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Gamma radiation dose rate measurements in granite quarries and schools in two mountainous towns in Benin

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Abstract: The radiation protection of the public against ionizing radiation emitted by natural sources from the earth's crust is a public health issue. The aim of this study, carried out in the granite quarries and schools of the towns of Glazoue and Dassa-zoume, is to assess the population's external exposure to ambient gamma radiation emitted by natural radionuclides (^{238}U, ^{232}Th, ^{40}K, etc.). It covered the dry season from January to April 2021. 12 quarries and 39 schools were included in the study. 510 ambient gamma dose equivalent rates were carried out during the study period with the radiometer and the portable NaI gamma detector simultaneously. For comparison purposes, ten (10) measurements were taken in the city of Cotonou. Gamma dose equivalent rates in the quarries of both cities ranged from 0.11 to 0.40 µSv/h, with an average of 0.255 µSv/h. Those for primary and secondary schools vary from 0.08 to 0.40 µSv/h, with an average of 0.24 µSv/h. The average dose equivalent rate recorded at Cotonou is is 0.045 µSv/h. The effective dose for a resident crusher ranges from 1.10 to 2.80 mSv/yr, with an average of 2.10 mSv/yr. Those for non-resident crushers range from 0.6 to 1.4 mSv/yr. Those for schools range from 0.144 mSv/yr to 0.432 mSv/yr, with an average of 0.252 mSv/yr. The effective dose obtained for granite crushers is higher than the value mentioned in the 2008 UNSCEAR report for outdoors and indoors exposure to terrestrial and cosmic radiation, which is equal to 0.87 mSv/yr.

Keywords: natural radionuclide, public health, radiometer, effective dose, granite crushers.

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Mesures des débits de dose de rayonnement gamma dans les carrières granitiques et les écoles de deux villes montagneuses du Bénin

Résumé: La radioprotection du public contre les rayonnements ionisants émis par des sources naturelles de croûte terrestre et cosmique est une question de santé publique. Cette étude, réalisée dans les carrières de granit et les écoles des communes de Glazoué et de Dassa-zoumé, a pour objectif d'évaluer l'exposition externe de la population aux rayonnements gamma ambiants émis par les radionucléides naturels (^{238}U, ^{232}Th, ^{40}K, etc.). Elle couvre la saison sèche de janvier à avril 2021. 12 carrières et 39 écoles ont été incluses dans l'étude. 510 débits d'équivalent de dose gamma ambiants ont été réalisés pendant la période d'étude avec un radiamètre et un détecteur gamma portatif à NaI simultanément. A titre de comparaison, dix (10) mesures ont été effectuées dans la ville de Cotonou. Les débits d'équivalent de dose gamma dans les carrières des deux villes varient de 0,11 à 0,40 µSv/h, avec une moyenne de 0,255 µSv/h. Ceux des écoles primaires et secondaires varient de 0,08 à 0,40 µSv/h, avec une moyenne de 0,24 µSv/h. Le débit moyen d'équivalent de dose enregistrés à Cotonou est de 0,045 µSv/h. La dose efficace pour un concasseur résident varie de 1,10 à 2,80 mSv/an, avec une moyenne de 2,10 mSv/an. Celles des concasseurs non résidents vont de 0,6 à 1,4 mSv/an. Celles des écoles vont de 0,144 mSv/an à 0,432 mSv/an, avec une moyenne de 0,252 mSv/an. La dose efficace obtenue pour les concasseurs de granit est supérieure à la valeur mentionnée dans le rapport 2008 de l'UNSCEAR pour les expositions du public aux rayonnements terrestres et cosmiques à l'extérieur et l'intérieur des habitations, qui est égale à 0,87 mSv/an.

Mots-clés: santé publique, radionucléides naturels, radiomètre, dose efficace, concasseurs de granit.

1. INTRODUCTION

As indicated by Zinsou et al. (2014), granite is a hard, crystalline magmatic rock composed of feldspar, quartz (containing crystalline silica) and mica. Because of its geomorphological characteristics, granite is of great interest as a source of strength materials appreciated by civil engineering and road and habitat construction companies on the one hand, and as a socio-economic, cultural and artistic source on the other [1]. Thus, the exploitation of boulders is a widespread activity in the hills of Benin. Studies by Dossou et al. (2014) and Aballo et al. (2007) in the granite quarries of Glazoue have shown that women and small children are involved in artisanal crushing all day long [2]. These studies showed the presence of significant chromosomal aberrations among granite stone crushers in the Glazoue quarries. Are these anomalies radio-induced or chemical effects?. These result from the process of unfaithful repair of molecular damage to DNA strands induced by human exposure to sources of ionizing radiation. The International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection (ICRP) recognize rocks and soils as a natural source of ionizing radiation of terrestrial origin, and include them in the category of existing exposure situations [3-5].

Uranium-238 and uranium-235 are alpha emitters with half-lives of 4.47 billion and 7.04 billion years respectively. They each have thirteen main alpha, beta and gamma emitting radioactive descendants, including radon-222 with a half-life of 3.82 days, radon-219 with a half-life of 3.96s and uranium-234 with a half-life of 0.246 million years. Uranium-238 with its three descendants, thorium-234 with a half-life of 24.1 days, metastable protactinium-234 with a half-life of 1.18 minutes, and uranium-234 are mainly ingested, and concentrate mainly in the bones and kidneys [6].

As described by Delacroix et al. (2006), the emission spectrum of 238U is characterized by the 113.5 keV (0.0174%) and 49.55 keV (0.0697%) gamma-ray photon lines. Uranium-235 is characterized by the 185.72 keV gamma ray (57%). Postassium-40 with a half-life of 1.2504E9 years is a beta+ (β+) emitter followed by electron capture with a probability of 10.75%. The β+ decay of potassium-40 yields argon-40. It also undergoes beta- (β-) decay in 89.25% and gives calicium-40. The characteristic energy of the emitted positron (e+) is 1504.69 keV. That of the negaton (e-) is equal to 1311.07 keV. Thus, the decay of potassium-40 is accompanied by gamma-ray energy lines of 511 keV from positron annihilation and 1460.82 keV from beta- (β-) decay [7]. These energies are the main source of daily public exposure. As a result, schoolchildren are exposed to gamma energies all day, every day.

According to the UNSCEAR report (2008), the outdoors means absorbed dose rate in air in Africa range 0.048 to 0.054 µGy/h with average 0.051 µGy/h in Libyan Arab Jamahiriya, 0.08 to 0.126 µGy/h with average 0.098 µGy/h in Mauritius and 0.098 to 0.121 µGy/h with average 0.104 µGy/h in Tanzania. The absorbed dose rate in air in North America range 0.031 to 0.075 µGy/h with average 0.054µGy/h in Canada and 0.023 to 0,184 µGy/h with average 0.0883 µGy/h in Mexico. In Central America, the absorbed dose rate in air range 0.035 to 0.147 µGy/h with average 0.0659 µGy/h in Costa Rica and 0.038 to 0.196 µGy/h with average 0.055 µGy/h in Cuba. In East Asia, the dose rate in air range 0.0116 to 0.523 µGy/h with average 0.0815 µGy/h in China, 0.045 to 0.102 µGy/h with average 0.0675 µGy/h in Indonesia and 0.018 to 0.20 µGy/h with average 0.079 in Korea. The average absorbed dose rate in air is 0.079 µGy/h and 0.045 µGy/h respectively in Taiwan and Philippens. In West Asia, the absorbed dose rate range 0.032 to 0.094 µGy/h with average 0.065 µGy/h in Turkey. In North Europe, the absorbed dose rate range 0.056 to 0.101 µGy/h with average 0.066 µGy/h in Denmark, 0.077 to 0.171 µGy/h with average 0.103 µGy/h in Finland, 0.079 to 0.115 µGy/h with average 0.095 µGy/h in Lithuania, 0.040 to 0.63 µGy/h with average 0.097 µGy/h in Sweden. In West Europe, the absorbed dose rate range 0.045 to 0.12 μGy/h with average 0.076 μGy/h in Belgium, 0.057 to 0.243 μGy/h with average 0.112 μGy/h in Italy [8].

Thus, each country assesses the level of external exposure to natural sources of ionizing radiation. Anjos et al. (2011) showed in Brazil that the external gamma radiation dose equivalent rate in commercial granites is 0,12 μGy/h [9]. Lespukh et al. (2013) assessed the external gamma dose rate at uranium mining sites in Asia. This study revealed effective doses of the order of 10 mSv/yr [10]. These levels compared to the absorbed dose rate data reported in the literature in Canada, Mexico, Costa Rica, Cuba, China, Indonesia, Korea, Taiwan, the Philippines, Turkey and Denmark are considered high [8]. The same objectives were pursued by Masahiro et al. (2015) in a study carried out in India in the city of Kerala. In August 2019, Takoukam et al. (2019) showed that radon-222 concentrations ranged from 31 ± 1 to 436 ± 12 Bq/m^3 in the city of Douala, Cameroon, using the RADUET CR-39 detector [11]. As demonstrated by Zinsou et al. (2023), several scientific studies have been carried out in various African countries to assess public exposure to natural sources of ionizing radiation, in this case radon [12].

Vaupotic et al. (2000; 2012) assessed the ambient gamma dose equivalent rate in schools in Slovakia, using an HpGe spectrometer [13,14]. Oikawa et al. (2005) investigated radon concentration in workplaces (school, office, hospital and factory) using the SSNTD[1] CR-39 detector as a function of season [15]. Clouvas et al. (2009) used a portable gamma spectrometer to measure indoor radon in 77 schools in the Xanthi prefecture in northern Greece [16]. The same authors carried out dose equivalent rate measurements in 512 schools in 8 Greek regions in 2011. Ciolini et al. (2010) measured radon concentration in 91 schools using the SSNTD detectors in Italy in 2010 [17]. Obed et al. (2011) measured radon concentration using the SSNTD detectors in 35 secondary schools in Nigeria [18]. Bochicchio et al. (2013) measured indoor radon in 334 elementary schools in 13

[1] Solid State Nuclear Track Detectors.

municipalities in southern Serbia using the SSNTD type CR-39 detectors [19]. Bossew et al. (2013) measured indoor radon in 340 elementary schools using the SSNTD type CR-39 detectors in Serbia [20].

Benin's geology features granitic zones, including the hills of Benin. More than four (04) cities with large populations are located in the hills of Benin. These populations are involved in practices involving granites. It is important to assess the level of terrestrial ionizing radiation and cosmic radiation in the granite quarries and in the schools of the hills of Benin, mainly in the towns of Glazoue and Dassa-zoume, in order to compare these national values with the thresholds recommended by the international community. The objective of this studies is to asses external gamma radiation doses from the ground in granitic zones and in building materials.

1.1. Frame

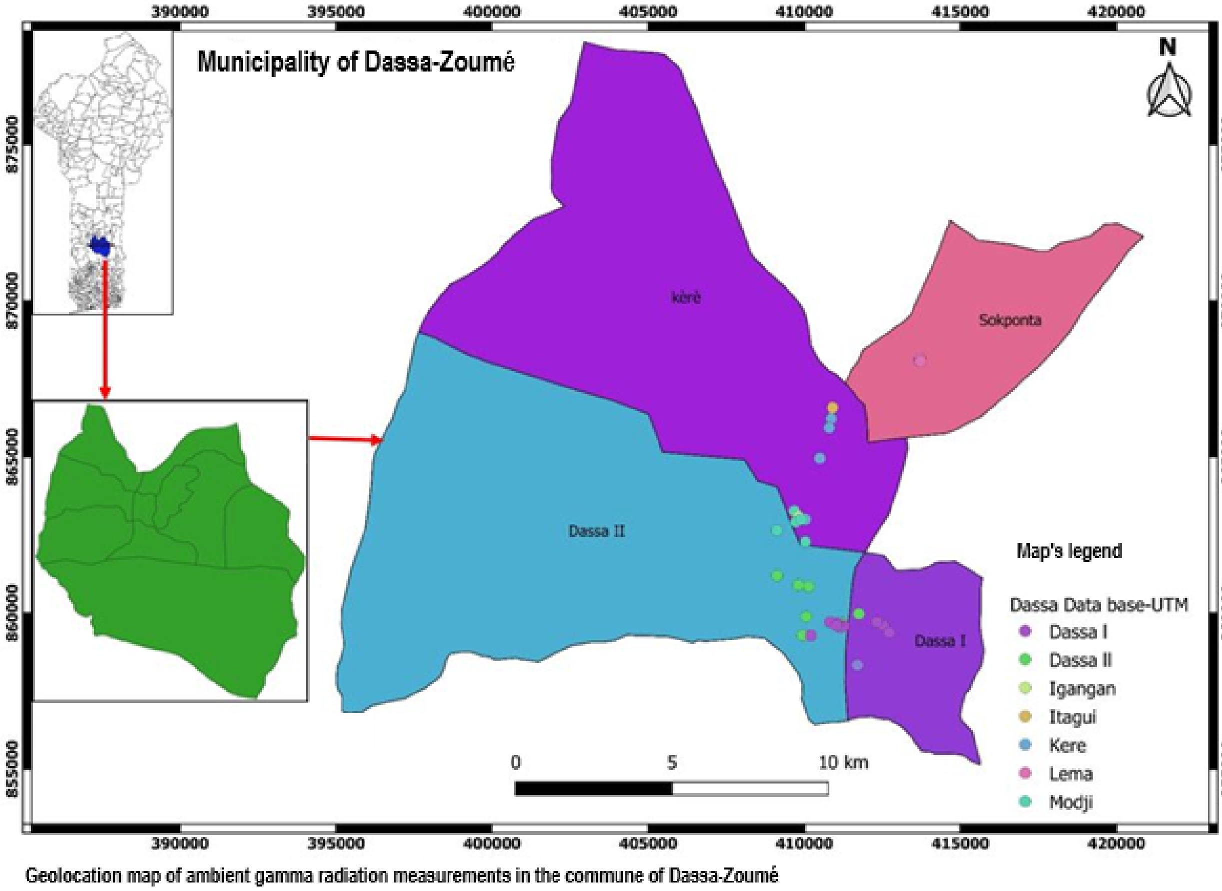
The present study was carried out in twelve (12) artisanal granite crushing quarries and thirty-nine (39) schools in both cities. Each site was subdivided into ten measuring points.

1.1.1. The town of Dassa-zoume

Dassa-zoume is a town in the Collines department of Benin, around 203 km from Cotonou [21]. This department lies between 7° and 8° North latitude and meridians 1°60' and 2°80' East longitude. The climate in Dassa-zoume ranges from equatorial to transitional tropical. Subdivided into ten (10) districts, Dassa-zoume has a dry season and a rainy season. Average rainfall is around 1,200 mm/year. Temperatures range from a low of 21°C to a high of 36°C. Evaporation is estimated at around 1,332 mm/year [22]. In Dassa, there are rocky outcrops that encourage the development of raw mineral soils unsuitable for agriculture. These rocky detachments constitute artisanal crushing sites for the local population. They work there all day long, along with their off-spring. As illustrated in the legend in Figure 1, Our work was carried out in five (05) districts, namely: Dassa I, Dassa II, Kere, Tre and

Lema. In Figure 1 you can observe the geolocation of the environment under study of the Dassa-zoume.

Figure 1: Geolocation map of the town of Dassa-zoume showing the sites studied.

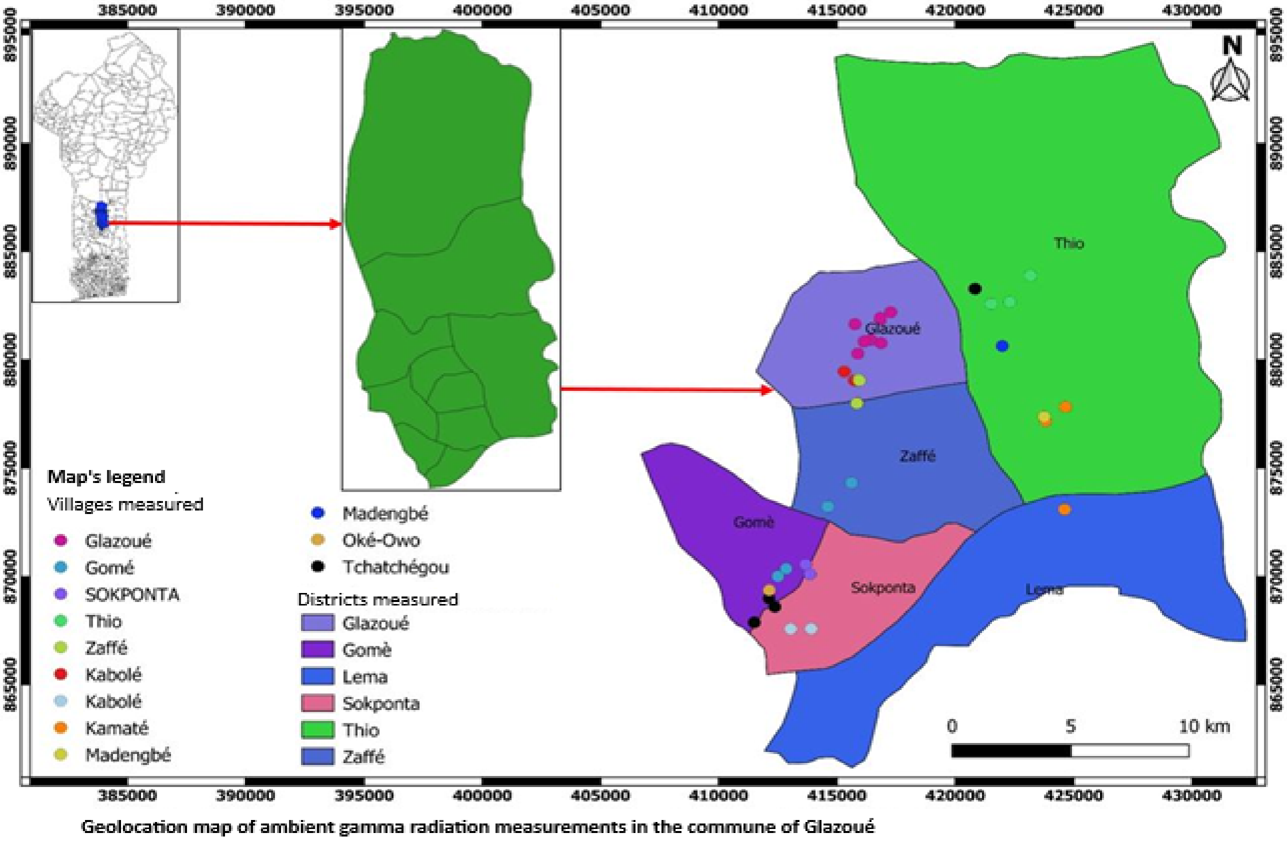


1.1.2. The town of Glazoue

The town of Glazoue is located in the collines department, 234 km north of Cotonou on the southern part of Benin's crystalline plateau. It is bordered by the towns of Dassa-Zoume, Save, Bante, Ouesse and Savalou. With a surface area of 1,750 km^2, it comprises 10 districts with 48 villages [22]. It forms part of the crystalline peneplain in a basement zone in a syntectonic granite complex similar to that of Dassa-zoume. The women and children reported that they crush stone every day from 7am to 7pm in the various quarries located there. There is a dry season and a rainy season. Average rainfall is around 1,200 mm/year.

Temperatures range from a low of 21°C to a high of 36°C. Evaporation is estimated at around 1,332 mm/year. Our work was carried out in five (05) districts, namely: Gome, Sonkpota, Thio, Zaffe and Glazoue. The figure 2 shows the geolocalized map of the sites explored in the town of Glazoue. In Figure 2 you can observe the geolocation of the environment under study of the Glazoue town.

Figure 2 : Geolocalized map of the Glazoue towns showing the sites studied.



2. MATERIALS AND METHODS

2.1. Survey form

A survey form was drawn up and used to select the twelve (12) crushing quarries and thirty-nine (39) schools. Three selection criteria were used: the granite nature of the site, the presence of the site in one of the boroughs of the two cities, and the artisanal use of the quarry by local residents. All schools in the districts of both cities are included in the study.

2.2. Measuring equipment

2.2.1. Radiometer AT1123

The AT1123 from APVL is a new-generation scintillation radiameter. It is part of the 55056 series. The figure 3 shows the image of the AT1123. It is equipped with a plastic scintillation detector (30mm×15mm) and a photomultiplier tube. Ideally suited to measurements X-rays, continuous, pulsed and gamma fields, its measurable energy range extends from 15 keV to 10 MeV. Its energy response is ± 25% in the 60 keV to 3 MeV range. The dose equivalent rate ($\dot{H}^*(10)$) measurement range for a continuous field is from 50 nSv/h to 10 Sv/h. It was calibrated by APVL on June 14, 2019 with Cesium-137. The calibration certificate reference is n° AT1123_ECPE55056_0519. Its maximum acceptance tolerance for measured values is 15%. In Figure 3, the radiometer mentioned in the study can be seen in partial view.

Figure 3: Radiameter AT1123 (APVL) © ZINSOU, 2021.

2.2.2. Spectrometer AT6102

The Identifinder AT6102 is a portable spectrometer. The figure 4 shows the image of the AT6102. It features two (02) types of integrated ionizing radiation detectors. These are:

- highly sensitive scintillation detector with NaI(Tl) crystal, 40x40 mm detection field, used to detect gamma radiation, gamma sources and radioactive contamination. It measures the energy distribution of gamma radiation and identifies radionuclides. It measures the ambient equivalent dose rate of $\dot{H}^*(10)$ gamma radiation;

- Geiger-Muller counter to detect gamma radiation and extend the gamma radiation dose rate measurement range up to 100 mSv/h;

- two proportional slow neutron counters, placed in a polyethylene moderator and used for neutron radiation and neutron source detection, and $\dot{H}^*(10)$ neutron radiation dose rate estimation.

Figure 4: The AT6102 spectrometer and its applications.

Reference: ATOMTEX, AT6102 spectrometer user manual.

Spectrometer sensitivity values as a function of recorded radiation type, radiation type and integrated detectors are shown in Table 1.

Before the start of the gamma-ray measurement on each site, the spectrometer is calibrated using the manufacturer's potassium-40 source.

Table 1: Technical specifications of the AT6102 spectrometer.

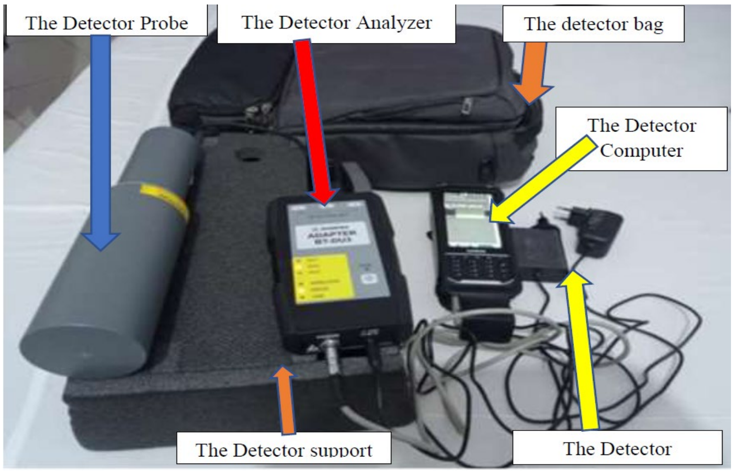
N°	Detector type	Type of radiation, radionuclides and radiation energy (keV)	Detector sensitivity $(\frac{cps}{\mu Sv/h})$
1	NaI(TI) 40x40 mm	Gamma rays ^{241}Am, 59.5	5600
		Gamma rays ^{137}Cs, 662	670
		Gamma rays ^{60}Co, 1250	330
2	Geiger-Muller counter	Gamma rays ^{137}Cs, 662	0.2
3	Neutron Counter	Neutron radiation ^{252}Cf, 2.13E3	0.67

Reference: ATOMTEX, AT6102 spectrometer user manual.

2.2.3. Backpack Atomtex ADAPTER BT-DU3

The figure 5 shows the image of the Backpack equipment. It is a large gamma and neutron (Ø63x63 mm) detector. It is used for the scanning of the gamma radiation with real time identification and categorization (NORM[2], medical, industrial and nuclear). The detectors' BTDUs (BlueTooth Detectors Units) are responsible for powering the detectors and transmitting data via a Bluetooth wireless connection to a laptop or handheld computer. It is also a neutron radiation source search tool. It has a GPS-referencing of measurement data.

Figure 5 : Backpack ADAPTER BT-DU3. © ZINSOU, 2023.



[2] Naturally Occurring Radioactive Material.

2.2.4. Physical measurement method

This external gamma radiation physical measurement study covered the dry season period from January to April 2021. One hundred and twenty (120) measurements were carried out simultaneously with the AT1123 survey meter and the AT6102 spectrometer at 12 granite quarries. Three hundred and ninety (390) measurements were carried out simultaneously with the AT1123 survey meter and the AT6102 spectrometer at 39 schools. Sites were identified by GPS coordinates. Background radiation was measured 100 m from each site, in a rock-free environment. Equivalent dose rates were measured at ten (10) points at each site, providing a representative measure-ment. For a comparative study, it was carried out equivalent dose rate measurements in the city of Cotonou, 225 km from the two study cities. A total of 510 equivalent dose rates were measured in the quarries and schools of the two municipalities with the radiometer AT1123 and the AT6102 portable spectrometer.

With the Back-Pack, we carried out the scanning of the two municipalities. The system records data on natural ionizing radiation equivalent dose rates on a continuous basis. Each value is recorded under a GPS-references following the operator's itinerary. The system generates an operating file called "waypoints.klm" (AT6101C) which contains all the GPS coordinates of the measurements made. This file is used in the Google Earth or GARM (Geolocation Application for Radiation Monitoring) software to produce distribution maps of the dose rates of the external exposure of the public in the two municipalities. A total of 2995 measurements of external equivalent dose rates were carried out by back-pack.

The formula below based on the 2008 UNSCEAR report was used to determine the annual radiological detriment (annual effective dose) of a potential user of artisanal crushing quarries (UNSCEAR, 2008).

$$\boldsymbol{E\ (mSv) = \dot{H}^{*}(10) \times t \times N}$$

Where:

E = annual effective dose; $\dot{H}^*(10)$ = average ambient equivalent dose rate expressed in μSv/h; t = estimated time of artisanal crushing practice per day and N = number of days of practice per year.

For non-resident granite crushers, N = 12 x 30 days, t = 12 hours. t x N = 4320 hours of exposure per year.

For a person living in the vicinity of artisanal crushing quarries, N = 365 x 24 hours, i.e. 8760 hours of exposure per year.

For schools, N = 9 months = 9 x 20 = 180 days and t = 8 hours/days, i.e. 1,440 hours of exposure per year.

We carried out a descriptive analysis of the data obtained with Normality test " Shapiro-Wilk ". The statistical analysis was done with R Software version 4.3.2 (2023-10-31 ucrt) with studio interface.

3. RESULTS AND DISCUSSIONS

3.1. Results

The results of the ionizing radiation measurements are twofold. Measurements taken in the granite quarries at Glazoue and Dassa-zoume, and those taken in the city of Cotonou.

The average equivalent dose rate recorded in Cotonou is 0.045 μSv/h, with an uncertainty of 3%. The table 2 show the results for ambient equivalent dose rates in the quarries in Glazoue and Dassa-zoume.

Table 2 : Ambient equivalent dose rates at twelve (12) granite quarry sites in the towns of Glazoue and Dassa-zoume.

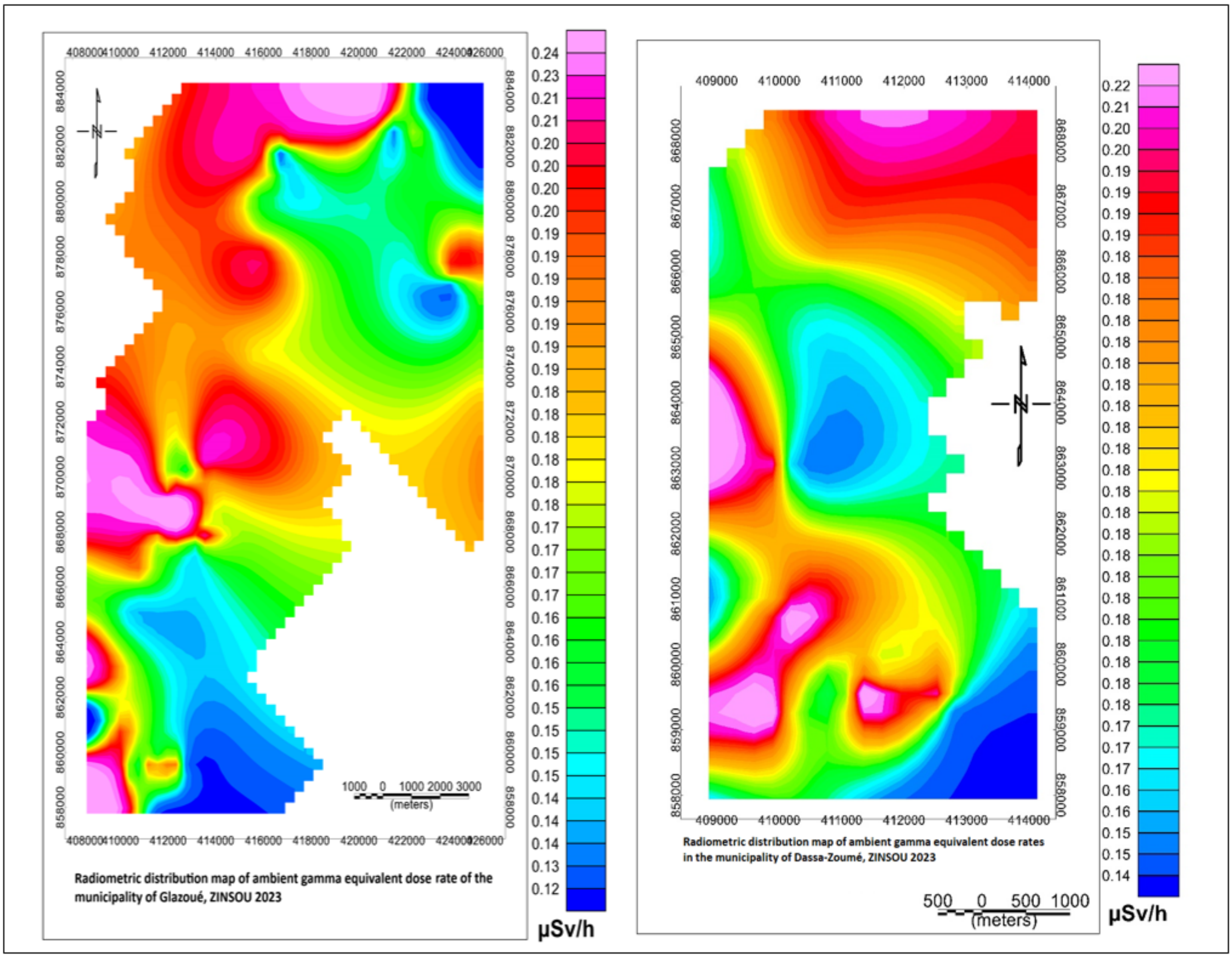
N°	Site name	GPS coordinates	Dose equivalent rate in µSv/h. Uncertainties ± 3%.			
			Values with AT1123.		Values with AT6102.	
			Maxi	Mini	Maxi	Mini
			TOWN OF GLAZOUE			
1	Kamate quarry (Itchakakpa)	7°52'15.3"N2°13'06.9"E	0.35	0.18	0.24	0.20
2	Madengbe quarry	7°56'05.9"N2°18'31.3"E	0.17	0.13	0.15	0.11
3	MOTA quarry	7°51'26.2"N2°12'18.4"E	0.28	0.24	0.32	0.21
4	Oke-Owo quarry	7°57'21.7"N2°17'53.7"E	0.16	0.14	0.17	0.13
5	Quarry 2, Mota crushing plant	7°59'24.5"N2°16'53.8"E	0.30	0.21	0.30	0.20
6	Tchatchegou Igbode quarry	7°56'32.1"N2°14'11.1"E	0.34	0.18	0.33	0.15
7	Lakoun quarry (Itchegou)	7°51'38.7"N2°12'10.4"E	**0.4**	0.25	**0.36**	**0.24**
			TOWN OF DASSA-ZOUME			
8	Modji quarry	7°48'32.2"N2°10'50.9"E	0.28	0.17	0.20	0.16
9	Lema quarry	7°51'08.8"N2°13'01.3"E	0.40	**0.27**	0.33	0.22
10	Issalou SOS quarry	7°47'13.5"N2°11'05.9"E	0.25	0.18	0.23	0.16
11	Modji C quarry	7°48'21.0"N2°10'52.6"E	0.28	0.19	0.24	0.16
12	Igangan quarry	7°48'26.3"N2°10'55.4"E	0.30	0.21	0.30	0.20

As seen in table 2 that the equivalent dose rate varies from 0.24 to 0.4 µSv/h in artisanal crushing quarries. The average equivalent dose rate is estimated at (0.32 ± 0.03) µSv/h (320 nSv/h).

The quarries at Lakoun in Itchegou in the town of Glazoue and in the arrondissement of Lèma in the town of Dassa-zoume recorded the highest equivalent dose rate values (0.40 ± 0.03) µSv/h. These values far exceed those obtained in Cotonou.

The figure 6 shows the radiometric distribution maps of ambient gamma equivalent dose rates in both towns.

Figure 6: Radiometric distribution maps of ambient gamma equivalent dose rates in both towns.

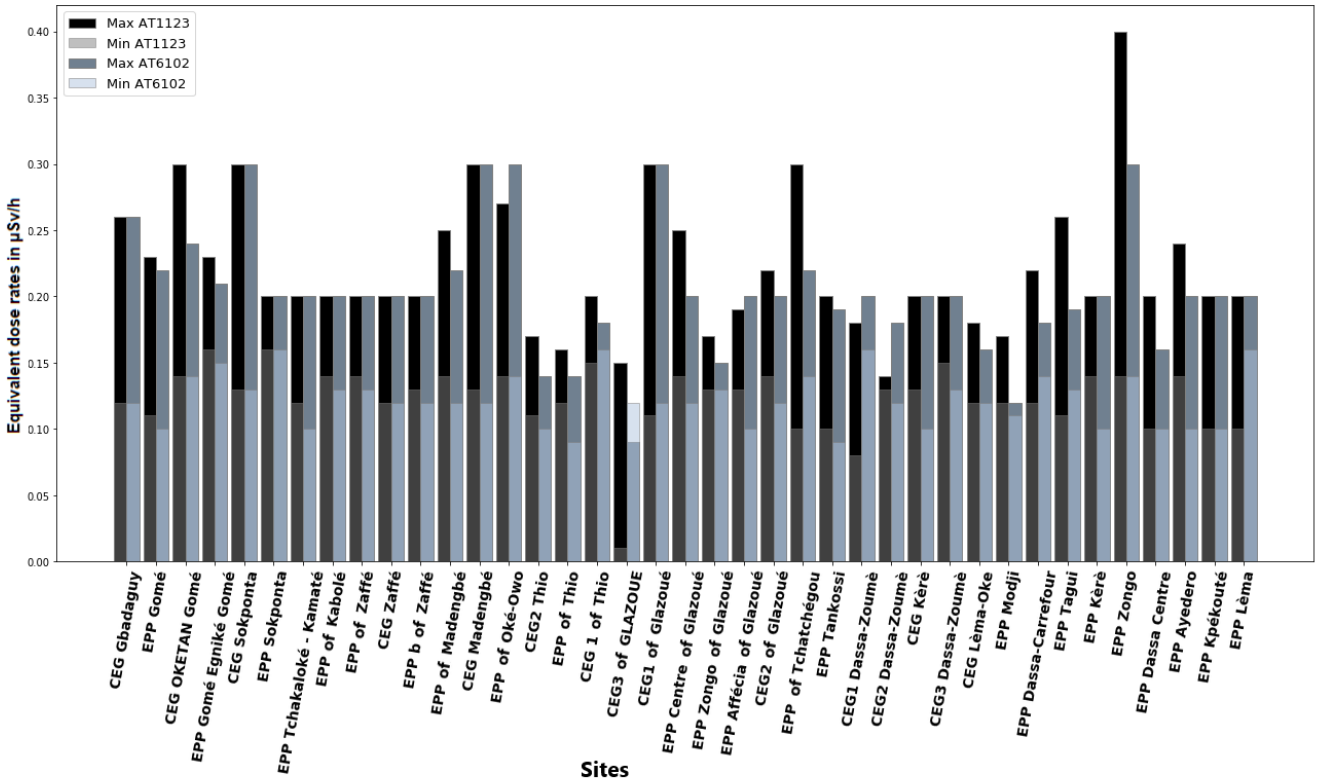


3.2. Measurements of ambient gamma equivalent dose rates in schools in the towns of Glazoue and Dassa-zoume

The figure 7 shows the ambient gamma equivalent dose rates in primary and secondary schools in both towns.

As seen in figure 7 that the dose equivalent rate varies from (0.10 to 0.40) ± 0.03 µSv/h in primary and secondary schools in the towns of Glazoue and Dassa-zoume. The average equivalent dose rate is estimated at 0.25 ± 0.03 µSv/h. Kere public elementary school has the highest equivalent dose rate in the sample. 80% (31 schools) of schools have a equivalent dose rate greater than or equal to 0.20 ± 0.03 μSv/h.

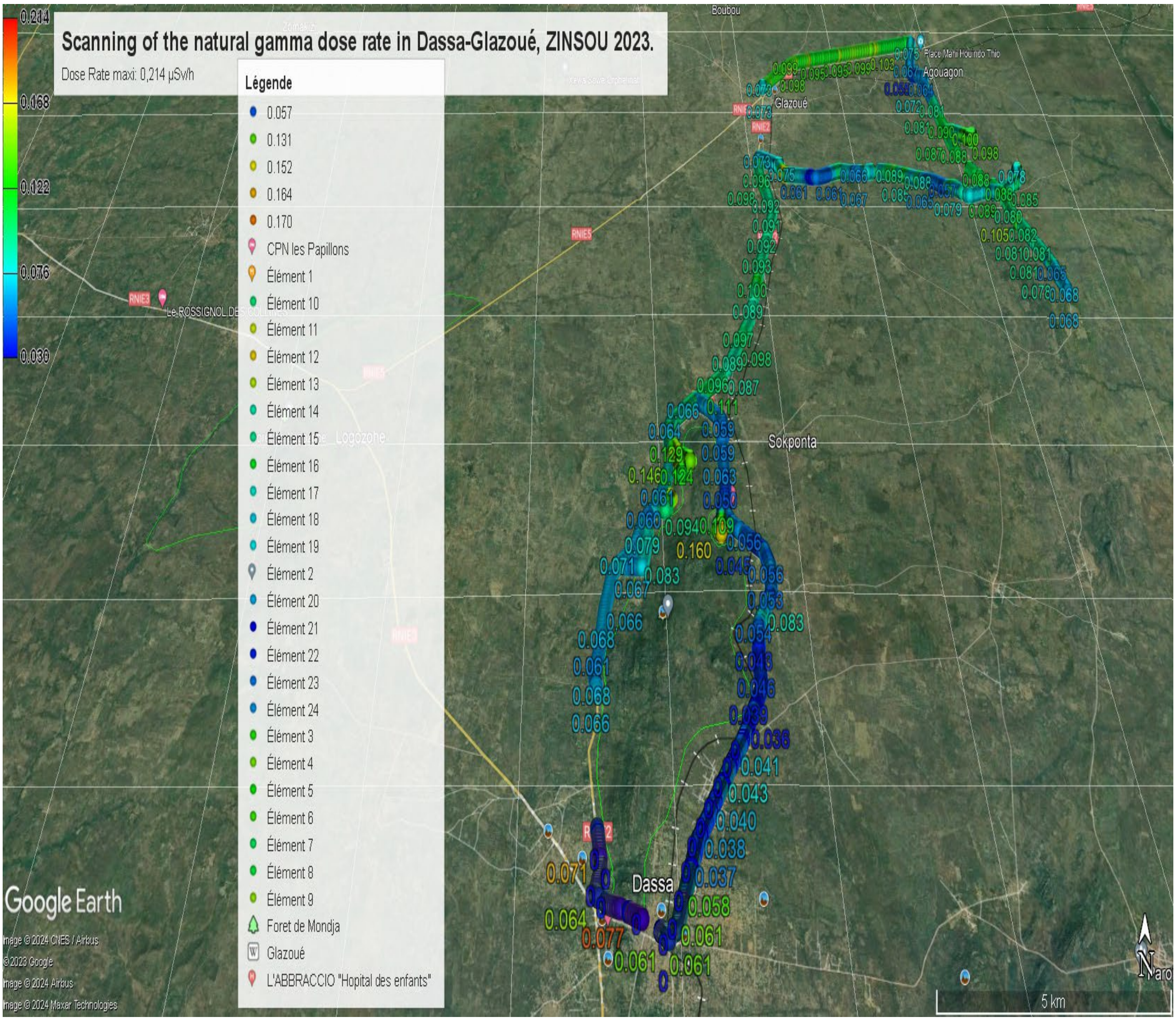
Figure 7: Bar graph comparing maximum and minimum ambient dose equivalent rates for each school.



3.2.1. The mapping of the natural dose rate in the granite quarries and schools of both towns

The figure 8 on the maps shows the results of our scanning of the two cities with the Ionizing Radiation Backpack Detector. It has been generated by Google Earth Pro.

Figure 8: Radiation Mapping in the two Beninese provinces. 1. Map legend, 2. map title, 3. scanning route in the two cities, 4. geolocated map orientation.

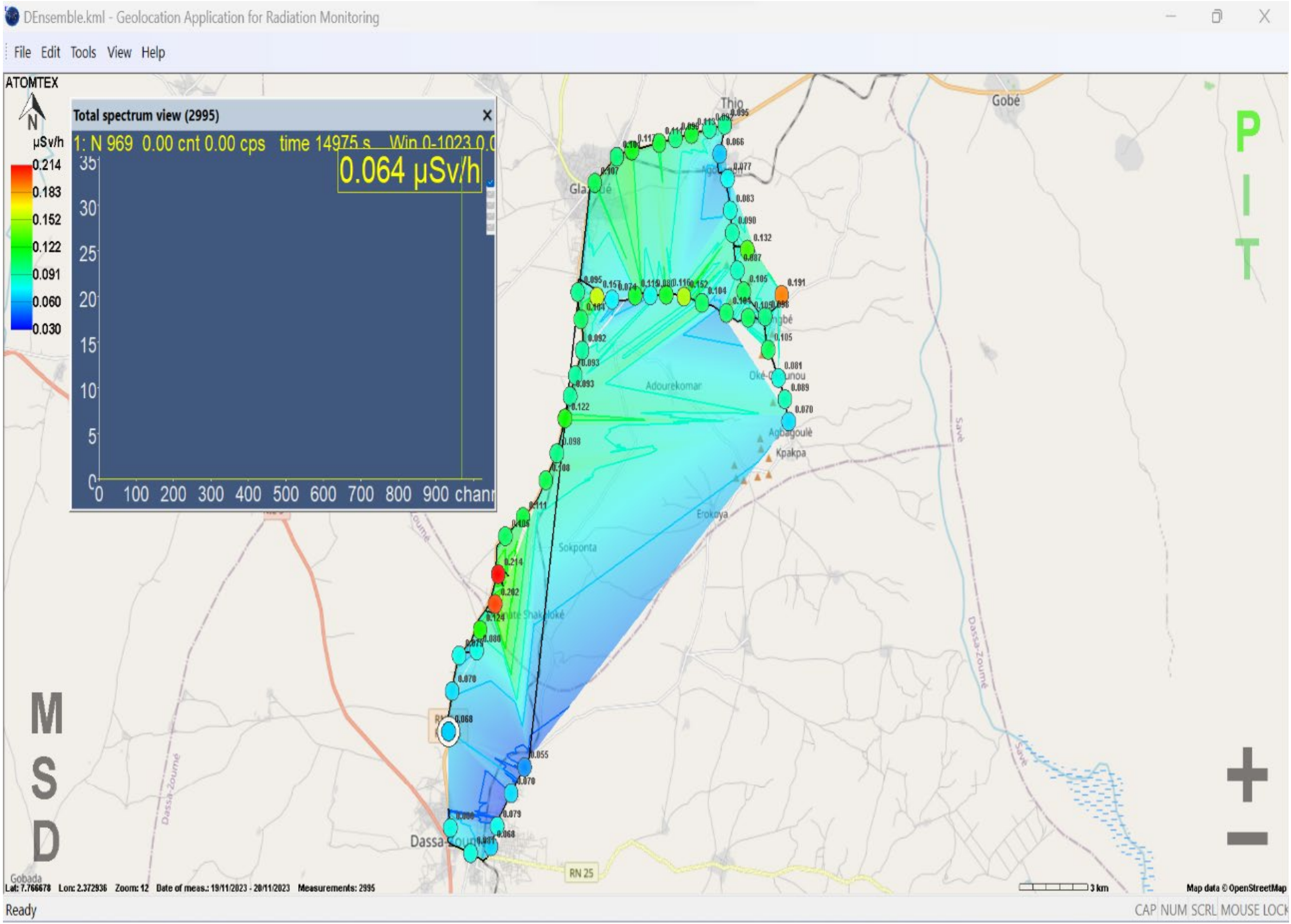


Source: Google Earth Mapping, January 2024.

3.2.2. The Scanning of the natural dose rate in both towns

The figure 9 on the maps shows the results of our scanning of the two cities with the Ionizing Radiation Backpack Detector. It had been generated by the Geolocation Application for Radiation Monitoring (GARM.msi of ATOMTEX for June 21th, 1999).

Figure 9: GARM software and Google Earth overview of scanning maps in the two cities. A total of 2,995 ambient gamma dose equivalent rate measurements are shown on this overview map.



Across scanning, ambient gamma dose equivalent rates in the two cities range from 0.030 to 0.214 µSv/h.

Across both towns, the average ambient gamma equivalent dose rate is equal to 0.064 µSv/h. From this average value, the annual effective dose for a representative person in the two towns not involved in crushing or school activities is estimated at 0.56 mSv/yr.

3.2.3. Summary of average ambient gamma equivalent dose rates at crushing sites

Tables 3 and 4 show the results for the averages equivalent dose rates in the quarries in Glazoue and Dassa-zoume.

As seen in these two tables shows that average ambient equivalent dose rates vary from (0.13 to 0.32) ± 0.03 µSv/h with average 0.23 ± 0.06 µSv/h in the granite quarries of the Glazoue. Those for granite quarries in the town of Dassa-zoume range from (0.2 to 0.31) ± 0.03 µSv/h with average 0.24 ± 0.04 µSv/h

The values obtained with the AT1123 are slightly higher than those obtained with the AT6102 spectrometer. This difference is justified by the sensitivity of the AT1123 radiameter in continuous fields, which is of the order of 0.05 µSv/h.

Table 3: Results of average ambient equivalent dose rates in the granite quarries of the Glazoue.

N°	Site name	Average equivalent dose rate in µSv/h. Uncertainties ± 3%.	
		Values with AT1123.	**Values with AT6102.**
1	Madengbe quarry	0.14	0.13
2	Kamate quarry (Itchakakpa)	0.24	0.22
3	MOTA quarry	0.25	0.26
4	Oke-Owo quarry	0.16	0.15
5	Quarry 2, Mota crushing plant	0.24	0.25
6	Tchatchegou Igbodè quarry	0.27	0.25
7	Lakoun quarry (Itchegou)	**0.32**	**0.30**
	Averages	**0.23 ± 0.06**	**0.22 ± 0.06**

Table 4: Results of average ambient equivalent dose rates in the granite quarries of the Dassa-zoume.

N°	Site name	Average equivalent dose rate in µSv/h. Uncertainties ± 3%.	
		Values with AT1123.	**Values with AT6102.**
1	Modji quarry	0.20	0.20
2	SOS Issalou quarry	0.22	0.20
3	Modji C quarry	0.23	0.21
4	Igangan quarry	**0.25**	**0.24**
5	Lema quarry	**0.31**	**0.30**
	Average	**0.24 ± 0.04**	**0.23 ± 0.04**

3.2.4. Comparison (AT1123 and AT6102) of average ambient equivalent dose rates in the granite quarries of the Glazoue town

Using the Two Sample t-test with the R sofware version 4.3.2. (2023-10-31 ucrt) with Studio Interface, the mean ambient dose equivalent rates measured with the AT1123 survey meter and the AT6102 spectrometer in the granite quarries of the Glazoue town were analyzed. Table 5 shows the results of this analysis.

Table 5 : Comparative analysis of AT1123 and AT6102 measurement results

Two Sample t-test		
Data: Average dose rate values per AT		
t = 0.25892	**df = 12**	**p-value = 0.8001**
Alternative hypothesis: the real difference in means between the AT1123 group and the AT6102 group is not equal to 0.		
Confidence interval of 95 % :	-0.06355742	0.08070028
Sampling estimate s:		
Average in AT1123 group 0.2314286		Average in AT6102 group 0.2228571

Reference: R sofware version 4.3.2. (2023-10-31 ucrt) with Studio Interface.

From this table, p-value = 0.8001 > 0.05. Thus, the mean ambient gamma radiation equivalent dose rates measured with the two pieces of equipment (AT1123 and AT6102) in the granite quarries of the Glazoue town are not statistically different.

3.2.5. Estimation of the annual effective dose of a member of the public

The tables 6 and 7 present the results of the estimation of the potential annual effective dose of a representative member of the public who does and does not live in the vicinity of the granite quarries studied. We have chosen the scenario of a member of the public residing in the same radiation environment for 365 days, i.e. 8760 hours of annual exposure. The effeictive doses are in mSv/year.

Table 6: Estimation of the annual effective dose in the granite quarries of the Glazoue.

N°	Site name	Annual effective doses in mSv/year			
		Values with AT1123.		Values with AT6102.	
		Annual effective dose for a resident crushers	Annual effective dose for non-resident crushers	Annual effective dose for a resident	Annual effective dose for non-resident crushers
1	Madengbe quarry	1.3	0.6	1.1	0.6
2	Kamate quarry (Itchakakpa)	2.1	1.0	1.9	0.9
3	MOTA quarry	2.2	1.1	2.3	1.1
4	Oke-Owo quarry	1.4	0.7	1.3	0.6
5	Quarry 2, Mota crushing plant	2.1	1.0	2.2	1.1
6	Tchatchegou Igbode quarry	2.4	1.2	2.2	1.1
7	Lakoun quarry (Itchegou)	**2.8**	1.4	**2.6**	1.3

Table 7: Estimation of the annual effective dose in the granite quarries of the Dassa-zoume.

N°	Nom du site	Annual effective doses in mSv/year.			
		Values with AT1123.		Values with AT6102.	
		Annual effective dose for a resident	Annual effective dose for non-resident crushers	Annual effective dose for a resident	Annual effective dose for non-resident crushers t
1	Modji quarry	1.8	0.9	1.8	0.9
2	SOS Issalou quarry	1.9	0.9	1.8	0.9
3	Modji C quarry	2.0	1.0	1.8	0.9
4	Igangan quarry	2.2	1.0	2.1	1.0
5	Lema quarry	**2.7**	**1.3**	**2.6**	**1.3**

As seen in these tables 6 and 7 shows that the annual effective dose from an artisanal crusher resident in the crushing zone ranges from 1.1 to 2.8, with an average of 2.1 in the town of Glazoue. That from a crusher in the town of Dassa-zoume ranges from 1.8 to 2.7, with an average of 2.07.

As seen in the estimated annual effective dose for a non-resident artisanal crusher in the crushing zone shows that it ranges from 0.6 to 1.4, with an average of 1 in the town of Glazoue. That of a non-resident crusher in the town of Dassa-zoume ranged from 0.9 to 1.3, with an average of 1.01.

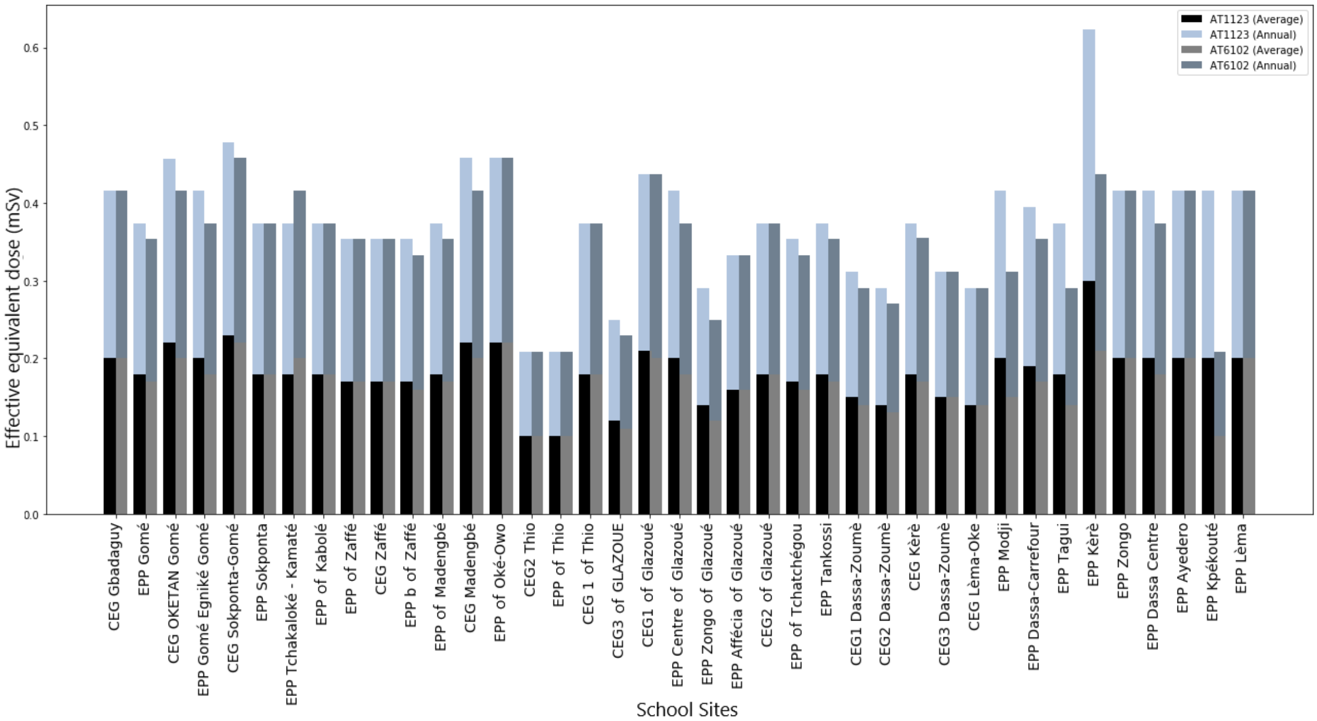
The quarries at Lakoun in Itchegou in the town of Glazoue and in the arrondissement of Lema in the town of Dassa-zoume are the most damaging.

The estimated annual effective dose obtained in Cotonou is equal to 0.394. This result, compared with those obtained in quarries in the hills of Benin, shows the variation in natural exposure depending on the geological nature of the soil.

3.2.6. Estimation of the annual effective dose for a potential member of the schools in the towns of Glazoue and Dassa-zoume

The figure 10 presents the results of the estimation of the annual effective dose of a potential user from the public working in primary and secondary schools in the towns of Glazoue and Dassa-zoume. We chose the scenario of a user of these schools. Annual equivalent effective doses were calculated using the equation presented in section 2.2.4.

Figure 10: Annual effective equivalent doses for a potential primary and secondary school user



As seen in figure 10 shows that the annual effective dose in schools varies from 0.108 to 0.324, with an arithmetic mean of 0.189. The CEG Sokponta-Gome and the public elementary schools of Oke-Owo and Kere present the most penalizing values.

3.3. DISCUSSION

The aim of this study is to address the issue of public exposure to natural sources of ionizing radiation of terrestrial and cosmic origin in artisanal granite crushing quarries and in primary and secondary schools.

According to Appendix B of the 2008 UNSCEAR report, the outdoors average absorbed dose rate in air from natural terrestrial radiation varies from 18 to 24 nGy/h in Africa, with an average of 23 nGy/h. That of cosmic radiation in air varies from 25 to 31 nGy/h in Africa, with an average of 28 nGy/h. Our results from the crushing quarries in the two towns remain above this regional value. Table 8 compares our results with those obtained in other regions of the world, according to the 2008 UNSCEAR report [8].

Table 8: Comparison of our results obtained with UNSCEAR 2008 dose rate values for terrestrial radiation [8].

Countries & Authors	**Average dose rate values in nGy/h**	**Average values for Benin (Collines) en nSv/h**
Africa	23 (18 – 24) ‹	
North America	24 (11 – 44) ‹	
Cuba	24 (4 – 162) ‹	
Costa Rica	29,9 (5,6 – 66,6) ‹	
Danemark	35 (25 – 70) ‹	- in artisanal crushing quarries: 255 (110 – 400) ;
Finland	71 (45 – 139) ‹	
Belgium	43 (13 – 80) ‹	
Germany	57 ‹	
Ireland	32 (2 – 110) ‹	
Italy	74 (11 – 209) ‹	
Spain	50,4 (19 – 88) ‹	
Bulgari	70 (48 – 96) ‹	- in primary and secondary schools in both towns: 240.
Czech Republic	66 (6 – 245) ‹	
Poland	47,4 (18,8 – 86,0) ‹	
Slovenia	56 (4 – 147) ‹	
Greece	31 (17 – 88) ‹	

Source: table 6 of the Annex B of the 2008 UNSCEAR report, page 329.

All the ambient dose rate values recorded are lower than the ambient equivalent dose values measured in the quarries and primary and secondary schools in the towns of Glazoue and Dassa-zoume. The values reported by UNSCEAR in 2008 are national averages for each country. The difference between our values and those recorded by UNSCEAR can be justified by the fact that our measurements were carried out in granite quarries and in schools in two towns with a high probability potentiality of natural radioactivity.

The general ambient gamma dose rate measurement carried out with the backpack in the two towns showed that ambient gamma radiation (cosmic and terrestrial radiation) has an average rate of 64 nSv/h. This average is higher than the average ambient dose rate (cosmic and terrestrial radiation) in Libya (51 nGy/h), Canada (54 nGy/h), Cuba (55 nGy/h) and Philippens (45 nGy/h) [8]. This average value is lower than the national average values recorded by UNSCEAR in Mauritius (98 nGy/h), Tanzania (104 nGy/h), Mexico (88.3 nGy/h), Finland (103 nGy/h), Italy (112 nGy/h), Lithuania (95 nGy/h), Sweden (97 nGy/h), Germany (89 nGy/h), Luxembourg (81 nGy/h), China (81.5 nGy/h), Azerbaijan (140 nGy/h), Bulgaria (100 nGy/h) and the Czech Republic (100 nGy/h). This average is similar to that obtained in Danmark (66 nGy/h), Costa Rica (65.9 nGy/h), Indonesia (67.5 nGy/h), Turkey (65 nGy/h) and Ireland (65 nGy/h). Similarly, the average ambient gamma dose rate measured in Cotonou, a non-granitic town, is equal to 45 nSv/h. This value is lower than the national average values announced by UNSCEAR in its 2008 report for Spain, Poland, Slovenia, Finland, Italy, Bulgaria and the Czech Republic.

The table 9 compares our results with those obtained in other studies found in the literature.

Table 9: compares our results with those obtained in other scientific studies.

Reference	Countries & Authors	Average dose rate in µSv/h	Average effective dose in mSv/yr	Average dose rate in µSv/h for our study	Average annual effective dose in mSv/yr for our study
[23]	Cameroon, Saidou et al. (2019)	0,057 ‹	0.46 ‹	- in artisanal crushing quarries : 0.255 (0.11 – 0.40).	- For a resident crusher on the Glazoue crushing site : 2.1. - For a resident crusher on the Dassa-zoume crushing site : 2.07. - For a non-resident crusher at the Glazoue crushing site: 1. - For non-resident crushers on the Dassa-zoume crushing site : 1.01.
[24]	Cameroon, Modibo et al. (2019)	(0.05 - 6.20) >	15.2 >		
[25]	Madagascar, Kall et al. (2015)	0.153 ‹	(0.14 - 0.25) ‹		
[26]	Cameroon, Bineng et al. (2020)	0.0504 ‹	0.33 ‹		
[27]	Cameroon, Nkoulou et al. (2018)	0.0367 ‹	0.29 ‹		
[28]	Cameroon, Koyang et al. (2022)	0.08 ‹	0.6 ‹		
[9]	Brazilian, Anjos et al. (2011)	0.120 ‹	-		
[10]	Tadjikistan in Asia, Lespukh et al. (2013)	-	‹ 10 >		
[33]	Norway, Sundal et al. (2004)	-	‹ 1 ‹		
[32]	Turkey, Turhan et al. (2012)	0.0554 – 0.0406 ‹	0.0266 – 0.0968 ‹		
[31]	Nigeria, Ademola et al. (2014)	-	81.3 >		
[30]	Nigeria, Ojo et al. (2015)	0.01235 – 0.17959 (Lagos) ‹ 0.00591 – 0.08329 (Ondo) ‹	0.0227 – 0.3306 (Lagos) ‹ 0.0073 – 0.1022 (Ondo) ‹		
[13]	Slovakia, Vaupotic et al. (2000)	0.095 ‹	-	- in primary and secondary schools in both towns : 0.24.	- For primary and secondary school students : 0.189.
[34]	Turkey, Kam et al. (2006)	0.04803 ‹	-		
[35]	Saudi Arabia, Al-Saleh (2007)	0.05 ‹	-		

Table 9 shows that our dose rate and effective dose values are lower than the maximum dose rate value obtained by Modibo et al. (2019) in the Kitongo uranium deposits in Cameroon. This difference is justified by the fact that our measurements were carried out in granite quarries and schools, which are not uranium deposits.

According to table 9, Saidou et al. (2019) showed that the ambient gamma dose rate varied from 25 to 102 nGy/h with an average of 57 nGy/h in the Poli uranium region of Cameroon [23]. The annual effective dose ranged from 0.20 to 0.83 mSv/yr, with an average of 0.46 mSv/yr.

Kall et al. (2015) showed that absorbed dose rates at 1 m above the ground surface at the French Bay shoreline in Antsiranana, Madagascar vary between 89 ± 14 nGy/h and 209 ± 29 nGy/h with an average of 153 nGy/h [25]. Annual effective doses range from 0.14 ± 0.02 mSv/yr to 0.25 ± 0.03 mSv/yr.

In areas containing Uranium and Thorium at Lolodorf in Cameroon, Bineng et al. (2020) showed that mean ambient absorbed dose rates, external effective dose and soil activity concentrations of uranium-238, thorium-232 and potassium-40 were 50.4 ± 7.2 nGy/h, 0.33 ± 0.05 mSv/yr and 33 ± 3 Bq/kg, 53 ± 9 Bq/kg, 182 ± 22 Bq/kg, respec-tively [26].

Nkoulou et al. (2018) showed that the mean values of ambient absorbed dose rate, external effective dose, radium equivalent activity, external hazard index and representative level index were 36.7±5.0 nGy/h, 0.29±0.04 mSv/yr, 83 ± 14 Bq/kg, 0.22 ± 0.03 and 0.58 ± 0.10 at Lolodorf, Cameroon, respectively [27]. These values are lower than our results. Similarly, Koyang et al. (2022) showed that the ambient equivalent dose rate and the effective dose of external and internal radiation were 0.08 μSv/h, 0.6 mSv/yr in the Far North zone of Cameroon [28]. These values are lower than our results..

Ojo et al. (2015) showed in Lagos and Ondo states in southwest Nigeria that ambient absorbed dose rates varied from 12.35 to 179.59 nGy/h and from 5.91 to 83.29 nGy/h respectively. Annual effective doses were estimated at 22.7 and 330.6 μSv/year and 7.3 and

102.2 μSv/year for occupancy factors of 30% and 20% for the two states respectively [30]. This result is lower than our values. This can be justified by the fact that Lagos and Ondo are certainly not of a geological nature susceptible to a high probability of natural radioactivity.

Ademola et al. (2014) proved in the mining surfaces of Itagunmodi in southwestern Nigeria that the mean annual effective dose was 81.3 μSv/yr which is about 16% higher than the world average. This study showed that the dose is a function of the geological nature of the soil [31]. This result is well above our own values. This is justified by the fact that these measurements were carried out on the mining surface.

In Turkey, Turhan et al. (2012) have shown that the average gamma dose and the population-weighted average are 55.4 and 40.6 nGy/h respectively. The corresponding mean annual effective dose to the public ranges from 26.6 to 96.8 μSv/yr [32]. These values are still lower than our results.

Sundal et al. (2004) measured natural gamma radiation in a Norwegian carbonatite zone. The values obtained correspond to an average effective dose equivalent of 1.0 mSv/yr and a range of 0.2 - 3.0 mSv/yr [33]. They are comparable to those obtained in the present study. Anjos et al. (2011) carried out a similar study and measured dose rates in dwellings built from Brazilian granites. They used Germanium detectors (HpGe) and NaI(TI) Scintillation Detectors. The highest equivalent dose rate was 0.12 μGy/h [9]. Lespukh et al. (2013) carried out an assessment of the radiological impact of gamma dose rates at former uranium mining sites in Tajikistan, Asia [10]. None of the sites studied did mean individual annual effective doses exceed 10 mSv/yr, which is the recommended threshold value for the general public in this country.

Ambient dose equivalent rates assessed in schools in the towns of Glazoue and Dassa-zoume ranged from 0.10 to 0.40 μSv/h with an average of 0.25 μSv/h. Using the HpGe spectrometer, Vaupotic et al. (2000) assessed the ambient gamma dose equivalent rate in schools in Slovakia in 2000 [13]. The dose rate measured in this particular geological area was

102 nGy/h arithmetic mean and 95 nGy/h geometric mean. These values are considerably lower than those obtained in the present study. Kam et al. (2006) showed that the absorbed gamma doses inside buildings and outdoors were 54.81 and 48.03 nGy/h, respectively, corresponding to a total gamma radiation level (of terrestrial and cosmic origin) of 0.33 mSv/yr [34]. Al-Saleh et al (2007) found that the annual gamma dose absorbed inside the city of Riyadh in Saudi Arabia ranges from 303.757 to 700.738 µGy/yr, with a mean value of 455.1745 µGy/yr. The corresponding annual effective dose calculated for the local adult population ranged from 212.740 to 490.727 µSv/yr, with a mean value of 318.577 µSv/yr.

Our scanning study showed that the average ambient gamma dose rate in both cities is 0.064 µSv/h. This value is still higher than the 0.051 µGy/h obtained in Libya according to the 2008 UNSCEAR report. It remains lower than those obtained in Mauritania and Tanzania, which are 0.098 µGy/h and 0.104 µGy/h respectively [8]. Our annual effective dose values for granite stone crushers are higher than the average values proposed by the 2008 UNSCEAR report for public exposure to natural sources of cosmic radiation (0.39 mSv/yr) and terrestrial radiation (0.48 mSv/yr), which is 0.87 mSv/yr [8].

In the present study, we have dealt only with external exposure of the public from land-based sources. It is therefore necessary to assess the contribution of natural internal exposure in the towns of Glazoue and Dassa-zoume.

4. CONCLUSIONS

The present study addressed public exposure due to natural sources of ionizing radiation of terrestrial origin. The gamma radiation equivalent dose rate in the towns of Glazoue and Dassa-zoume ranged from 0.24 to 0.40 µSv/h, with an average of 0.32 µSv/h. In schools, the gamma radiation equivalent dose rate ranged from 0.10 to 0.40 µSv/h, with an average of 0.25 µSv/h. The estimated annual effective dose for resident crushers ranged from 1.1 to 2.8 mSv/yr, with an average of 2.1 mSv/yr, while non-resident crushers had doses ranging from 0.6 to 1.4 mSv/yr, with an average of 1 mSv/yr. In schools, the annual effective dose ranged from 0.108 to 0.324 mSv/yr, with an arithmetic mean of 0.189 mSv/yr. The effective dose obtained for granite crushers is higher than the value mentioned in the 2008 UNSCEAR report for exposure to terrestrial and cosmic radiation (outdoors and indoors), which is equal to 0.87 msv/yr. The doses for non-resident crushers and schools were lower but still noteworthy compared to the reference value.

Elevated radiation levels in granite quarries pose a higher health risk to resident crushers, while prolonged exposure in schools could have long-term health implications, especially for children. It is recommended to implement protective measures for quarry workers, such as limiting exposure time and using personal protective equipment, and to conduct regular radiation monitoring in schools, taking steps to reduce exposure by improving ventilation and avoiding construction in high-radiation areas. Continuous monitoring of radiation levels is essential to ensure public exposure remains within safe limits. It is necessary for granite stone crushers to use nasal protection face masks (FFP1, FFP2 or FFP3) to avoid inhalation of granite dust which could be a source of internal exposure. In conclusion, monitoring and managing natural radiation exposure in these areas is crucial to protect public health, particularly for those working in granite quarries and attending schools in Glazoue and Dassa-zoume.

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CONFLICT OF INTEREST

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