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Assessment of Outdoor Terrestrial Gamma Radiation Dose Rates of Serule Village, Botswana

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Abstract: Terrestrial Gamma Radiation Dose rate (TGRD) measurements were carried out in 45 locations across this village, to determine the dose distribution across the entire village. The mean value for the distribution, annual effective dose, and associated cancer risks were determined. The TGRD rate measurements were carried out using a calibrated Thermo scientific FH40G-L10 survey meter, while the sampling positions across the studied area were determined using a Garmain GPS. The gamma isodose map was generated using ARCGIS 9.3 software to illustrate the dose distribution across the entire village. The TGRD rates were found to range between 80-180 nGy/h, with a mean value of 117.3 nGy/h. This value is two times higher than the world average of 59 nGy/h. The average outdoor annual effective dose to the public was found to be 0.137089 mSv/annum with an average cancer risk of 0.000559.

Keywords: Exposure risk, Dose rate, Effective dose.

1 Introduction

The naturally occurring radioactive particles such as ^{40}K, ^{238}U, and ^{232}Th present in the soil may cause health risks to the exposed population if they exist in high concentrations. [1]. These elements, together with their decay products, have a serious potential to cause contamination of the air that we inhale, soil, and water which communities heavily rely on for food production [2]. For example, daughter products of uranium decay such as the radioactive radon gas have the potential to escape from the underground into the air, and once inhaled, they can cause massive cases of lung cancer if not properly monitored [3,4]. Radon is also highly soluble in water and can easily contaminate underground water that is mainly used for human consumption and other agricultural activities. Activities such as mining may bring contaminated subsoil to the surface. Thus, baseline data before mining resumes is an absolute requirement for assessing the environmental consequences of mining activities.

Similar studies have been done in other places like India [5] and Eastern Caribbean Islands [6]. Currently, large Uranium deposits have been discovered in the central region of Botswana near a village called Serule, with mining operations expected to commence any time in the area [7]. However, limited research information on naturally occurring radioactive material (NORM) is available in this country [8]. The main goal of the current work is to provide baseline data on NORMs in and around Serule village, where a lot of agricultural activities are ongoing. The study will involve measurements and mapping of activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in soils from the study area. The obtained data will also be used to identify potential radiation hotspots in and around the region and to estimate exposure-induced risks from these upcoming mining and related activities.

2 Experimental Section

2.1 Study area

Serule is a settlement in Botswana's central district, some 350 kilometers north of the capital Gaborone. It is located at latitude 2156'60 S and longitude 2718'0 E. The village and its surrounding area have a population of over 4000 with the majority of them relying on subsistence farming and small livestock. In 2007, an Australian-based mineral exploration company, A-Cap Resources Ltd Company, discovered large deposits of uranium ore weighing over 150 million pounds within a lease mining area of around 70 km^2 [9, 10].

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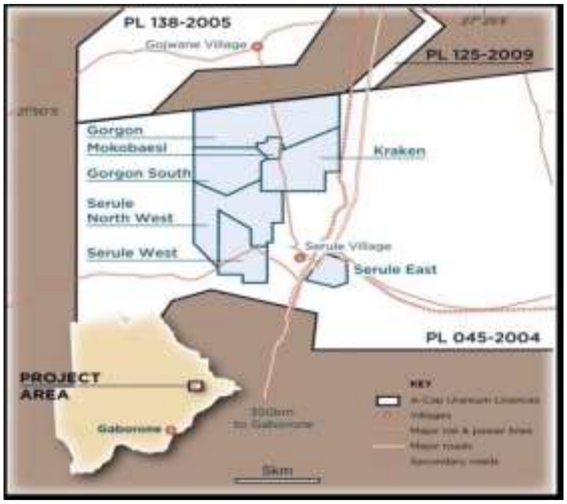

Fig. 1:A-cap resources Uranium mining licensed area in Serule **[**9**].**

2.2 Instrumentation and Measurement of TGRD rates

A Thermo scientific FH 40G-L10 microsievert per hour (μSv/h) survey meter was used in the present work to measure TGRD rates in the air in the Serule village. This digital alert background radiation monitor is used to measure the ambient equivalent dose rate H*(10) of gamma rays and x-rays. It is a health and safety tool. The dosage rate measurement from this device ranges from 10 nSv/h to 100 mSv/h **[**11**]**. The survey meter used has a linear response to gamma radiation in the energy regions 0.030 MeV – 4.4 MeV which covers the majority of the emitted TGRDs **[**12**]**. The Model FH40G-L10 is a stand-alone machine with an inbuilt proportional detector that can work with an external detector at the same time.

Dosage rates of the TGRD rates were collected at 45 different locations within the Serule village using a Thermoscientific FH 40G-L10 microsievert per hour (μSv/h) survey meter. The coordinates of each location were also recorded, using the Global Positioning System instrument from Garmin (GPS Map 76). Due to the scattering of homesteads and limited access to some homesteads within the village, the initially suggested systematic sampling technique was not effective in carrying out the measurements, hence a random sampling technique has to be adopted. Therefore, dose readings were taken at various random locations within the village. At each sampling location, the survey meter was kept 1m above the ground level during measurement. To minimize errors, measurements were collected when the reading on the survey meter was stable, with at least four sets of readings taken from each spot. The meter readings obtained from the instrument were in the units micro-Sievert per hour (μSv/h). The obtained results were then converted to (nGy/h) using the conversion factor 1μSv/h = 1000nGy/h.

2.3 Health Risk Assessment

Contaminants such as radionuclides do not pose a threat unless one has been exposed to them **[**13**]**. The process of determining the nature and probability of adverse health effects in humans who may be exposed to environmental toxins is known as human health risk assessment. This informs decision-makers on the potential consequences of activities, as well as a source of treatment, disposal, and remediation choices, as well as contaminated site clean-up standards. Hazard identification, exposure assessment, toxicity dose–response) assessment, and risk characterization are the four main steps in the risk assessment process. The possibility of incurring injury is described as risk, and the source of risk is hazard. Hazard identification studies the presence, concentration, and spatial distribution of contaminants on a site.

TGRDs were identified as a potential community danger in this investigation. Exposure assessment measures the intensity, frequency, and duration of human exposure to a pollutant. The TGRDs from the research area were used to determine exposure. To calculate cancer risk and hazard indices, risk characterization combines data from hazard identification, exposure assessment, and toxicity evaluation.

2.4 Radiological Risk Assessment

According to Sotiropoulou and Flurou **[**14**],** the assessment of the risk of radionuclides in people is done through the use of several estimate parameters as well as simulation models. For ionizing radiation received and its biological efficiency, some of the numbers and units that were employed in this study were the dose rate in air (D), which was acquired using the survey meter and the results were used to obtain the annual effective dose equivalent (AE). The outdoor annual effective dose rate (OAEDR) was estimated using,

$$OAEDR_{\left(\frac{mSv}{y}\right)} = TGDR_{\left(\frac{nGy}{h}\right)} * \ ET\ x\ OF * \ D_{air} \qquad (1)$$

where *ET* and O*F* are exposure time and occupancy factor respectively, and D(air) is the conversion coefficient from the absorbed dose in air to the effective dose. The occupancy factor for an outdoor effective dose and the conversion coefficient from the absorbed dose in air to the effective dose are 0.2 & 0.7 $Sv.Gy.yr^{-1}$ respectively, while $D_{(air)}$ can be taken as 0.7 x 10^{-6}mSv **[**15**]. E**quation (1) simplifies to,

$$OAEDR_{\left(\frac{mSv}{y}\right)} = TGDR_{\left(\frac{nGy}{h}\right)} * 24h * 365 * 0.2x10^{-6} * D_{air} \qquad (2)$$

The cancer risk (R) was evaluated using,

$$R = AE * AL_T * RF \quad (3)$$

where; (AE) is the Annual effective dose, (AL_T) is the Average life expectancy, and (RF) is the risk factor. AL_T was taken as 70 years and the corresponding risk factor was 5.82 x 10^{-2} **[**16**]**.

2.5 Radiological Mapping

As defined by the International Radiation Protection and Measurement Association, a radiological map is a representation of a place or an apparatus at a specific time in which the location and amount of surface contamination are very clearly displayed using numerals or color codes. A radiological map is created all along the life of a nuclear power plant's infrastructure, first to detect anomalies in its routine operations, then to classify waste and assist decontamination actions during the plant's dismantling phase, and finally to provide proof that corrective measures have been successful when the level of contamination is below a predetermined limit. Radiological mapping necessitates the use of three types of tools: software that generates a geographical representation of the research region, sensors for the detection and measurement of radioactivity, and computation tools that supplement measurements through interpolation and/or mathematical models. The radiological map is used to determine the level of radiation risk **[**17-19**]**. Radiological mapping of the study area was plotted using ARCGIS 9.3 software.

3 Results and Discussion

Table 1 shows outdoor TGRD, and cancer risk calculations together with their corresponding GPS locations. The results show a TGRD range of 80-180 nGy/h with a mean of 117.3nGy/h. The TGRD for the area is about twice higher than the world average of 59 nGy/h. Though the mean TGRD is higher than the world average, it is however lesser than in some areas of literature **[**20**].** The high TGRD rate may be due to the large uranium deposits discovered in the area. The risk of developing fatal cancer from such an exposure ranged from 0.000400 to 0.000899 with an average of 0.000559

Table 1: TGRD rate measurements, OAED, and cancer risk assessments

Location coordinates		Ambient dose (μSv/h)	TGRD (nGy/h)	OAE (mSv/y)	Cancer Risk
South	East				
21.92160	27.28943	0.16	160	0.196160	0.000799
21.92624	27.28966	0.11	110	0.134860	0.000549
21.92492	27.28825	0.09	90	0.110340	0.000450
21.92661	27.28833	0.13	130	0.159380	0.000649
21.92512	27.28978	0.09	90	0.110340	0.000450
21.92716	27.28841	0.08	80	0.098080	0.000400
21.92501	27.28821	0.09	90	0.110340	0.000450
21.92506	27.29008	0.11	110	0.134860	0,.000549
21.92506	27.29008	0.10	100	0.122600	0.000499
21.92333	27.29051	0.14	140	0.171640	0.000699
21.92304	27.29001	0.13	130	0.159380	0.000649
21.92381	27.29349	0.15	150	0.183900	0.000749
21.92552	27.29677	0.13	130	0.159380	0.000649
21.92550	27.29239	0.15	150	0.183900	0.000749
21.92610	27.29377	0.11	110	0.134860	0.000549
21.92615	27.29539	0.10	100	0.122600	0.000499
21.92716	27.29468	0.11	110	0.134860	0.000549
21.92525	27.29437	0.10	100	0.122600	0.000499
21.92556	27.29598	0.10	100	0.122600	0.000499
21.92361	27.29619	0.09	90	0.110340	0.000450
21.92283	27.29509	0.12	120	0.147120	0.000599
21.92238	27.29509	0.13	130	0159380	0.000649
21.92308	27.29592	0.12	120	0.147120	0.000599
21.92398	27.29643	0.12	120	0.147120	0.000599
21.92158	27.2948	0.11	110	0.134860	0.000549
21.92070	27.29364	0.08	80	0.098080	0.000400
21.91795	27.29301	0.12	120	0.147120	0.000599
21.91947	27.29128	0.12	120	0.147120	0.000599
21.91932	27.28926	0.10	100	0.122600	0.000499
21.92072	27.29041	0.18	180	0.220680	0.000899
21.91888	27.2921	0.15	150	0.183900	0.000749
21.91761	27.29263	0.14	140	0.171640	0.000699
21.91917	27.29381	0.15	150	0.183900	0.000749
21.92009	27.29544	0.16	160	0.196160	0.000799
21.91828	27.29506	0.12	120	0.147120	0.000599
21.91698	27.29399	0.10	100	0.122600	0.000499
21.91514	27.29551	0.10	100	0.122600	0.000499
21.91514	27.29551	0.11	110	0.134860	0.000549
21.91257	27.29663	0.12	120	0.147120	0.000599

21.91562	27.30107	0.14	140	0.171640	0.000699
21.91321	27.30298	0.10	100	0.122600	0.000499
21.91222	27.30455	0.11	110	0.134860	0.000549
21.91731	27.30303	0.08	80	0.098080	0.000400
21.91546	27.30439	0.09	90	0.110340	0.000450
21.92100	27.30071	0.14	140	0.171640	0.000699
Average		**0.117**	**117.3**	**0.137089**	**0.000559**

In the isodose map (**Fig 2**) the red color represents locations with the highest TGRD values, which was expected since uranium deposits have been discovered in the area. The average TGRD rate for Serule was found to be higher than those of Japan rated at 50 nGy/h **[**21**]** but was also found to be less than those of Kenya at 440 nGy/h **[**22**]**.

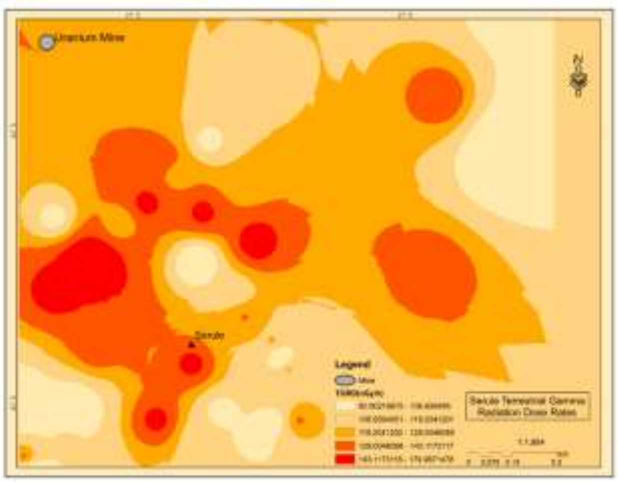

Fig.2: The gamma isodose map of Serule village.

4 Conclusion

The study presents the TGRD rates baseline data for Serule village where uranium mining is expected to commence anytime. The average TGRD of 117.3 nGy/h was found to be twice higher than the world average of 59 nGy/h and understandably so due to large uranium deposits near the village. The results are similar and, in some cases, less than in some places in the literature. The average fatal cancer risk for the area was found to be 0.00586 with an average outdoor annual effective dose of 0.137089 mSv/y. This value is less than the average effective dose for members of the public of 1 mSv/y.

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