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ARTICLE

Estimation of radiation hazard indices from syenite building rocks in the South-western region of Cameroon

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Abstract – Radium equivalent (Ra_{eq}) and external hazard index (H_{ex}) were estimated based on ^{226}Ra, ^{232}Th and ^{40}K measurements in syenite building rocks collected from various sampling sites of Lolodorf area, South-western region of Cameroon to assess the radiation hazards due to the use of these rocks in dwellings construction. The analysis has been carried out by γ-ray spectrometry using a high purity germanium (HPGe) detector. Ra_{eq} varied from 186 ± 4 to $2564 \pm 24\,Bq \cdot kg^{-1}$, while H_{ex} varied from 0.5 ± 0.01 to 6.93 ± 0.06. The corresponding mean values are $1463 \pm 930\,Bq \cdot kg^{-1}$ and 3.95 ± 2.51 in Awanda subdivision while in Madong subdivision, these values are $683 \pm 553\,Bq \cdot kg^{-1}$ and 1.84 ± 1.49, respectively. Absorbed dose rate ranged from 98 ± 2 to $1171 \pm 11\,nGy \cdot h^{-1}$ while annual effective dose ranged from 0.60 to $7.18\,mSv \cdot year^{-1}$. The average absorbed dose rates are $670 \pm 420\,nGy \cdot h^{-1}$ and $313 \pm 245\,nGy \cdot h^{-1}$ in Awanda and Madong, respectively. These average values give rise to a mean annual effective dose of $4.11\,mSv \cdot year^{-1}$ and $1.92\,mSv \cdot year^{-1}$. All syenite building rocks have shown Ra_{eq} activity concentrations higher than the limit set in the Organization for Economic Cooperation and Development ($370\,Bq \cdot kg^{-1}$), equivalent to external gamma dose of $1.5\,mSv \cdot year^{-1}$. The obtained values of the annual external effective dose in Awanda and Madong are higher (nine-fold and four-fold, respectively) than the worldwide mean annual effective dose ($0.48\,mSv \cdot year^{-1}$). The syenite rocks in the corresponding localities can be considered as high radiation's material not recommended for dwellings construction.

Keywords: radium equivalent / external hazard index / syenite building rock / absorbed dose / effective dose

1 Introduction

Syenite is a coarse-grained igneous rock, similar in appearance and composition to granite. Unlike granite, it contains little or no quartz. They are occasionally substituted for granites as building stones. Syenite rock is used worldwide in the glass and ceramic industries. The use of syenite in ceramic industry makes it an important source of radiation exposure. It is known that the syenite rock contains various concentrations of uranium, thorium, radium and their daughters products (Beyala Ateba *et al.*, 2010, 2011). This rock is internationally traded in large quantities. The mining of syenite rock for international trading and its processing and use in the manufacture of glass, therefore, redistributes the radioactive trace elements throughout the environment. Considerable attention has been given to possible exposures of humans to ionizing radiation from external and internal environmental sources. This attention is due to the fact that external radiation exposures from natural radionuclides contribute about one third of the average annual dose to humans from all radiation sources with a great variability due to rock contents and/or altitude (UNSCEAR, 1982, 1993, 2000).

Ele Abiama *et al.* (2010) and Beyala Ateba *et al.* (2010, 2011) studied the background radiation exposure to the public from the Lolodorf area. This study concluded that the concerned region could be said to have a high natural background radiation due to the high concentrations of radium and thorium in soils and rocks samples. Radon and thoron have been measured in some houses of Bikoue and Ngombas of Lolodorf area by Saïdou *et al.* (2015). The results revelled high concentrations of thoron.

Since the syenite is used in dwellings construction in south region of Cameroon, the aim of the present study is to determine radium equivalent activities and the external hazard index in order to decide whether they are acceptable according to the OECD criterion (OECD, 1979).

The radium equivalent activity concentrations, the external hazard index, the outdoor absorbed dose rate and the annual

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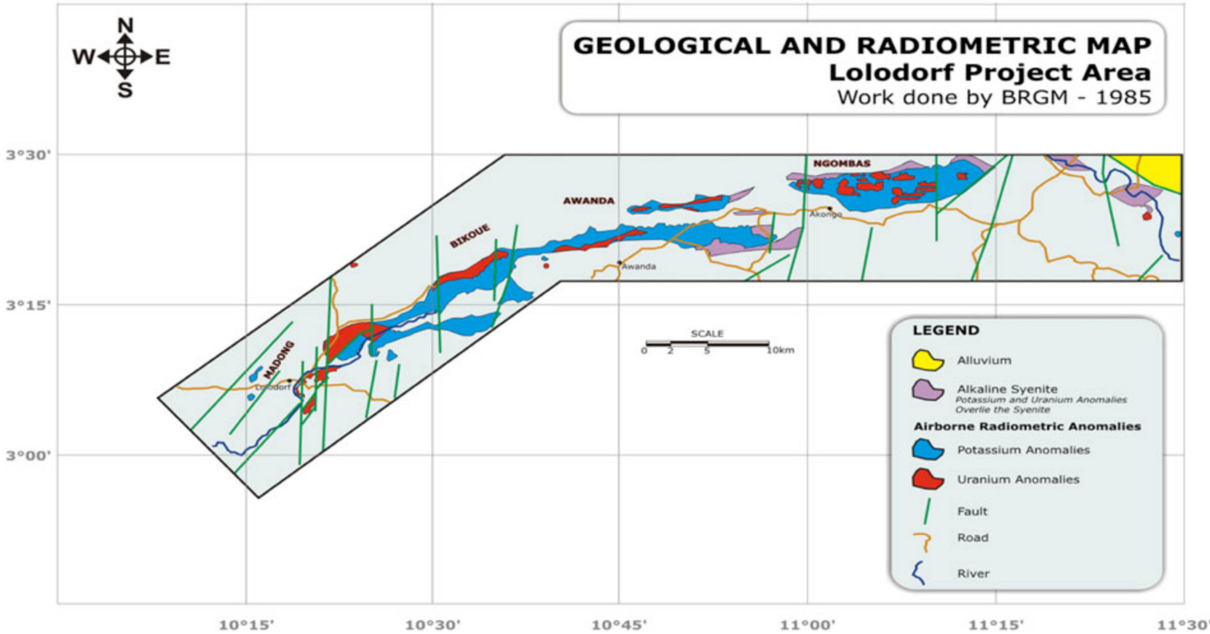

Fig. 1. Geological and radiometric map of Lolodorf area.

effective dose are reported and discussed in the light of the international recommendations. The radiation hazards arising due to the use of syenite building rocks reported in this study can be included into baseline map of radioactivity background levels in Cameroon, which will contribute to improve available data worldwide. The knowledge of radiation level is required by the building construction corporation to adopt preventive measures to prevent from the harmful effects of ionizing radiation.

2 Experimental procedure

2.1 Sampling and sample preparation

The localities of Awanda and Madong can be considered as public areas with intense human activities covering all sectors of the economy (agricultural lands, schools...). Awanda and Madong were thus considered for sampling and include respectively five and six inhabited areas. Each area where five samples have been collected randomly is considered as sampling site. Twenty-five and thirty syenite building rocks were thus collected in Awanda and Madong, respectively (Fig. 1). All samples were brought to the laboratory where they were dried overnight at a temperature of 250 °C, crushed into small pieces and homogenized. The samples were transferred to polyethylene bottles of 87 cm^3 volume and stored for more than 30 days to reach secular equilibrium amongst ^{226}Ra, ^{232}Th, and their short-lived decay products.

2.2 γ-spectrometer and radiation measurements

A γ-ray spectrometer consisted with an n-type HPGe detector (CANBERRA model GR3019) and a multi-channel analyzer (CANBERRA Inspector 2000) was used for the measurement. The energy resolution of 1332.5 keV γ-ray line from ^{60}Co was found to be 1.85 keV at full width of half-maximum (FWHM) with the relative efficiency of 34.9%. The detector was lead shielded (CANBERRA model 777) with 1 mm thick Sn and 1.5 mm thick Cu graded liner of the inside to absorb characteristic X-rays of Pb. Measurement of γ-ray energy range was adjusted to 0–2000 keV and calibrated using a mixed gamma-nuclides source of ^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{137}Cs, ^{88}Y and ^{60}Co. Samples were measured for 6 hours and the obtained γ-ray spectra were analyzed by a γ-ray spectrum analysis software CANBERRA Genie 2000.

Radiation measurements were performed for quantitative determination of radionuclides present in the samples. The main objective was the determination of the specific activity concentration of ^{226}Ra, ^{232}Th and ^{40}K using γ-ray spectrometry. The activity concentrations of natural radionuclides in samples were calculated following the method described by Beyala Ateba *et al.* (2010).

3 Estimation of radiological hazard

The radium equivalent Ra_{eq} was estimated by using Beretka and Mathew (1985) relation. According to Stranden (1976) and Krisiuk *et al.* (1971), it is assumed that 370 $Bq \cdot kg^{-1}$ of ^{226}Ra, 259 $Bq \cdot kg^{-1}$ of ^{232}Th and 4810 $Bq \cdot kg^{-1}$ of ^{40}K produce the same gamma ray dose rate. A radium equivalent of 370 $Bq \cdot kg^{-1}$ in building materials will produce an exposure of about 1.5 $mSv \cdot year^{-1}$ to the inhabitants (UNSCEAR, 1982).

The model proposed by Krieger (1981) was used for the calculation of external hazard index H_{ex}.

The total air absorbed dose rate ($nGy \cdot h^{-1}$) due to the mean specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K was calculated using the formula given by UNSCEAR (1993).

In order to estimate the annual effective dose rates, the conversion coefficient from the absorbed dose in air to the effective dose ($0.7\ Sv \cdot Gy^{-1}$), the outdoor occupancy factor (0.2) and the indoor occupancy factor (0.8) proposed by UNSCEAR (2000) were used. Since the objective of the study

Table 1. Analytical result of rock samples from Awanda.

Location	Sampling site ID	Number of samples	Mean radioactivity concentration ($Bq \cdot kg^{-1}$)			Dose rate ($nGy \cdot h^{-1}$)	Radiation hazard indices	
			^{226}Ra	^{232}Th	^{40}K		Ra_{eq} ($Bq \cdot kg^{-1}$)	H_{ex}
Awanda	AW-01	05	350 ± 9	577 ± 8	2106 ± 30	608 ± 10	1337 ± 22	3.61 ± 0.06
	AW-02	05	1184 ± 11	801 ± 7	3050 ± 38	1171 ± 11	2564 ± 24	6.93 ± 0.06
	AW-03	05	7 ± 1	9 ± 1	2164 ± 25	98 ± 2	186 ± 4	0.50 ± 0.01
	AW-04	05	1303 ± 9	499 ± 4	1597 ± 23	978 ± 8	2139 ± 16	5.78 ± 0.04
	AW-05	05	174 ± 6	514 ± 6	2300 ± 27	496 ± 6	1086 ± 14	2.93 ± 0.04
	Mean[a]	–	**604 ± 598**	**480 ± 290**	**2243 ± 524**	**670 ± 420**	**1463 ± 930**	**3.95 ± 2.51**

[a] Uncertainties show standard deviations of the gamma-ray counts.

Table 2. Analytical result of rock samples from Madong.

Location	Sampling site ID	Number of samples	Mean radioactivity concentration ($Bq \cdot kg^{-1}$)			Dose rate ($nGy \cdot h^{-1}$)	Radiation hazard indices	
			^{226}Ra	^{232}Th	^{40}K		Ra_{eq} ($Bq \cdot kg^{-1}$)	H_{ex}
Madong	MA-01	05	18 ± 2	299 ± 3	1580 ± 18	260 ± 4	567 ± 8	1.53 ± 0.02
	MA-02	05	21 ± 1	183 ± 4	1861 ± 22	201 ± 4	426 ± 8	1.15 ± 0.02
	MA-03	05	38 ± 1	78 ± 1	1050 ± 6	110 ± 1	230 ± 3	0.62 ± 0.01
	MA-04	05	283 ± 6	819 ± 6	1995 ± 22	723 ± 8	1607 ± 18	4.34 ± 0.04
	MA-05	05	89 ± 2	580 ± 2	1990 ± 16	485 ± 3	1072 ± 6	2.89 ± 0.02
	MA-06	05	18 ± 1	20 ± 1	1902 ± 14	99 ± 2	193 ± 4	0.52 ± 0.01
	Mean[a]	–	**78 ± 104**	**329 ± 311**	**1730 ± 366**	**312 ± 245**	**683 ± 553**	**1.84 ± 1.49**

[a] Uncertainties show standard deviations of the gamma-ray counts.

is to estimate radiological hazards from building rocks, it is very important to take into account both components of annual effective dose.

4 Results and discussion

Tables 1 and 2 present the concentrations of ^{226}Ra, ^{232}Th and ^{40}K, the absorbed dose rate, the radium equivalent activity concentrations and the external hazard index due to syenite building rocks collected from five and six sampling sites of Awanda and Madong, respectively.

Maximum and minimum radium equivalent activity values are $2564 \pm 24\ Bq \cdot kg^{-1}$ and $186 \pm 4\ Bq \cdot kg^{-1}$ calculated in building rock samples from sampling sites AW-02 and AW-03, respectively. The Ra_{eq} of syenite rocks from four sampling sites of Awanda, namely (AW-01, AW-02, AW-04 and AW-05) and four sampling sites of Madong (MA-01, MA-02, MA-04 and MA-05) were higher than the international accepted value of $370\ Bq \cdot kg^{-1}$.

According to Tables 1 and 2, absorbed dose rates estimated at a height of 1 m above the ground surface ranged from 98 ± 2 to $1171 \pm 11\ nGy \cdot h^{-1}$ with average of $670 \pm 420\ nGy \cdot h^{-1}$ and $313 \pm 245\ nGy \cdot h^{-1}$ in the villages of Awanda and Madong, respectively. Ra_{eq} activity concentrations varied from 186 ± 4 to $2564 \pm 24\ Bq \cdot kg^{-1}$, while H_{ex} varied from 0.5 ± 0.01 to 6.93 ± 0.06. The corresponding mean values are $1463 \pm 930\ Bq \cdot kg^{-1}$ and 3.95 ± 2.51 in Awanda while in Madong these values are $683 \pm 553\ Bq \cdot kg^{-1}$ and 1.84 ± 1.49, respectively. Annual effective doses ranged from 0.60 to $7.18\ mSv \cdot year^{-1}$ with mean values of $4.11\ mSv \cdot year^{-1}$ and $1.92\ mSv \cdot year^{-1}$ in Awanda and Madong respectively. These values are about nine-fold and four-fold higher, respectively than the resulting worldwide mean annual effective dose.

Similar studies focused on radiation hazard indices from cement, tiles, gravel and bricks have been done in the world (Amrani and Tahtat, 2001; Kumar *et al.*, 2003; Ngachin *et al.*, 2007; Mehdizadeh *et al.*, 2011). From the radiological point of view, the results of the various radiation hazard indices for the corresponding studies are all lower than the maximum permissible levels.

According to the study of radioactivity levels in granite of Gable Gattar II in the north eastern desert of Egypt (El-Shershaby, 2002), radium equivalent and external hazard index were found to be $28317\ Bq \cdot kg^{-1}$ and 77, respectively. These values are typical for the region under study. According to the radiation hazard indices, syenite rocks examined in the framework of this study are not acceptable for use as building material as defined by the OECD criterion.

5 Conclusion

The radium equivalent activity concentrations and the external hazard indices obtained for the syenite building rocks in this study were higher than the criterion limit. Therefore, the use of these materials in dwellings construction is considered to be unsafe for inhabitants according to OECD (1979). The health hazard of inhabitants due to natural background radiation from syenite rocks used in dwellings construction in South-western region of Cameroon can be significant. The data obtained in this work are reference values to be used as a data baseline for drawing a radiological map of the region.

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