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Assessment of mortality and morbidity risks due to the consumption of some sachet drinking waters produced in the district of Abidjan, (Côte d'Ivoire)

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ABSTRACT

Natural radioactivity of sixty sachet waters produced by fifteen different enterprises was measured by gamma spectrometry technique. The concentrations of the main natural radionuclides, ^{40}K, ^{226}Ra, and ^{232}Th in the samples varied respectively from 0.87 to 5.70 Bq/L, 0.16 to 0.47 Bq/L and 0.17 to 0.60 Bq/L in the samples with mean values respective of 2.66± 0.60 Bq/L, 0.22± 0.65 Bq/L and 0.34± 0.07 Bq/L. The annual effective doses due to the ingestion of these radionuclides varied from 45.48 to113.07 µSv/y with a mean of 78.41± 15.51 µSv/y. The mortality and morbidity risks assessed in samples, varied respectively from 4.94×10^{-5} to 1.17×10^{-4} and 7.20×10^{-5} to 1.24×10^{-4} with average values of 6.75×10^{-5} and 9.84×10^{-5}. This study showed a morbidity risk relatively high, thus harmful for the population.

Keywords: *Mortality risk, morbidity risk, sachet drinking water*

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I. INTRODUCTION

Water is one of the indispensable and important substances of all living beings. It safety became the highest priority for public health and the environmental protection at the point where access to the durable quality drinking water has become one of the United Nations Millennium Development Goals [1]. However, like all geological formations, water contains a radioactivity whose the major contribution comes from natural radionuclides [2].

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 the WHO [3]. UNSCEAR [2] has shown that the worldwide average exposure to natural sources in food and drinking water (internal exposure), is 0.29 mSv/yr (about 0.17 mSv/yr from K-40 and 0.12 mSv/yr from uranium and thorium).

In these last decades, in Côte d'Ivoire and in particular in Abidjan, the production and consumption of sachet water have considerably increased. In fact, the increasing rate of poverty of 46.3% [4], enabled the proliferation of selling sachet water affordable for middle classes. However, this proliferation of sachet water in the market poses the quality of the water consumed and therefore the health risk associated to.

Many studies have been made on sachet waters; to assess the quality and the health risks related to the consumption of these water. [5, 6]. Unfortunately, all these studies focused on the physico-chemical and bacteriological parameters. Meaning that, the radiological parameters of the waters and consequently the radiological quality of the sachet waters are neglected. So it is important to make this study whose main objective is to assess the radiological risks due to the consumption of some sachet waters produced in the district of Abidjan. To do this the activity concentrations of natural radionuclides, ^{40}K, ^{226}Ra and ^{232}Th presents in the samples, were measured by a gamma spectrometry technique.

II. MATERIALS AND METHODS

2.1. Sample collection

This study was conducted in the district of Abidjan which 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. It regroups thirteen (13) townships with a population of about 4,707 000 inhabitants representing 20.47% of the total population of the country [7].

Each sachet water contains 0.5 litre. Two (2) litres of sachet water per branch were collected. A total of sixty (60) sachet waters were taken from fifteen (15) different branches. The water samples were collected from different popular areas of the district.
All 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 beaker and stored in a refrigerator prior to analysis.

2.2. Sample preparation technique
In RPI's laboratory, the physico-chemical parameters such as pH, electrical conductivity (EC), and Total Dissolved Solids (TDS) were measured in the samples using a four-in-one Combo pH & Electric Conductivity detector.
The sachet waters were poured into one litre (1L) Marinelli beakers, previously well washed with distilled water, dried and rinsed with acetone to avoid any contamination of the samples. Then, the samples were sealed, labelled and placed on top of an HPGe detector to be counted for 36,000 s.

2.3. Radioactivity measurement in the samples
The detector used for the radioactivity measurement is a lead-shielded 60.5 x 61.5 mm HPGe semi-conductor detector crystal (Model GX4020 and N^{o}b 14130 series, Canberra Inc.) coupled to a Canberra Series Multichannel Analyser (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 analysed 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 [8, 9].

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

Where, N_{sam}- the background corrected net counts of the radionuclide in the sample, P_E- the gamma ray emission probability (gamma yield), $\varepsilon(E_{\gamma})$ - the total counting efficiency of the detector system, T_c- the sample counting time, and M_{sam} - the mass of sample (kg) or volume (L).
The ^{226}Ra activity concentration 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 photo peak 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.

2.4 Calculation of the annual effective dose due to ingestion.
The annual effective dose (mSv/y) from ingestion of radionuclide in sachet water samples depends on the mean activity concentrations of the radionuclides, the daily water consumption rate of 2 L/day (730 L/year) and the conversion factor or dose per unit intake. The annual effective dose due to ingestion of ^{238}U, ^{232}Th et ^{40}K for an adult member of the public was calculated by using the equation 2 [10].

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

Where, A_{sp} - the specific activity concentrations of radionuclides in the water samples in Bq/L, I_w - the radionuclide intake in litre per year, assumed to be 2 L average water intake per day and DCF_{ing}(U, Th, K) - the dose conversion factors of the radionuclides in Sv/Bq recommended by [3].

2.4 Lifetime cancer risk assessment in the samples
Although the radionuclide concentrations are generally low in water, there is nevertheless a radiological risk to the health of populations linked to their ingestion over a long time. Radiological risks expressed in terms of mortality risk and morbidity risk were calculated using radionuclide specific risk coefficients (also called slope factors) developed by the U.S. EPA in FGR No. 13 [11]. The lifetime risk was calculated using the following equation 3:

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

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 [12] and r - mortality or morbidity risk coefficient.

III. RESULTS AND DISCUSSIONS

3.1. Physico-chemical parameters of samples

The physico-chemical parameters such as pH, electrical conductivity (EC), and Total Dissolved Solids (TDS), are assumed to influence the activity concentration of the natural radionuclides presents in water. These parameters were measured and are presented in Table 1.

According to Table 1, the pH values in the sachet water samples vary from 7.1 to 8.3 with an average value of 8.01. The lowest value of pH was measured in MAF7 and the highest value in OMI5. These results show that the sachet water samples have a basic character (pH > 7). However, according to the World Health Organization (WHO), the pH values of the samples are acceptable because they range in the acceptable values of pH of 6.5 to 8.5 [3].

The electrical conductivities of the samples vary from 49 µS/cm to 361 µS/cm with an average value of 157 µS/cm. These results show that the electrical conductivities of the samples are lower than the reference value of 700 µS/cm recommended by WHO [3]. This means that the consumption of sachet waters is safe for populations. Electrical conductivity is also a useful indicator for the mineralization of water and it is linked to the Total Dissolved Solids (TDS) of water.

According to Table 1, the TDS of the water samples vary from 45 mg/L to 180 mg/L with an average value of 82.5 mg/L. The TDS values of the sachet water samples are strictly lower than the TDS value recommended by WHO. WHO recommended that the value of TDS in water should range between 600 mg/L and 1000 mg/L [3].

Table 1. Physico-chemical parameters of the sachet water samples

Name of the sample branches	Sample codes	Conductivity (µS/cm)	pH	TDS (ppm)
BEST	BES1	104	8.0	52
DELICE	DEL2	186	8.2	90
EYE ADOM	EYA3	49	8.0	24
FIDELE	FID4	104	8.2	52
OMIRA	OMI5	138	8.3	70
ROYAL	ROY6	222	8.1	113
MAFOU	MAF7	361	7.1	180
VITA	VIT8	108	8.2	87
OCEANE	OCE9	188	8.0	95
PURETE	PUR10	213	8.1	75
FRESH WATER	FRW11	98	8.1	112
NENE EAU	NEN12	112	7.8	45
O DELICE	ODE13	160	8.2	75
ATLANTIC	ATL14	215	8.1	65
TOP EAU	TOP15	197	7.8	102
Range		49- 361	7.1-8.3	24-180
Average		157	8.01	82.5

3.2. Activity concentrations of ^{40}K ^{226}Ra and ^{232}Th in the samples

Activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th, present in the samples are presented in Table 2. According to Table 2, concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the sachet water samples varied respectively from 0.87 to 5.70 Bq/L, 0.16 to 0.47 Bq/L and 0.17 to 0.60 Bq/L with average values of 2.66± 0.60 Bq/L, 0.22± 0.65 Bq/L and 0.34± 0.07 Bq/L respectively. The lowest concentrations of ^{40}K, ^{226}Ra, and ^{232}Th were measured respectively in OMI5, EYA3 and FID4 samples whereas the highest concentrations were found respectively in NEN12, NEN12 and BES1. Table 2 shows only one sample, BES1, presenting a thorium concentration relatively higher than the maximum value of thorium concentration recommended by WHO of 0.6 Bq/L in drinking water [3].

The difference in radionuclide activities is probably due to various factors such as differences in the origins of the water used to produce the sachet water and products used to mineralize the water. In fact, in Abidjan, most of sachet waters are produced with tap water distributed by the public supplier in different areas. Therefore the difference in radionuclide concentrations could be due to different levels of the radioactivity in the lithology of the aquifers or rocks and soils in the different areas. Since the occurrence and distribution of radioactivity in water depends on local geological characteristics of the source, and the soil or rock from which the water interacts with [13]. In addition to the origin of the water, treatment techniques could also enhance the radionuclide concentrations in water sachet. Many chemical products are added into the tap water to mineralize it. Since the products used may change from one enterprise to another, the radionuclide concentrations can also be different in the different sachet waters.

3.3. Annual effective dose due to ^{226}Ra, ^{232}Th and ^{40}K in water

The effective doses from sachet water due to the intake of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides were calculated and the results are shown in Table 2. According to Table 2, the effective doses varied from 45.48 µSv/y to 113.07 µSv/y with an average value of 78.41± 15.51 µSv/y. The lowest value of effective dose was measured in FID4 whereas the maximum value was found in BES1. According to WHO, the annual committed effective dose due to the ingestion of radionuclides in water should not exceed 100 µSv/y [14]. Considering this reference value of WHO, two samples representing 13.33% of the samples, presented effective doses higher than the WHO's recommended value. But generally, the average annual effective dose measured in the samples is largely lower than the recommended dose.

Considering also the average annual effective dose in drinking water recommended by UNSCEAR, of 290 µSv/y with a typical range from 200 µSv/y to 800 µSv/y [2], effective doses measured in the samples are all low. The comparison of the measured effective doses in samples and the worldwide average doses recommended by WHO and UNSCEAR is shown by Fig 1. The results of this work show that the consumption of the sachet waters analysed could not cause any health hazard to the populations. However there is a radiological risk associated to it.

Table 2: Activity concentrations and annual effective dose in the sachet water samples

Sample Codes	Activity Concentrations (Bq/L)			Annual effective Doses (µSv/yr)
	^{40}K	^{226}Ra	^{232}Th	
BES1	1.20± 0.70	0.21± 0.07	0.60± 0.02	113.07± 8.83
DEL2	2.22± 0.66	0.17± 0.06	0.42± 0.10	86.15± 21.75
EYA3	2.36± 0.70	0.16± 0.07	0.34± 0.06	73.02± 15.54
FID4	2.29± 0.68	0.20± 0.04	0.17± 0.09	45.48± 19.50
OMI5	0.87± 0.70	0.23± 0.06	0.30± 0.04	66.90± 11.86
ROY6	1.07± 0.70	0.19± 0.06	0.35± 0.13	69.85± 26.97
MAF7	1.40± 0.69	0.17± 0.06	0.52± 0.12	99.27± 25.24
VIT8	2.20± 0.70	0.21± 0.05	0.25± 0.04	58.84± 11.53
OCE9	1.50± 0.66	0.20± 0.06	0.45± 0.02	88.91± 8.32
PUR10	1.38± 0.70	0.17± 0.07	0.32± 0.06	65.56± 15.54
FRW11	3.63± 0.25	0.23± 0.03	0.41± 0.10	92.82± 18.91
NEN12	5.70± 0.51	0.47± 0.04	0.36± 0.09	101.68± 18.73
ODE13	5.51± 0.50	0.17± 0.05	0.23± 0.04	69.14± 10.62
ATL14	2.45± 0.33	0.31± 0.06	0.35± 0.04	80.04± 10.18
TOP15	4.62± 0.61	0.18± 0.04	0.23± 0.03	65.44± 9.11
Range	0.87– 5.70	0.17– 0.47	0.17- 0.60	45.48 – 113.07
Average	2.66± 0.60	0.22± 0.05	0.34± 0.07	78.41± 15.51

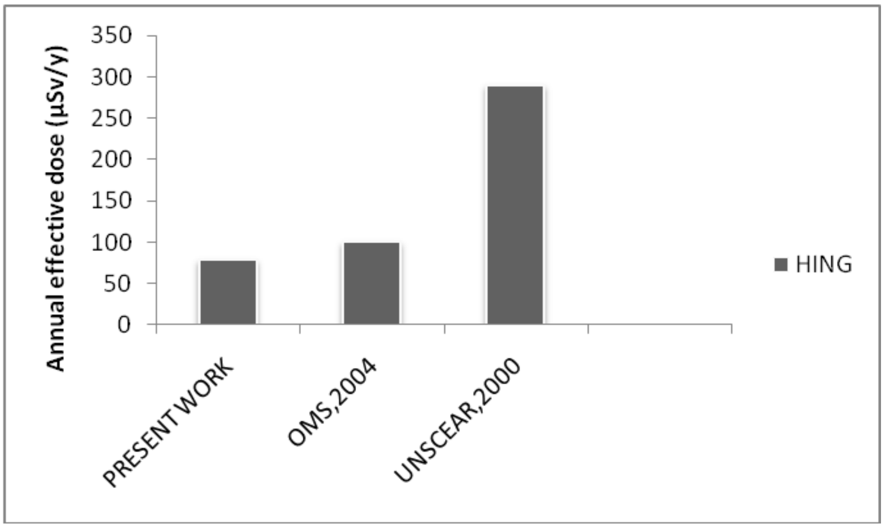

Fig 1. Comparison of average effective dose measured with worldwide average doses

3.4. Lifetime risk assessment in the sachet water samples

Mortality and morbidity risks to cancer calculated in the sachet water samples are presented in Table 3. According to Table 3, mortality and morbidity risks varied respectively form 4.94×10^{-5} to 1.17×10^{-4} and 7.20×10^{-5} to 1.24×10^{-4} with averages of 6.75×10^{-5} and 9.84×10^{-5} respectively.

The highest value of mortality risk of 1.17×10^{-4} was found in NEN12 sample. This means that more than one person out of 10,000 people could die from cancer by consuming this sachet water. According to Table 3, only one NEN1 sample had a mortality risk slightly above the US EPA acceptable range of risks of 10^{-6} to 10^{-4} [15]. The average mortality risk of 6.75×10^{-5}, means approximately seven persons out of 100,000 people are likely to die from cancer by consuming these sachet waters. However this average value of mortality risk is below the EPA acceptable range of risks.

For the morbidity risk, the highest value of 1.24×10^{-4} was found in ATL14. This means that more than one person out of 10,000 people are likely to suffer from any cancer by drinking this water. Table 3 shows that six samples out of the fifteen samples (40%), had morbidity risks slightly above the US EPA acceptable range of risks. It shows also that the average morbidity risk was 9.84×10^{-5}. That means almost one person out of 10,000 people is likely to suffer from radio-induced cancer in his life by drinking the sachet waters analysed. Therefore, we can say that the consumption of collected sachet waters could cause health hazard to the populations in Abidjan.

IV. CONCLUSION

The aim of this study was to assess radiological risks for the population health. Therefore 60 sachet waters representing 15 different samples were analysed with a gamma spectrometry analytical technique. The analysis gave activity concentrations varying from 0.87 to 5.70 Bq/L, 0.16 to 0.47 Bq/L and 0.17 to 0.60 Bq/L respectively for ^{40}K, ^{226}Ra, and ^{232}Th with averages of 2.66± 0.60 Bq/L, 0.22± 0.65 Bq/L and 0.34± 0.07 Bq/L respectively. The annual effective doses due to the ingestion of these radionuclides in water were also calculated and they varied from 45.48 to 113.07 μSv/yr with an average of 78.41± 15.51 μSv/yr. The results showed two samples, BES1 and NEN12, having annual effective dose slightly higher than the reference effective dose in drinking water recommended by WHO. However, the average annual effective dose measured in sachet water samples was lower than average effective doses recommended by WHO and UNSCEAR. Therefore, it is possible to notify that the consumption of the sachet waters produced in the district of Abidjan could not cause a significant health effect for the population. However the lifetime risk assessment showed a low mortality risk for the population with an average value below the EPA acceptable range of risks and a high morbidity risk for the population which could be harmful for the population. Therefore we recommend to governmental authorities in charge of drinkable water a strict control in the production of sachet waters in order to reduce this risk in the district of Abidjan.

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