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Assessment of radiological risks due to natural radioactivity in tap water from the District of Abidjan, Cote d'Ivoire

Ponaho Claude Kezo and Issa Konate

Abstract
Water is an indispensable substance for life, but good quality water is necessary for the good health of the population. Unfortunately, people's concern about environmental pollution and a priori the quality of drinking water is growing in the district of Abidjan.
The purpose of this study is to evaluate the risk of cancer of populations due to the ingestion of natural radionuclides in Abidjan flap water.
Thus, using the analytical technique of gamma spectrometry, 43 water samples were analyzed. The results show varying concentrations of radionuclides and effective annual doses below the WHO guideline in more than 93% of the samples.
The cancer risk assessment yielded values ranging from 1.98×10-5 to 1.62×10-4 and from 2.89×10-5 to 2.70×10-4 respectively for mortality risk and morbidity risk, with average values of 7.63×10-5 and 1.11×10-4 respectively. According to United States Environmental Protection Agency, more than 81% of the water samples have a mortality risk lower than the maximum permissible value of risk. While for the morbidity risk, only 60.47% of samples contain acceptable risk values. These results have shown that not only the contribution of tap drinking-water to the proliferation of cancer in the study area but also provide a database for radioactivity in drinking-water in Cote D'Ivoire.

Keywords: Natural radioactivity, activity concentration, annual effective dose, mortality and morbidity risks

1. Introduction
Drinking-water is one of the most essential and indispensable substances for human life or actually for the whole living world (International Decade for Action 'Water for Life, 2013) [1]. The safety of drinking-water is often of the highest priority for public health and environmental protection and meanwhile to access sustainable safe drinking-water had become one of the United Nations Millennium Development Goals (Onda, Lo Buglio, Bartram, 2012) [2]. Unfortunately, like all geological formations, groundwater contains radioactivity whose main contributors are naturally occurring radioactive materials (NORMs) (UNSCEAR, 2000) [3], namely radionuclides coming from the decay series of uranium and thorium and the non-series of potassium decay (Farai, Jibiri, 2003) [4]. According to World Health Organization (WHO), the health risk associated with the presence of naturally occurring radionuclides in drinking-water should be taken into consideration, although the contribution of drinking-water to total exposure to radionuclides is very small under normal circumstances (WHO, 2004) [5]. It has been established that high concentrations of uranium greater than 15µg.l-1 in domestic water may present harmful biological effects in humans (WHO, 2008) [6]. It is also established that the acceptable maximum concentration of thorium in drinking water is 0.6 Bq/L (WHO, 2004) [5].
These last years, because of the socio-political crisis, the population of the District of Abidjan has greatly increased. This rapid population growth and difficult living conditions of the populations cause not only the problem of access to drinking water, but also a degradation of the environment and a deterioration of water quality. According to Yapo *et al.* the District of Abidjan is experiencing deterioration in the quality of its surface and groundwater due to uncontrolled urbanization and poor control (Yapo, Mambo, Seka, Ohou, Konan, Gouzile, 2010) [7]. Many studies in this area have shown the deterioration of the water quality.

Adjiri for example, has indicated that the urban wastes from the Akouedo dump result in a permanent flow to the lagoon waters of leachate that could reach the groundwater (Adjiri, Goné, Kouamé, Kamagaté, Biémi, 2008) [8].

Because of the occurrence of natural radionuclides, radioactivity of drinking-water is always an important judging criterion for the quality of drinking-water, just as what microbiological and chemical criteria are (Fawell, Nieuwenhuijsen, 2003) [9]. The radioactivity of drinking water has been a major topic of study in many countries that have established their own national water quality guidelines based on that of WHO and UNSCEAR. The global mean values of exposure to natural radioactivity in drinking water and food are 0.1 mSv and 0.29 mSv per year, respectively for WHO and UNSCEAR (UNSCEAR, 2000; WHO, 2011) [3, 10].

In Côte d'Ivoire, the natural radioactivity of drinking water is very little studied. Consequently, people have no idea on the radioactivity in drinking water just because no significant data on the radioactivity of drinking water are available. So, despite the Koua's study and our previous work respectively on the radioactivity in tap water in Yopougon and radiological risks assessment in mineral water and sachet waters produced in Abidjan, data still are insufficient (Kezo, Monnehan, Gogon, Dali, 2016; Kezo, Monnehan, Gogon, Dali, Koua, 2017) [11, 12].

Therefore, in order to provide data and establish a database of the natural radioactivity in water, it was necessary to conduct this work. The main objective of this study is to estimate the cancer risks of the population due to natural radionuclides in tap drinking water.

2. Materials and methods

2.1 Description of the study area

The Abidjan District, which is our focus, is located in the south of Côte d'Ivoire. It is located between latitudes 5° 10 and 5° 38 North and longitudes 3° 45 and 4° 21 west. With an area of 2,119 km2, the District of Abidjan has a growth rate of 3.7% per year and a population density of 2,221 inhabitants / km2. It includes a population estimated in 2014 at about 4,707,000 inhabitants (RGPH, 2014) [13].

In geological and hydrogeological plans, the district of Abidjan belongs to the coastal sedimentary basin which is 400 km long and 40 km wide from Fresco to the Ghanaian boundary. The sedimentary formations of this basin consist of sandy clays, sands and sandstones, conglomerates, glaucous sands and marl (Tastet, 1979) [14]. This basin is a Cretaceous to Quaternary basin with enormous potential in groundwater (Jourda, 1987) [15].

These groundwater resources are contained in three aquifer levels of unequal importance. These three main aquifers are: the Quaternary aquifer, the Maastrichtian aquifer, and the Continental Terminal aquifer. The Continental Terminal is one of the aquifers of this basin, operated for the supply of water in the district of Abidjan.

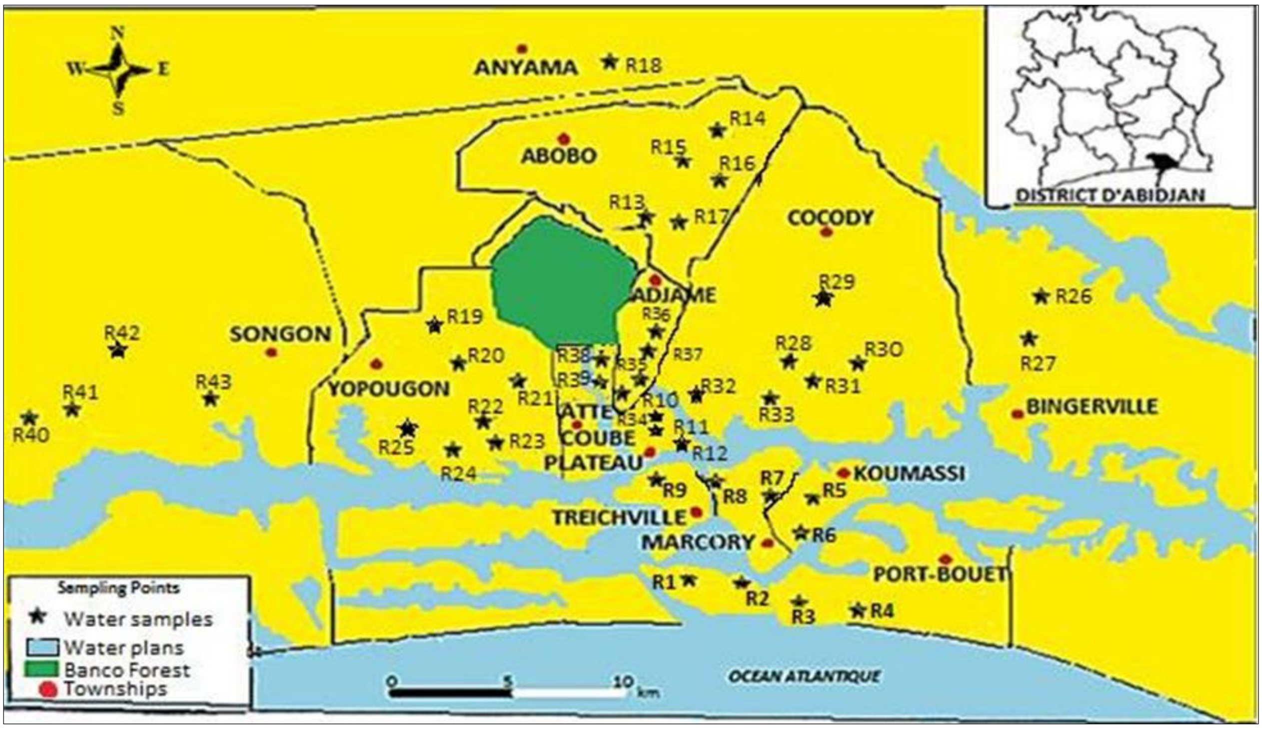

Fig 1: Sampling points and the study area location map; Source: CCT-BNET

2.2 Choice and sampling of water samples to be analyzed

Many types of water are used in households in the study area. However, in order to better assess the radiological risks due to ingestion, the sample type is chosen according to some essential criteria such as its accessibility to all and frequency of consumption. Therefore, tap water which contributes the most to the improvement of the index of human development was chosen (Yéradé, 2018) [16].

A total of 43 tap water samples were collected from 13 townships in the District. These samples are collected some minutes after continuous tap opening to remove stagnant substances in the pump that could contaminate the samples.

Then, they are collected in 1.5 liter polyethylene bottles previously well washed, rinsed with nitric acid and labeled. The collected samples are immediately acidified with a few drops of nitric acid HNO_3 (1M) to prevent adherence of the radionuclides to the walls of the containers

(AS/NZS, 1998) [17]. The bottles are filled to the brim with water to prevent the accumulation of carbon dioxide (CO_2) on the surface and the dissolution of this gas in water that could change the chemical properties of water.

After collection, the samples were transported to the Institute of Radiation Protection (RPI) of the Atomic Energy Commission of Ghana (GAEC) where they were prepared into 1 L Marinelli beakers and stored in a refrigerator prior to analysis.

2.3 Activity concentrations of in samples

The technique used to determine the radioactivity of the samples is gamma spectrometry and the standard procedures of this method as described in the literature were followed (Jibiri, Alausa, Farai, 2009; Jibiri, Farai, Alausa, 2007; Darko, Adukpo, Fletcher, Awudu, Otoo, 2010) [18, 19, 20].

The detector used for the radioactivity measurements is a lead-shielded 60.5×61.5 mm HPGe semi-conductor detector crystal (Model GX4020 and Nob14130 series, Canberra Inc.) coupled to a Canberra Series Multichannel Analyzer (MCA) through a preamplifier. It has an energy resolution of 2 keV Full Width at Half Maximum (FWHM) for cobalt 60Co gamma ray energy of 1332 keV and a relative efficiency 40% which is considered adequate to distinguish the gamma ray energies of interest in this study. Each water sample was placed on top of the HPGe detector and counted for 36,000 s. After counting, the spectra of each sample were analyzed by computer software, Genie™ 2000 (Model S501).

The specific activity concentrations of 238U, 232Th and 40K in Bq/L for the water samples respectively were determined using the following expression (Uosif, El-Taher, Abbady, 2008; Darko, Faanu, 2007) [21, 22]. The 238U activity was determined by taking the mean activity of the two separate photo peaks of the daughter nuclides: 214Pb at 352.0 keV and 214Bi at 609.3 keV, 232Th was determined using photo peaks of 228Ac at 911.1 keV and the photopeak of 212Pb at 583.1 keV and 40K was directly determined using 1460.8 keV photopeak.

The specific activity concentrations of 238U, 232Th and 40K in Bq/L for the water samples respectively were determined using the equation 1(Alam MN, Chowdhury MI, Kamal M, Ghose S, Islam MN, Anwaruddin, 1999; Awudu, Darko, Schandorf, Hayford, Abekoe, Ofori- Danson, 2010) [23, 24].

$$A_{sp} = \frac{N_{sam}}{\varepsilon(E_\lambda)\times P_E \times t_c \times M_{sam}} \quad (1)$$

Where N*sam* is the net count of the sample in a gamma energy peak Eλ, M*sam* is the mass of the sample, ε (Eλ) is the photopic yield, PE is the storage factor of the radionuclide, tc is the counting time.

2.4 Annual effective dose and radiological risks due to ingestion

The calculation of the effective dose due to ingestion is based on concentrations of radionuclides measured in the water samples. The daily water consumption rate was considered at 2L/day and the dose conversion factors for an adult of 4.5x10-5 mSv/Bq for 238U, 2.3x10-4 mSv/Bq for 232Th and 6.2 x 10-6 mSv/Bq for 40K were used (WHO, 2004) [5].

The annual effective dose due to ingestion of radionuclides, 238U, 232Th and 40K in water was calculated using Equation 2 (Alam MN, Chowdhury MI, Kamal M, Ghose S, Islam MN, Anwaruddin, 1999) [23].

$$H_{ing}(w) = I_w . \sum_{i=1}^{3} A_{sp} . DCF_{ing}(U, Th, K) \quad (2)$$

Where *Hing (w)* is the annual effective dose due to the ingestion of radionuclides in water, *Asp* is the concentration of radionuclide specific activity, *Iw* is the daily water consumption rate estimated at 2 liters or 730 L / year for an adult, and *DCFing (U, Th, K)* is the dose conversion factor due to ingestion of U, Th and K established by the WHO.

Then, to estimate the probability of a fatal cancer over the lifetime of an exposed individual, radiation cancer health risks in terms of mortality and morbidity were calculated. This calculation was done using radionuclide the specific risk coefficients (also called slope factors) developed by the United States environmental protection agency (EPA). EPA's risk coefficients for ingestion of tap water are given in FGR No. 13 (Eckerman, Leggett, Nelson, Puskin, Richardson, 1998) [25]. The lifetime risk was calculated using the following equation:

$$R = A_{sp} . I_w . T_L . r \quad (3)$$

Where

R = Lifetime risk

A_{sp} = Activity concentration of a radionuclide in water

I_w = Intake of drinking water per day, assuming 2 L average water intake per day for 365days/y (730 L/y),

T_L = Average life expectancy estimated at 50.7 years in Cote d'Ivoire [26], and

r = Mortality or morbidity risk coefficient.

3. Results and Discussion

3.1 Activity concentrations of 40K, 238U and 232Th and annual committed effective dose

Activity concentrations of natural radionuclides 40K, 238U, and 232Th in the water samples are shown in Table 1.

Table 1 recorded activity concentrations varying from 0.82 to 5.91Bq/L, < 0.004 to 0.82 Bq/L, and < 0.002 to 0.73Bq/L for 40K, 238U, and 232Th, respectively with average activity concentrations of 2.26, 0.50 and 0.12 Bq/L for 40K, 238U, and 232Th. It also showed that the average activity concentrations of the natural radionuclides are acceptable. However, the activity concentration of 232Th obtained in sample R36 is slightly higher than the WHO's maximum acceptable concentrations of 0.6 Bq/L (WHO, 2004) [5].

Higher activity concentrations in tap water may be due to the longer contact time of groundwater with soil and bedrock, during which minerals dissolve in the groundwater. Additionally, human activities in the areas such as the uncontrolled urbanization, the bad domestic and industrial waste management etc. could contribute to the increase of natural radionuclide concentrations in water.

The annual committed effective dose to an adult due to ingestion of radionuclides in tap water from the district varied from 8.06 to 127.41 µSv with an average of 42.48 µSv.

According to World Health Organization (WHO) guidance level in drinking water on intake of radionuclide, an annual dose equivalent to any single organ or tissue should not exceed 0.1 mSv (WHO, 2011) [10]. This shows that, the calculated annual average effective dose due to ingestion of radionuclide in water to any individual adult's organ or tissue in the population group is lower than the average value set by WHO. And it also shows that, from radiation protection point of view, the analyzed samples might not pose any radiological health hazards to the public within these doses are below the recommended public annual dose limit of 1mSv (WHO, 2011) [10]. The annual effective doses recorded in samples such as R30, R36 and R38, slightly higher than the recommended guideline value might due to human activities in areas that could increase concentrations of radionuclides.

3.2 Lifetime risks from in radionuclides

Risk assessment is an estimate of the probability of a fatal cancer over the lifetime of an exposed individual. Radiation cancer health risks in terms of mortality and morbidity calculated in samples were recorded in Table 2. The results show a variation of the mortality and morbidity risks from 1.98×10-5 to 1.62×10-4 and from 2.89×10-5 to 2.70×10-4 respectively.

For the mortality risk, the average value recorded was 7.63×10-5 and its highest value of 1.62×10-4 was recorded in sample R30 while the lowest value was obtained in sample R15.

This average value of mortality risk of 7.63×10-5 means that approximately eight persons out of 100,000 people are likely to die from cancer in the area after ingestion of radionuclides through tap water. Although the average value is lower comparing to the maximum value of risk established by US EPA of 10-4, mortality risk values in 18.6% of the samples were slightly above the US EPA acceptable range of risks of 10-6 to 10-4 (IAEA, 2010) [27].

In term of the morbidity risk, the average value was 1.11×10-4 with a highest of 2.70×10-4 recorded in sample R30. According to the results, more than one person out of 10,000 people is likely to suffer from any form of cancer in the study area. The results also show that the morbidity risks in 60.47% of water samples collected were above the US EPA acceptable range of risks. These results show an acceptable mortality cancer risks and a quite significant morbidity cancer risks for the population in the study area.

Table 1: Specific activity and effective dose due to ingestion natural radionuclides in tap drinking water samples from the District of Abidjan

Sample codes	Sample name	Specific Activities (Bq/L) ^{40}K	^{238}U	^{232}Th	Annual Effective Dose (µSv/yr)
R1	PORT BOUET VRIDI T53	3.01 ± 0.76	0.51 ± 0.06	0.31± 0.13	82.43 ± 27.34
R2	PORT BOUET VRIDI SIR	2.37 ± 0.78	0.27 ± 0.04	0.22 ± 0.06	56.53 ± 14.92
R3	PORT BOUET MAIRIE	2.37 ± 0.74	0.29 ± 0.03	0.24 ± 0.13	60.55 ± 25.16
R4	PORT BOUET LYCEE M	3.12 ± 0.67	0.28 ± 0.07	< 0.002	23.65 ± 5.33
R5	KOUMASSI SICOGI	2.17 ± 0.78	0.37 ± 0.08	< 0.002	22.31 ± 6.16
R6	KOUMASSI BIA SUD	1.85 ± 0.75	0.31 ± 0.04	< 0.002	18.89 ± 4.71
R7	MARCORY STE THERESE	1.62 ± 0.72	0.24 ± 0.08	< 0.002	15.55 ± 5.88
R8	MARCORY REMBLAIS	1.97 ± 0.72	0.12 ± 0.06	< 0.002	13.19 ± 5.23
R9	TREICHVILLE AV2-RUE7	1.84 ± 0.60	0.22 ± 0.06	< 0.002	15.89 ± 5.02
R10	CITE ADMINISTRATIF	1.88 ± 0.68	0.41 ± 0.07	< 0.002	22.31 ± 5.24
R11	PLATEAU COLLEGE MODERN	1.85 ± 0.73	0.37 ± 0.06	0.23 ± 0.08	59.14 ± 18.70
R12	PLATEAU JARDIN PUBLIC	2.15 ± 0.24	0.36 ± 0.06	< 0.002	21.89 ± 2.40
R13	ABOBO AKEKOI	1.78 ± 0.66	0.32 ± 0.06	< 0.002	18.90 ± 4.96
R14	ABOBO SOGEFIA	1.05 ± 0.80	0.34 ± 0.04	0.16 ± 0.07	42.78 ± 16.69
R15	ABOBO PLAQUE	0.98 ± 0.73	0.10 ± 0.03	< 0.002	8.06 ± 4.28
R16	ABOBO MAIRIE	2.25 ± 0.67	0.50 ± 0.08	0.23± 0.06	65.23 ± 15.60
R17	ABOBO MARLE	3.12 ± 0.35	0.25 ± 0.07	0.31 ± 0.13	74.38 ± 25.71
R18	ANYAMA LA GARE	3.13 ± 0.76	0.24 ± 0.03	0.45 ± 0.11	97.61 ± 22.90
R19	YOPOUGON PORT BOUET 2	2.32 ± 0.75	0.22 ± 0.07	< 0.002	18.06 ± 5.69
R20	YOPOUGON BANCO 2	1.68 ± 0.72	0.51 ± 0.06	< 0.002	24.62 ± 5.23
R21	YOPOUGON SIPOREX	1.90 ± 0.70	0.68 ± 0.27	< 0.002	31.27 ± 5.47
R22	YOPOUGON SICOGI	1.65 ± 0.44	0.41 ± 0.06	< 0.002	21.27 ± 3.96
R23	YOPOUGON SAGUIDIBA	1.82 ± 0.74	0.20 ± 0.05	< 0.002	15.14 ± 5.00
R24	YOPOUGON SIDECI	1.45 ± 0.47	0.46 ± 0.05	< 0.002	22.01 ± 3.77
R25	YOPOUGON KOUTE	1.25 ± 0.75	0.42 ± 0.05	< 0.002	19.79 ± 5.04
R26	BINGERVILLE CENTRE	0.94 ± 0.74	0.31 ± 0.04	< 0.002	14.78 ± 4.66
R27	BINGERVILLE HARRIS	1.03 ± 0.73	0.25 ± 0.07	0.43 ± 0.01	85.07 ± 7.79
R28	COCODY RIVIERA 2	2.42 ± 0.72	0.13 ± 0.07	< 0.002	15.56 ± 5.56
R29	COCODY PALMERAIS	2.33 ± 0.69	0.30 ± 0.06	< 0.002	20.74 ± 5.09
R30	COCODY AKOUEDO	2.28 ± 0.76	0.79 ± 0.07	0.43 ± 0.13	108.47 ± 27.57
R31	COCODY CITE DES ARTS	0.82 ± 0.68	0.40 ± 0.06	< 0.002	17.19 ± 5.05
R32	COCODY ANONO VILLAGE	0.84 ± 0.71	0.82 ± 0.05	< 0.002	31.07 ± 4.86
R33	COCODY UNIV FHB	5.91 ± 0.57	0.33 ± 0.04	0.28 ± 0.13	84.60 ± 25.72
R34	ADJAME IDENIE	2.12 ± 0.74	0.42 ± 0.05	< 0.002	23.73 ± 5.00
R35	ADJAME LIBERTE	1.76 ± 0.74	0.18 ± 0.06	< 0.002	14.21 ± 5.32
R36	ADJAME CITE RAN	1.04 ± 0.72	< 0.004	0.73 ± 0.21	127.41 ± 38,52
R37	ADJAME LA GARE	2.25 ± 0.62	0.31 ± 0.04	0.12 ± 0.08	40.52 ± 17.55
R38	ATTECOUBE CARREFOUR	2.64 ± 0.74	0.41 ± 0.04	0.51 ± 0.14	111.05 ± 28.17
R39	ATTECOUBE BROMAKOTE	1.74 ± 0.74	0.35 ± 0.04	0.47 ± 0.14	98.29 ± 28.17
R40	SONGON DAGBE	3.78 ± 0.06	0.59 ± 0.11	< 0.002	36.83 ± 3.89
R41	SONGON CITE SOCOMCI	4.25 ± 0.45	0.35 ± 0.03	< 0.002	31.07 ± 3.00
R42	SONGON CASSEMBLE	4.92 ± 0.50	0.09 ± 0.04	0.20 ± 0.03	58.80 ± 8.61
R43	SONGON AYAME	5.45 ± 0.60	0.33 ± 0.06	< 0.002	35.84 ± 4.69
Range		**0.82 – 5.91**	**< 0.004 – 0.82**	**< 0.002 – 0.73**	**8.06 – 127.41**
Average		**2.26 ± 0.66**	**0.50 ± 0.05**	**0.12 ± 0.04**	**42.48 ± 11.15**
Standard Deviation		**1.15**	**0.23**	**0.19**	**31.86**

Table 2: Mortality risk and morbidity risk in the tap water samples

Sample Codes	Sample names	Radiological Risks Mortality	Morbidity
R1	Port Bouet Vridi T53	$1.22\times10\text{-}^{4}$	$1.78\times10\text{-}^{4}$
R2	Port Bouet Vridi SIR	$6.84\times10\text{-}^{5}$	$9.97\times10\text{-}^{5}$
R3	Port Bouet Mairie	$7.37\times10\text{-}^{5}$	$1.07\times10\text{-}^{4}$
R4	Port Bouet Lycee M	$5.53\times10\text{-}^{5}$	$8.05\times10\text{-}^{5}$
R5	Koumassi Sicogi	$7.30\times10\text{-}^{5}$	$1.06\times10\text{-}^{4}$

R6	Koumassi Bia Sud	6.12×10^{-5}	8.91×10^{-5}
R7	Marcory Ste Therese	4.74×10^{-5}	6.90×10^{-5}
R8	Marcory Remblais	2.38×10^{-5}	3.46×10^{-5}
R9	Treichville AV2-RUE7	4.35×10^{-5}	6.33×10^{-5}
R10	CITE Administrative	8.09×10^{-5}	1.18×10^{-4}
R11	Plateau College	8.88×10^{-5}	1.29×10^{-4}
R12	Modern	7.08×10^{-5}	1.03×10^{-4}
R13	Plateau Jardin Public	6.31×10^{-5}	9.20×10^{-5}
R14	Abobo Akekoi	7.80×10^{-5}	1.14×10^{-4}
R15	Abobo Sogefia	1.98×10^{-5}	2.89×10^{-5}
R16	Abobo Plaque	1.14×10^{-4}	1.67×10^{-4}
R17	Abobo Mairie	7.07×10^{-5}	1.03×10^{-4}
R18	Abobo Marle	7.84×10^{-5}	1.14×10^{-4}
R19	Anyama La Gare	4.35×10^{-5}	6.33×10^{-5}
R20	Yopougon Port Bouet 2	1.01×10^{-4}	1.46×10^{-4}
R21	Yopougon Banco 2	1.34×10^{-4}	1.95×10^{-4}
R22	Yopougon Siporex	8.09×10^{-5}	1.18×10^{-4}
R23	Yopougon Sicogi	3.95×10^{-5}	5.76×10^{-5}
R24	Yopougon Saguidiba	9.07×10^{-5}	1.32×10^{-4}
R25	Yopougon Sideci	8.28×10^{-5}	1.21×10^{-4}
R26	Yopougon Koute	6.12×10^{-5}	8.91×10^{-5}
R27	Bingerville Centre	7.90×10^{-5}	1.15×10^{-4}
R28	Bingerville Harris	2.57×10^{-5}	3.75×10^{-5}
R29	Cocody Riviera 2	5.92×10^{-5}	8.63×10^{-5}
R30	Cocody Palmerais	1.85×10^{-4}	2.70×10^{-4}
R31	Cocody Akouedo	7.89×10^{-5}	1.15×10^{-4}
R32	Cocody Cite Des Arts	1.62×10^{-4}	2.35×10^{-4}
R33	Cocody Anono Village	8.44×10^{-5}	1.23×10^{-4}
R34	Cocody Univ Fhb	8.28×10^{-5}	1.21×10^{-4}
R35	Adjame Idenie	3.56×10^{-5}	5.18×10^{-5}
R36	Adjame Liberte	5.13×10^{-5}	7.49×10^{-5}
R37	Adjame Cite Ran	6.93×10^{-5}	1.01×10^{-4}
R38	Adjame La Gare	1.16×10^{-4}	1.69×10^{-4}
R39	Attecoubecarrefour	1.01×10^{-4}	1.48×10^{-4}
R40	Attecoube Bromakote	1.16×10^{-4}	1.69×10^{-4}
R41	Songon Dagbe	6.91×10^{-5}	1.01×10^{-4}
R42	Songon Cite Socomci	3.16×10^{-5}	4.60×10^{-5}
R43	Songon Cassemble	6.51×10^{-5}	9.49×10^{-5}
R44	Songon Ayame	1.98×10^{-5}-	2.89×10^{-5}-
Range		**1.85×10^{-4}**	**2.70×10^{-4}**
Average		**7.63×10^{-5}**	**1.11×10^{-4}**
Standard D		**3.45×10^{-5}**	**5.02×10^{-5}**

4. Conclusion
This work has estimated radiological risks for population health in the District of Abidjan. So, forty three tap water samples were analyzed by the gamma spectrometry analytical technique. The analysis of samples has given average activity concentrations of 40K, 238U, and 232Th of 2.26 Bq/L, 0.50 Bq/L and 0.12 Bq/L respectively. The results have also showed annual effective doses varying from 8.06 to 127.41 µSv/yr with an average value of 42.48 µSv/yr. According to the world health organization, the average annual effective dose of the overall samples is lower to the recommended value of dose of 100 µSv/yr. However, individually, almost 7% of samples presented annual effective doses higher than this reference value.

The assessment of lifetime cancer risks gave a variation from 1.98×10-5 to 1.85×10-4 and 2.89×10-5 to 2.70×10-4 for mortality risk and morbidity risk respectively with average values of 7.63×10-5 and 1.11×10-4 respectively. Results of mortality risk showed that more than 81% of samples have acceptable values of risk according to US EPA guideline because these values ranged between the acceptable values of risk of 10-6 to 10-4. While for the morbidity risk, in 60.47% of the samples the risk value is higher than the maximum value of risk of 10-4. This could indicate the harmful effect of the consumption of tap water in the District of Abidjan. It also provides data for future radiological studies in the area.

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