of the survey. The data was collected using a systematic random technique, as depicted in Figure 1(a) [3].

The SmartRad operates within a measurement range of 0.1 μSv/hr to 10 mSv/hr for dose rate and 1μSv to 10 Sv for cumulative dose. It has an energy range of 60 keV to 1.5 MeV. One of the critical features of the SmartRad is its ability to inform the user of both direct measurement and cumulative external dose. This makes it a valuable tool for anyone close to ionizing radiation sources. This includes but is not limited to workers in institutions using isotopes, individuals involved in import, export, and distribution-related tasks, those in agriculture and fishery-related roles, frequent business travelers, and anyone interested in measuring radiation.

In addition to the SmartRad, we employed a separate GPS device to measure coordinates. The collected data, which included dose level and coordinates point, was manually recorded on a pre-prepared worksheet. This comprehensive approach allowed us to gather a robust dataset for our study.

The data undergoes processing to generate a two-dimensional map illustrating the spread of radiation dose rates within the research zone. This map creation is achieved using Quantum Geographical Information System (QGIS) software [5] to add and link all measurement points of the occupational exposure using the points-to-path option. Additional analysis involves determining the effective dose individuals receive.

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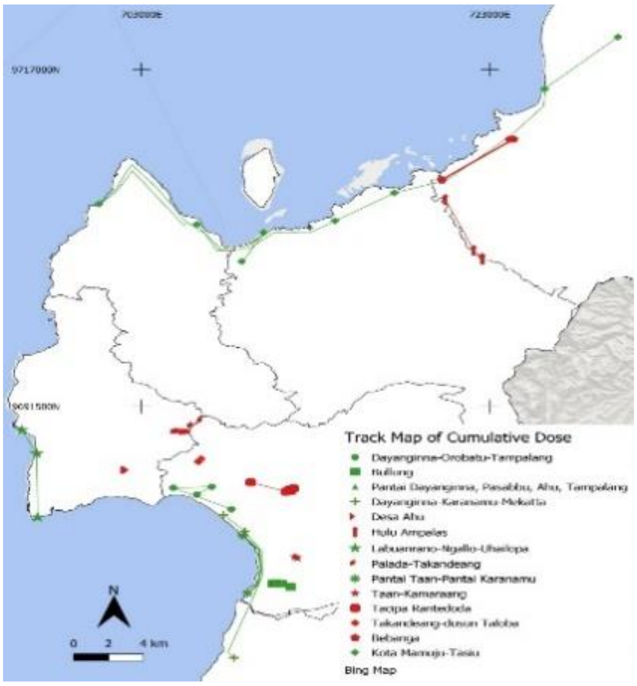

(a)

(b)

Figure 1 (a) Track of the personal dosimetry measurements, (b) position of the personal dosimeter device hanging on the chest of a team member.

The effective dose measures the average absorbed dose from a uniform whole-body radiation exposure that yields the same total radiation detriment as the nonuniform, partial-body exposure being evaluated. This concept, originally proposed by Jacobi in 1975 and further elaborated in McCollough and Schueler, is calculated using a specific equation provided by the International Commission on Radiological Protection (ICRP) in their latest publication in 2021 [6]:

$$H_T = \sum W_R \cdot D_{T,R} \quad (1)$$

where H_T is the equivalent dose, W_R is the radiation weighting coefficient, and $D_{T,R}$ is the average dose absorbed to tissue.

Result and Discussion

In this study, we collected 75 data points of external radiation dose rates, measured in microsieverts per hour (µSv/hr). These measurements were taken over a period of minutes. We computed the average, standard deviation, and median values from the external radiation dose rate data.

Table 1 Dose rate value in the research area.

	Dose Rate (µSv/h)
N	75
Average	0.94
Standard Deviation	0.79
Max	4.20
Median	0.64
Min	0.15

Based on the measurements, the average dose rate recorded was 0.94 µSv/h, which equates to an estimated annual dose of 8.24 mSv. This finding indicates a relatively high radiation exposure level in Indonesia's Mamuju region. Therefore, the current measurement aligns with previous findings, reinforcing Mamuju's status as a region with high natural radiation. This underlines the importance of ongoing monitoring and research to understand the potential health implications for the local population.

The histogram presented in Figure 2 analyzes the dose rate distribution based on the collected data. Most of the distribution, specifically from 42 data points, falls within the range of 0.152 to 0.822 µSv/h. This indicates that the most frequently observed dose rates are within this range. However, there is an outlier in the data, with one data point showing a significantly higher dose rate value, ranging between 4.172 and 4.842 µSv/h. This suggests a substantial increase in the dose rate for this particular data point compared to the rest.

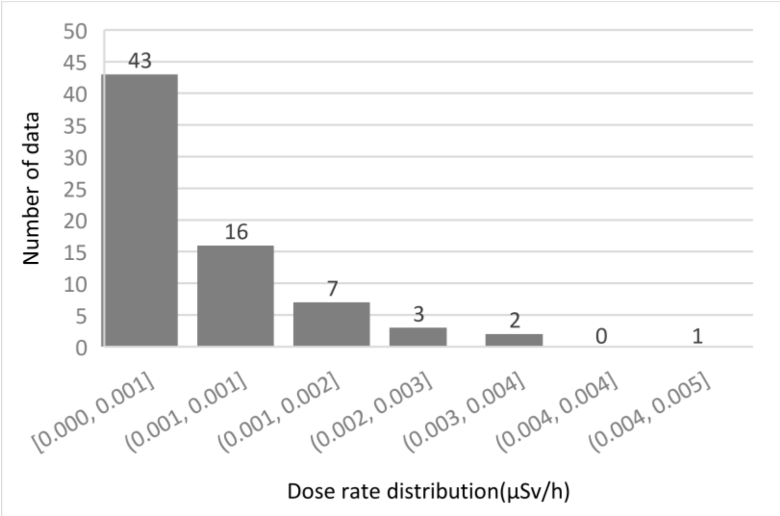

Figure 2 Dose rate measurement distribution.

Figure 3 displays a box-and-whisker plot, a type of quartile diagram illustrating the distribution of the measured dose rate values. The distribution is positively skewed, indicating that most data points are concentrated towards the lower end of the scale, with fewer data points extending towards the higher end.

The presence of outliers, specifically in the upper whisker (the section between the third quartile and the maximum value), is noteworthy. These outliers represent unusually high radiation dose rates. The high radiation dose rates may be attributed to substantial radioactive element mineralization or regions with radioactive mineral deposits.

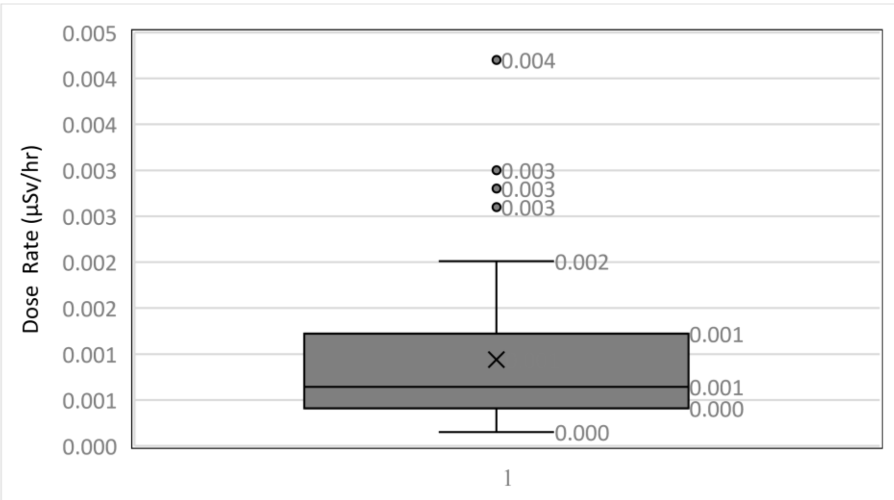

Figure 3 A quartile diagram showing the distribution of dose rate data that is positively skewed.

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Table 2 records radiation dose measurements taken at various locations in Mamuju, Indonesia. The measurements include the cumulative dose, external exposure in millisieverts (mSv), time of measurement in minutes, and the projected annual radiation dose in mSv. The effective dose, measured in millisieverts, is particularly noteworthy as it represents the radiation risk to the entire body. This is especially relevant considering that the average person in the U.S. is exposed to about 3 mSv per year from natural radiation [9,10].

The data revealed a wide range of radiation levels across different locations. For instance, the location with the highest recorded cumulative dose and the projected annual dose was Ahu, while the location with the lowest recorded values was Dayanginna-Tampalang. This variation underscores the importance of accurate and consistent radiation dose measurements [11]. These findings are crucial for understanding the health effects related to chronic low-dose-rate radiation exposure. They can also be used as the main input in future epidemiological studies.

The accuracy of these measurements is paramount, as errors can lead to severe consequences such as failure of tumor control or unacceptable normal tissue damage. To ensure accuracy, the study adhered to the guidelines provided by various organizations such as the European Society of Radiology and the International Atomic Energy Agency (IAEA). These organizations provide recommendations, calibration services, and internationally harmonized dosimetry codes of practice [12,13].

Furthermore, the study consulted other research efforts in the field. For example, a study published in the British Medical Journal that calculated descriptive statistics for CT scans by patient, institution, practice volume, machine, and country. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) also conducts tests for ongoing equipment validation [14,15].

These studies highlight the importance of accurate radiation dose measurements and the efforts made by various countries and international organizations to ensure consistency and quality assurance in this field.

Table 2 Cumulative and effective dose measured in mSv per year.

Location	Cumulative Dose				External exposure (mSv)
	µSv	mSv	Time of measurement (Minutes)	mSv in 1 year	
Dayanginna-Tampalang	1.00	0.001	304	1.73	1.52
Dayanginna-Malunda	0.50	0.001	135	1.95	1.71
Pantai Taan-Karanamu	0.10	0.000	25	2.10	1.85
Mamuju - Tasiu	2.20	0.002	363	3.19	2.80
Labuanrano	0.40	0.000	62	3.39	2.98
Bullung	0.70	0.001	86	4.28	3.76
Kamarang, Taan	0.60	0.001	71	4.44	3.91
Rantedoda	4.40	0.004	311	7.44	6.54
Desa Taan, Kec. Tapalang	5.00	0.005	352	7.47	6.57
Palada, Takandeang	2.70	0.003	178	7.97	7.06
Hulu Ampalas	5.30	0.005	250	11.14	9.81
Taloba, Takandeang	1.82	0.002	61	15.68	13.80
Ahu	8.40	0.008	189	23.36	20.57

The bar graph presents a comparison of the cumulative dose per year (in milliSieverts, or mSv) across various locations, such as Dongguan, Donghai, Fuzhou, Manjur, Kamming, Hulu, Fuzhou, Anhui, and others. The y-axis, ranging from 0 to 25 mSv, represents the cumulative dose per year. Two data sets or categories are depicted for each location, represented by red and blue bars. Generally, the red bars are taller than the blue ones, indicating higher values for the data they represent. The graph provides a clear visual representation of the variation in cumulative dose per year across different locations. A consistently taller red bar is seen in Ahu, typically higher across all locations than those represented by the blue bars. Regardless of location, the red bars, which represent one set of data, consistently show higher values than the blue bars. This finding suggests a significant difference between the two data sets across all examined locations.

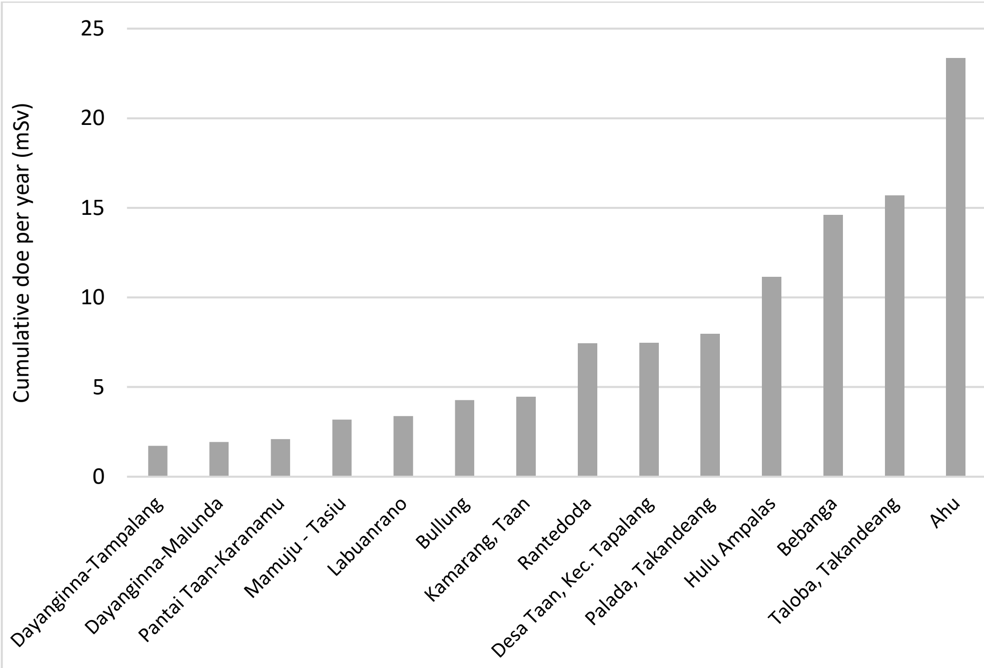

Figure 4 Distribution of cumulative dose values received by individuals in one year.

The high radiation dose rate and cumulative dose recorded in this study using a personal dosimeter can be attributed to uranium and thorium mineralization, two common natural radioactive elements with high concentrations in the Earth's crust. Their natural radioactivity plays a significant role in environmental sciences for monitoring radiation dose and geological sciences for understanding sedimentary processes. For instance, the Odisha coastal area in eastern India is a well-known high background radiation area rich in monazites and rutile. The concentrations of uranium and thorium were measured using inductively coupled plasma mass spectrometry (ICP-MS). The ratios of Th/U and Th/K varied from 4 to 37 and 13 to 1058, respectively. These results clearly indicate that the samples from the coastal region were formed in an oxidizing and intense chemical weathering terrestrial environment with enrichment of radiogenic heavy minerals (monazites and zircon) and clay mineral association. Since most samples have undergone moderate to intense weathering in the oxidizing environment, uranium is leached from the soil and sand matrix. Eventually, thorium resides in the matrix and is a major source of radiation exposure in the environment [17-19].

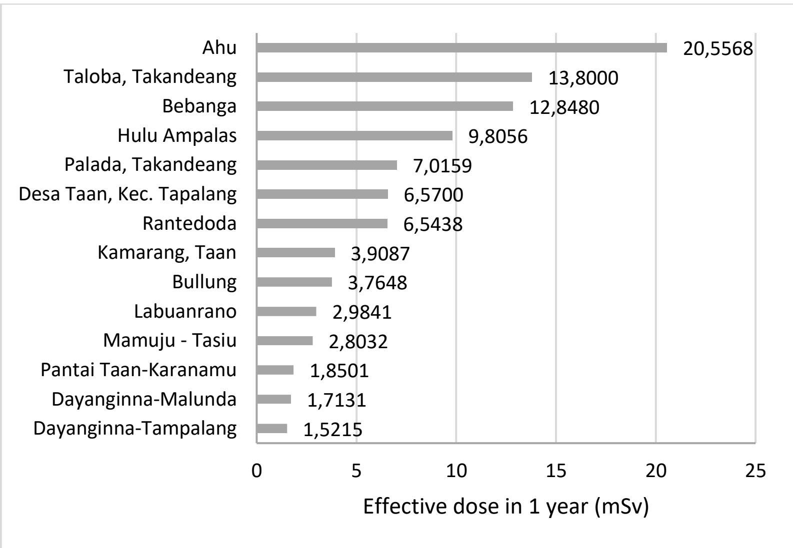

Figure 5 Distribution of effective dose in the study area.

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The elevated cumulative dose values observed in the study regions are further evidenced by the distribution of effective dose values, as illustrated in Figure 6 and Table 2. The maximum effective dose value is found in areas identified as radioactive mineral deposit areas, represented by the red bars in the graph. The highest value was recorded in Taloba, within the village of Takandeang.

Summary

This study in Indonesia's Mamuju region aimed to measure external exposure using a personal dosimeter. It was found that this area has a relatively high radiation exposure level. The average external dose rate was 0.94 µSv/h, which is equal to an estimated annual dose of 8.24 mSv. This aligns with previous findings that characterized Mamuju as a high natural background radiation area (HNBRA), with residents potentially receiving an average cumulative dose as high as 2.2 Sv. The location with the highest recorded cumulative dose and annual external dose was Ahu. The high radiation dose rate and cumulative dose recorded in this study can be attributed to uranium and thorium mineralization. Their natural radioactivity plays a significant role in environmental sciences for monitoring radiation dose and geological sciences for understanding sedimentary processes. These findings are crucial for understanding the health effects of chronic low-dose-rate radiation exposure and can be used as the main input in future epidemiological studies.

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