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Research Article

Assessment of the Exposure to Natural Radioactivity to Public from the Consumption of Tap Drinking Water in the Six Most Populated Townships of the District of Abidjan

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Abstract: This study assesses the level of natural radioactivity due to radionuclides, ^{226}Ra, ^{232}Th and ^{40}K, in 28 tap water samples collected from 6 most populated townships of Abidjan by using gamma spectrometry method for analysis. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K varied from < AMD to 0.82 Bq/L, < AMD to 0.73 Bq/L and 0.82 to 5.91 Bq/L, respectively, with mean values of 0.36±0.06 Bq/L, 0.11±0.04 Bq/L and 2.08±0.69 Bq/L respectively, measured from all the water samples studied. The annual effective doses due to the ingestion of the natural radionuclides measured in the samples ranged from 8.06 to 127.41 μSv/y with an average value of 39.62±11.62 μSv/y. This average calculated annual effective dose was found to be much lower than the guideline doses of 100 μSv/y and 290 μSv/y respectively recommended by WHO and UNSCEAR. Therefore no harmful effect is expected directly to the population by drinking this water.

Keywords: Activity concentration, annual effective dose and lifetime risk, drinking water, natural radioactivity, populated townships

INTRODUCTION

There is no water resource that does not contain Naturally Occurring Radioactive Materials (NORM) (DWAF, 2002) which are the main component of the natural radioactivity, thus the major contributor of the total radiation dose of people (UNSCEAR, 1988). The potential health hazard associated with drinking water will therefore mainly be the result of chronic exposure to elevated levels of dissolved NORM, because of the ubiquitous nature of NORM (DWAF, 2002).

Potential health hazards from natural radionuclides in consuming water have been considered worldwide, with many counties adopting guideline activity concentration for drinking water quality recommended by WHO (2004). In order to estimate the possible radiological hazards to human health, considerable attention has been paid in the last two decades to low level exposure arising from members of uranium and thorium decay chains and by potassium-40. These natural radionuclides have a high geochemical mobility that allows them to move easily and to contaminate mainly the environment, so the water resource with which human comes in contact.

^{238}U, in particular is easily mobilized in ground water and surface water. As a result, uranium and its decay product enter the food chain through irrigation water and enter the water supply through ground water, well and surface water streams and rivers (Otton, 1994).

In Côte d'Ivoire, in particular, in the six most populated townships of the district of Abidjan, the populations have a difficult living condition. Most of people are pour. So the tap water is the main source of drinking water supply for them. However, any radiological control is made by the authorities to provide necessary information on the natural radioactivity of this important source of drinking water.

Therefore, this study aimed firstly to establish a baseline data of natural radioactivity levels in tap water in the area by determining the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K. This baseline data will be used as reference information to assess any change in the radiological background levels due to any artificial effects of radiation measurements. Secondly, this study aimed to assess the health hazards associated with the exposure of natural radioactivity in drinking water from the tap by calculating the annual effective dose.

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MATERIALS AND METHODS

Description of the study area: This study was carried out in six populated townships of the district of Abidjan: ABOBO, ADJAME, COCODY, KOUMASSI, PORT-BOUET and YOPOUGON. The area is located at the south of Côte d'Ivoire (West Africa) and laid between latitudes 5°10 and 5°38 N and longitudes 3°45 and 4°21 W respectively. The district of Abidjan regroups (13) townships with a population of about 4 707 000 inhabitants with about 3 250 000 inhabitants representing 69% of the population living in this studied area (RGPH, 2014).

On the geological and hydrogeological plan, the District of Abidjan belongs to the sedimentary basin of Cretaceous to Quaternary age representing only 2.5% of the country's surface (Tastet, 1979). It stretches on a length of 400 km and a width of 40 km from Fresco (Côte d'Ivoire) to the boundary of Ghana. This sedimentary basin is composed of continuous groundwater aquifers in Quaternary, Tertiary and Upper Cretaceous rocks (Jourda, 1987). The sedimentary formations of this basin are composed mainly of lenticular stratification of coarse sands, clays, ferruginous sandstone and iron ore (Aghui andBiémi, 1984). This basin contains three levels of aquifer with an unequal importance. Continental Terminal aquifer is one of the aquifers of this basin exploited for supplying people in Abidjan with drinking-water. Figure 1 shows the study area with the different sampling points.

Sample collection and preparation techniques: A total of 28 water samples were collected from taps in different areas of the six populated townships of the district. Samples were obtained after leaving the tap water flow some minutes in order to remove stagnant substances that can contaminate the samples from the pump.

The tap water was collected in the 1.5 L plastic bottle, previously well washed, rinsed with the nitric acid and labeled. In order to prevent adherence of the radionuclides to the walls of the containers, the samples were acidified with few drops of the concentrated nitric acid (HNO_3) (1M) (AS/NZS, 1998). The bottles were filled to the brim without any head space to prevent trapping of gas that could change the chemical properties of the water. The bottles were tightly covered with the lids and labeled appropriately.

The collected samples were transported to the Radioprotection Institute's (RPI) laboratory at the Ghana Atomic Energy Commission (GAEC) where they were prepared into 1 L Marinelli beakers and stored in a refrigerator prior to analysis.

Radioactivity measurements in the water samples: The method employed for the measurements of the

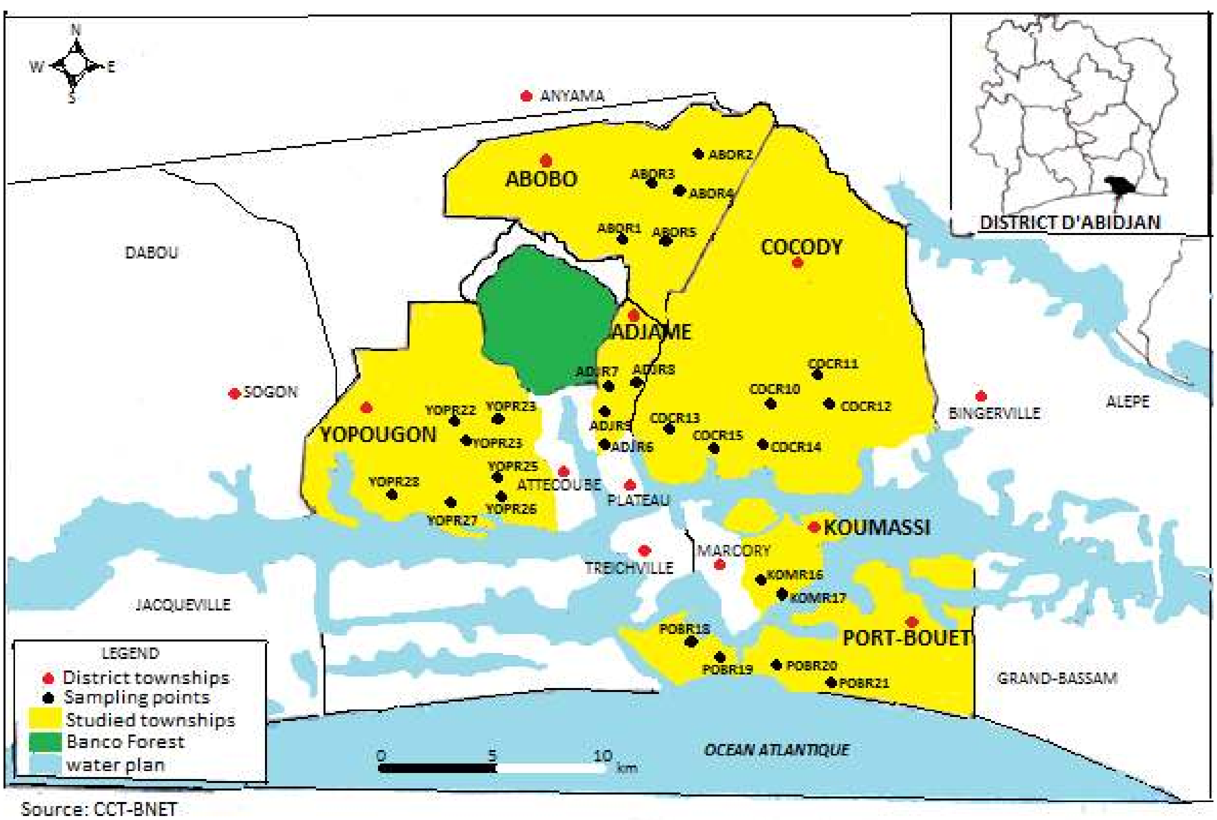

Fig. 1: Sampling points and the study area location map; Source: CCT-BNET

radioactivity in the samples was the gamma-ray spectroscopy and the standard procedures of this method as described in literatures were followed (Jibiri*et al*., 2007, 2009; Darko*et al*., 2010).

The detector used for the radioactivity measurements is a lead-shielded 60.5×61.5 mm HPGe semi-conductor detector crystal (Model GX4020 and No.b 14130 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 ^{60}Co 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 ^{226}Ra, ^{232}Th and ^{40}K in Bq/L for the water samples respectively were determined using the equation 1 (Alam*et al*., 1999; Awudu*et al*., 2010).

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

where,

- N_{sam} = The background corrected net counts of the radionuclide in the sample
- P_E = The gamma ray emission probability (gamma yield)
- $\varepsilon(E_\lambda)$ = The total counting efficiency of the detector system
- T_c = The sample counting time
- M_{sam} = The mass of sample (kg) or volume (L)

The ^{226}Ra activity was determined by taking the mean activity of the two separate photo peaks of the daughter nuclides: ^{214}Pb at 351.9 keV and ^{214}Bi at 609.3 keV, the activity of ^{232}Th was determined using photo peaks of ^{228}Ac at 911.1 keV and the photopeak of ^{212}Pb at 238.6 keV and the activity of ^{40}K was directly determined using its gamma rays emitted at 1460.8 keV.

Calculation of the annual effective dose due to ingestion: The effective dose received from ingestion of radionuclides is an important component in the analysis of the total annual effective dose from natural sources for human population.

The annual effective dose (mSv/y) from ingestion of radionuclide in water samples was calculated on the basis of the mean activity concentrations of the radionuclides. The daily water consumption rate was considered to be 2 L/day (730 L/year) and the conversion factor or dose per unit intake by ingestion for naturally occurring radionuclides for adult members of the public was taken to be 4.5×10^{-5}mSv/Bq for ^{238}U, 2.310^{-4}mSv/Bq for ^{232}Th and 6.2×10^{-6}mSv/Bq for ^{40}K were used (WHO, 2006).

The annual effective dose $H_{ing}(w)$ was given from the Eq. (2) (ICRP, 1996):

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

where,

- $DCF_{ing}(U, Th, K)$ = The dose conversion coefficients of the radionuclides in Sv/Bq
- A_{sp} = The specific activity concentrations of radionuclides in the water samples in Bq/L
- I_w = The radionuclide intake in liter per year, assuming 2 L average water intake per day for 365 days/y (730 L/y)

Calculation of lifetime risk due to ingestion: 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 can be calculated using radionuclide specific risk coefficients (also called slope factors) developed by the U.S. EPA. EPA's risk coefficients for ingestion of tap water are given in FGR No. 13 (Eckerman *et al*., 1998). The lifetime risk was calculated using the following equation:

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

where,

- R = The lifetime risk
- A_{sp} = The concentration of a radionuclide in water
- I_w = The intake of drinking water per day, assuming 2 L average water intake per day for 365 days/y (730 L/y)
- T_L = The average life expectancy estimated at 50.7 years in Cote d'Ivoire (Ehrhart, 2015)
- r = Mortality or morbidity risk coefficient

RESULTS AND DISCUSSION

Activity concentrations of ^{40}K ^{226}Ra and ^{232}Th in the samples: The results of the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in the samples are presented in Table 1. The activity concentration of ^{40}K varied from 0.82 Bq/L to 5.91 Bq/L with an average value of 2.08±0.69 Bq/L and a standard deviation of 0.99 Bq/L. The lowest value of ^{40}K activity concentration was measured in COCR13. (Cite des arts) whereas the

Table 1: Specific activity and effective dose due to ingestion de ^{40}K, ^{226}Ra, ^{232}Th in tap drinking water samples

		Specific activity concentration (Bq/L)			
Sample code	Sample name	^{40}K	^{226}Ra	^{232}Th	Effective Dose (µSv/y)
ABOR1	Marle	1.78±0.66	0.32±0.06	< MDA	18.90±4,96
ABOR2	Akekoi	1.05±0.80	0.34±0.04	0.16±0.07	42.78±16.69
ABOR3	Sogefia	0.98±0.73	0.10±0.03	< MDA	8.06±4.28
ABOR4	Plaque	2.25±0.67	0.50±0.08	0.23±0.06	65.23±15.60
ABOR5	La gare	3.12±0.35	0.25±0.07	0.31±0.13	74.38±25.71
ADJAR6	Indénié	1.76±0.74	0.18±0.06	< MDA	14.21±5.32
ADJR7	Cite Ran	1.04±0.72	< MDA	0.73±0.21	127.41±38.52
ADJR8	Liberte	2.25±0.62	0.31±0.04	0,12±0.08	40.52±17.55
ADJR9	La gare	2.12±0.74	0.42±0.05	< MDA	23.73±5.00
COCR10	Riviera 2	2.42±0.72	0.13±0.07	< MDA	15.56±5.56
COCR11	Palmerais	2.33±0.69	0.30±0.06	< MDA	20.74±5.09
COCR12	Akouedo	2.28±0.76	0.79±0.07	0.43±0.13	108.47±27.57
COCR13	Cité des arts	0.82±0.68	0.40±0.06	< MDA	17.19±5.05
COCR14	Anono village	0.84±0.71	0.82±0.05	< MDA	31.07±4.86
COCR15	Université	5.91±0.57	0.33±0.04	0.28±0.13	84.60±25.72
KOMR16	Sicogi	2.17±0.78	0.37±0.08	< MDA	22.31±6.16
KOMR17	Bia sud	1.85±0.75	0.31±0.04	< MDA	18.89±4.71
POBR18	VridiTerm 53	3.01±0.76	0.51±0.06	0.31±0.13	82.43±27.34
POBR19	Vridi Sir	2.37±0.78	0.27±0.04	0.22±0.06	56.53±14.92
POBR20	Mairie Port-B	2.37±0.74	0.29±0.03	0.24±0.13	60.55±25.16
POBR21	Lycée Moder	3.12±0.67	0.28±0.07	< MDA	23.65±5.33
YOPR22	Port Bouet 2	2.32±0.75	0.22±0.07	< MDA	18.06±5.69
YOPR23	Banco 2	1.68±0.72	0.51±0.06	< MDA	24.62±5.23
YOPR24	Siporex	1.90±0.70	0.68±0.27	< MDA	31.27±5.47
YOPR25	Sigogi	1.65±0.44	0.41±0.06	< MDA	21.27±3.96
YOPR26	Saguidiba	1.82±0.74	0.20±0.05	< MDA	15.14±5.00
YOPR27	Sideci	1.45±0.47	0.46±0.05	< MDA	22.01±3.77
YOPR28	Kouté	1.25±0.75	0.42±0.05	< MDA	19.79±5.04
Range		0.82 – 5.91	< MDA-0.82	<MDA-0.73	8.06-127.41
Average Value		2.07±0.69	0.36±0.06	0.11±0.04	39.62±11.62
Standard deviation		0.99	0.19	0.18	30.84

maximum value was measured in sample COCR15 (University).

For ^{226}Ra and ^{232}Th, the activity concentrations in the samples varied from values less than the minimum detection activity (MDA) of the detector system to 0.82 Bq/L and 0.73 Bq/L respectively. The average values of ^{226}Ra and ^{232}Th activity concentrations measured in the samples were 0.36±0.06 Bq/L and 0.11±0.04 Bq/L respectively with standard deviations of 0.18 Bq/L et 0.17 Bq/L respectively.

The minimum value of ^{226}Ra activity concentration was measured in ADJR7 (Cite Ran) whereas the maximum value was found in COCR14 (Anono village).

According to the results shown in Table 1, the lowest activity concentration of ^{232}Th, less than the MDA was measured in almost all the samples. This demonstrates that the thorium tenor of the tap water samples is low and acceptable in the water. The highest activity concentration of ^{232}Th of 0.73±0.21 Bq/L was measured in ADJR 7 (Cite Ran).

Table 1 shows that the average activity concentrations of ^{232}Th of 0.11±0.04 Bq/L obtained in tap water from the six townships is slightly lower than the World Health Organization (WHO, 2004) maximum acceptable concentration of 0.6 Bq/L.

The difference in radionuclide activity concentrations in the samples probably due to different levels of the radioactivity in the lithology of the aquifers or rocks and soils in the different areas. The occurrence and distribution of radioactivity in water largely depends on factors such as, the local geological characteristics of the source and the soil or rock from which the water interact with Shashikumar *et al*. (2011). It can also due to human activities in the areas that could technologically increase the concentrations of natural radionuclides in water by the infiltration of domestic and industrial waste into the water distribution supply.

Annual effective dose due to ^{226}Ra, ^{232}Th and ^{40}K in water: The effective doses from the drinking water due to the intake of ^{226}Ra, ^{232}Th and ^{40}K radionuclides were calculated and the results are shown in Table 1.

The effective doses varied from 8.06 µSv/y to 127.41 µSv/y with an average value of 39.62±11.62 µSv/y and a standard deviation of 30.54 µSv/y. The lowest value of effective dose was measured in ABOR3 (Sogefia) whereasthe maximum value of 127.41±38.52 µSv/y was measured in ADJR7 (Cite RAN).

According to the World Health Organization (WHO), the annual committed effective dose due to the ingestion of radionuclides in water should not exceed 100 µSv/y (WHO, 2006). Taking account to this recommendation, the average annual effective dose of

39.62±11.62 µSv/y measured in this study is low. This measured average effective dose is also lower than the average effective dose recommended by UNCSCEAR of 290 µSv/y with a typical range from 200 µSv/y to 800 µSv/y (UNSCEAR, 1988). Therefore comparing the results in this study with the recommended levels from these two world organizations, drinking of water from taps in the six townships of district of Abidjan where the study was carried is not expected to cause harm for the population living in these areas. Figure 2 shows the comparison between average effective doses recommended by WHO and UNSCEAR and the average effective dose measured in this study.

Lifetime risk assessment due to ingestion of radionuclides in water: The results of the lifetime risk calculated using Eq. (3) are shown in Table 2. The results show that the mortality and morbidity risks

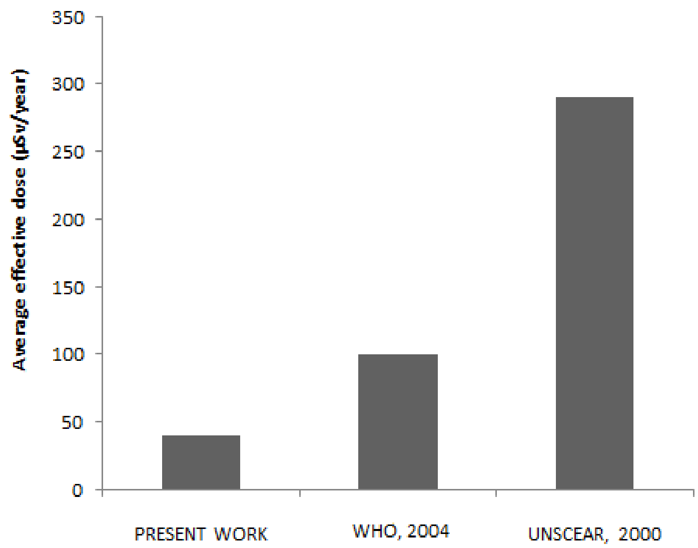

Fig. 2: Comparison ofthe recommanded average effective doses of WHO and UNSCEAR and the measured average effective dose in this study

Table 2: Lifetime (Mortality and morbidity) cancer risks assessment

Sample code	Specific activity concentration (Bq/L) ^{226}Ra	^{232}Th	Mortality Risk	Morbidity Risk
ABOR1	0.32±0.06	< MDA	$6.31.10^{-5}$	$9.02.10^{-5}$
ABOR2	0.34±0.04	0.16±0.07	$7.80.10^{-5}$	$1.14.10^{-4}$
ABOR3	0.10±0.03	< MDA	$1.98.10^{-5}$	$2.89.10^{-5}$
ABOR4	0.50±0.08	0.23±0.06	$1.14.10^{-4}$	$1.67.10^{-4}$
ABOR5	0.25±0.07	0.31±0.13	$7.07.10^{-5}$	$1.03.10^{-4}$
ADJAR6	0.18±0.06	< MDA	$3.56.10^{-5}$	$5.18.10^{-5}$
ADJR7	< MDA	0.73±0.21	$5.13.10^{-5}$	$7.49.10^{-5}$
ADJR8	0.31±0.04	0.12±0.08	$6.93.10^{-5}$	$1.01.10^{-4}$
ADJR9	0.42±0.05	< MDA	$8.28.10^{-5}$	$1.21.10^{-4}$
COCR10	0.13±0.07	< MDA	$2.57.10^{-5}$	$3.75.10^{-5}$
COCR11	0.30±0.06	< MDA	$5.92.10^{-5}$	$8.63.10^{-5}$
COCR12	0.79±0.07	0.43±0.13	$1.85.10^{-4}$	$2.70.10^{-4}$
COCR13	0.40±0.06	< MDA	$7.89.10^{-5}$	$1.15.10^{-4}$
COCR14	0.82±0.05	< MDA	$1.62.10^{-4}$	$2.35.10^{-4}$
COCR15	0.33±0.04	0.28±0.13	$8.44.10^{-5}$	$1.23.10^{-4}$
KOMR16	0.37±0.08	< MDA	$7.30.10^{-5}$	$1.06.10^{-4}$
KOMR17	0.31±0.04	< MDA	$6.12.10^{-5}$	$8.91.10^{-5}$
POBR18	0.51±0.06	0.31±0.13	$1.22.10^{-4}$	$1.78.10^{-4}$
POBR19	0.27±0.04	0.22±0.06	$6.84.10^{-5}$	$9.97.10^{-5}$
POBR20	0.29±0.03	0.24±0.13	$7.37.10^{-5}$	$1.07.10^{-4}$
POBR21	0.28±0.07	< MDA	$5.53.10^{-5}$	$8.05.10^{-5}$
YOPR22	0.22±0.07	< MDA	$4.35.10^{-5}$	$6.33.10^{-5}$
YOPR23	0.51±0.06	< MDA	$1.01.10^{-4}$	$1.46.10^{-4}$
YOPR24	0.68±0.27	< MDA	$1.34.10^{-4}$	$1.95.10^{-4}$
YOPR25	0.41±0.06	< MDA	$8.09.10^{-5}$	$1.18.10^{-4}$
YOPR26	0.20±0.05	< MDA	$3.95.10^{-5}$	$5.76.10^{-5}$
YOPR27	0.46±0.05	< MDA	$9.07.10^{-5}$	$1.32.10^{-4}$
YOPR28	0.42±0.05	< MDA	$8.28.10^{-5}$	$1.21.10^{-4}$
Average Value	0.36	0.11	$7.88.10^{-5}$	$1.15.10^{-4}$
Standard. Deviation	0.19	0.18	$3.71.10^{-5}$	$5.41.10^{-5}$

ranged respectively from 1.98×10^{-5} to 1.85×10^{-4} and from 2.89×10^{-5} to 2.70×10^{-4} with average values of 7.88×10^{-5} and 1.15×10^{-4} respectively. The highest value of the mortality risk of 1.85×10^{-4} was found in sample COCR12. The average value of mortality risk of 7.88×10^{-5} means that approximately eight persons out of 100,000 people are likely to die from cancer in the area.

In the case of morbidity risk the highest value of 2.70×10^{-4} was found in the same sample than the mortality risk meaning COCR12 while the lowest value of 2.89×10^{-5} was found in ABOR3. The average value of morbidity risk of 1.15×10^{-4} means that approximately 2 persons out of 10,000 people are likely to suffer from any form of cancer in the area.

According to Table 2, 21% of the samples had mortality cancer risks slightly above the US EPA acceptable range of risks of 10^{-6} to 10^{-4} (IAEA, 2010). So about 79% of collected samples had mortality cancer risks in US EPA acceptable range of risks.

For the morbidity risk, Table 2 shows that 64% of the samples had morbidity cancer risks above the US EPA acceptable range of risks while 36% of the samples had morbidity cancer risks in the US EPA acceptable range of risks. These results show that the morbidity cancer risks are quite significant and the mortality cancer risks are insignificant for the population in the study area.

CONCLUSION

This study represents the first results on natural radionuclide activity concentrations and effective dose due to ingestion of radionuclides measurements in tap water samples from six populated township of the district of Abidjan.

The measurements were made on 28 water samples using gamma spectrometry method. Results have shown that thorium concentration in the samples was low and activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K varied values less than the MDA to 0.82 Bq/L and 0.73 Bq/L for uranium and thorium respectively and from 0.82 to 5.91 Bq/L for ^{40}K. The effective dose due to the intake of water for an adult varied from 8.06 to 127.41 µSv/y with an average value of 39.62±11.62 µSv/y. The results show that the average effective dosemeasured in this study is lower than the international average doses established by WHO and UNSCEAR. So the health hazard for the population due to intake of tap water in the study area is not significant.

The international organizations have established recommended guidelines for radionuclide concentrations and effective dose in drinking water. Manycountieshave based their national recommendations on these international guidelines. Unfortunately, Côte d'Ivoire has not introduced any legal regulation yet concerning radionuclide concentration and dose due to the ingestion of radionuclides in drinking water. Waiting for the regulatory authority to be established, we will thoroughly continue to assess radionuclide concentrations in the drinking water in every part in the country in order to provide a database for the future radiological controls and the protection of the population against ionizing radiation.

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