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Public Effective Dose Assessment Using Gross Alpha and Beta Radioactivity Levels of Tap Drinking Water in the District of Abidjan, Cote d'Ivoire

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Abstract

In order to assess public effective dose due to gross alpha and beta in water, 43 tap water samples were collected from different areas in the District of Abidjan. Using the low background Gas-less Automatic Alpha/Beta counting system (Canberra iMatic^{TM}) for analysis, the gross alpha and beta concentrations found varied from 0.001 ± 0.002 to 0.063 ± 0.050 Bq/l with an average of 0.013 ± 0.012 Bq/l and from 0.067 ± 0.080 to 0.320 ± 0.120 Bq/l with an average of 0.174 ± 0.076 Bq/l, respectively in samples. The public effective dose assessment showed values of dose to ingestion of alpha and beta emitter radionuclides lower than the recommended value of dose for drinking water 0.1 mSv/y, except in 30% of the samples. These results show the need for additional studies to be conducted in order to clarify the hazardousness of these water samples. However, this study still remains important because it has provided necessary data for future tap water quality monitoring studies in the District of Abidjan.

Keywords

Gross Alpha and Beta Concentration, Tap Water, Effective Dose, District of Abidjan

1. Introduction

Water is very important in our life. It forms 50% - 60% of the weight of our body and plays an active role in all the vital processes of our body. Therefore, water must be free from organisms that are capable of causing disease and from minerals and organic substances that could produce adverse physiological effects [1]

[2]. However, any source of water is completely free of radioactive isotopes due to the presence of natural decay series of uranium, thorium and actinium and other isotopes such as ^{40}K [3].

This presence of radionuclides in water poses a number of health hazards, especially when these radionuclides are deposited in the human body through drinking. Dissolved radionuclides in water emit particles (alpha and beta) and photons (gamma) which gradually expose living tissues [4] [5]. Studies have shown that radiation exposure at low to moderate doses may increase the long-term incidence of cancer [6] [7].

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 [8]. It has been established that a high concentration of uranium greater than 15 $\mu g \cdot l^{-1}$ in domestic water may present harmful biological effects in humans [9]. It is also established that the acceptable maximum concentration of thorium in drinking water is 0.6 Bq/L [8].

Since 2002, the population of the District of Abidjan has greatly increased because of the socio-political crisis. This rapid population growth and difficult living conditions of populations have caused not only the problem of access to drinking water, but also the degradation of the environment and the 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 [10]. Many studies in this area have shown the deterioration of the water quality.

Therefore, it is necessary to perform regular measurements of radioactivity parameters of different types of drinking water in each region using simple, low-cost and reliable methods [11] [12] [13]. The most commonly used radiometric methods of drinking water analysis for routine monitoring are the screening methods based on the measurement of gross alpha and gross beta activity [13] according to ISO methods [14] [15]. In the case that the measured values of radioactivity do not exceed the screening values adopted by the World Health Organization [1], no further radiological investigation for specific radionuclides is required [16] [17].

The main objective of this study is to assess public effective doses using gross alpha and beta activities from the most commonly used type of drinking water (tap water) in the district of Abidjan.

The results as the first of its kind in the area of study will be used as a data base to evaluate possible future changes in the region.

2. Material and Methods

2.1. Description of the Study Area

The district of Abidjan 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 2119 km^2, the district of Abidjan has a growth rate of 6% per year and a population density of 2221 inhabitants/km^2. It includes a population estimated in 2021 at about 6,321,017 inhabitants [18].

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 [19]. This basin is a Cretaceous to Quaternary basin with enormous potential in groundwater [20].

These groundwater resources are contained in three aquifer levels of unequal importance. The three main aquifers are: Quaternary aquifer, Maastrichtian aquifer, and Continental Terminal aquifer. The Continental Terminal is one used for the supply of water in the district of Abidjan. The sampling points are indicated on the (**Figure 1**) below.

2.2. Collection and Preparation of Samples

A total of 43 tap water samples were collected from 13 townships in the District. They were collected in 1.5 liter polyethylene bottles previously well washed, rinsed with nitric acid and labeled. The collected samples were immediately acidified with a few drops of nitric acid HNO_3 (1 M) to prevent adherence of the radionuclides to the walls of the containers.

For the measurement of gross alpha and beta activities in samples, 300 mL of water from each sample were transferred into 400 mL beakers, previously thoroughly washed and rinsed with ultrapure water to avoid contamination of the samples. The beaker and their contents were slowly heated to a low temperature (below 65˚C) on an electric hot plate to evaporate the water sample contained at a small volume. The temperature was uniform throughout the plate to avoid areas of "overheating" that could cause losses by projections.

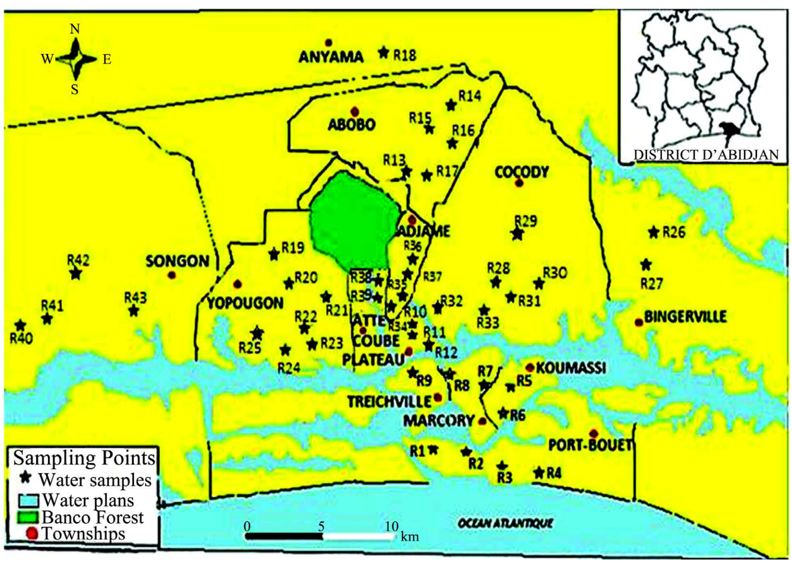

Figure 1. Sampling points and the study area location map; Source: CCT-BNET.

After heating, the small amounts remaining in the beakers were dissolved with few drops of nitric acid (HNO_3) (1 M) to prevent the radionuclides from sticking to the walls of the cups. Then the dissolved quantities were transferred to cylindrical stainless steel cups with a diameter of 47 mm and labeled to differentiate the samples.

The steel cups and the contents were heated on the electric hot plate to be dried to obtain radioactive residues (**Figure 2**). The steel cups were placed in a dryer to cool them at laboratory temperature but also to prevent them from absorbing moisture. The dried samples were then placed in a gross alpha and beta activity counter for analysis.

2.3. Sample Analysis

The prepared samples were counted to determine alpha and beta activity concentration using the low background Gas-less Automatic Alpha/Beta counting system (Canberra iMatic™) calibrated with alpha (^{241}Am) and beta (^{90}Sr) standards. The system uses solid state silicon (Passivated implanted Planar Silicon, PIPS) detector for alpha and beta detection. The samples were counted for 200 min.

The alpha and beta efficiencies were determined to be 36.39% ± 2.1% and 36.61% ± 2.2% respectively. The background readings of the detector for alpha and beta activity concentrations were 0.04 ± 0.01 and 0.22 ± 0.03 cpm. All the measurements were carried out at the Ghana Atomic Energy Commission, Accra.

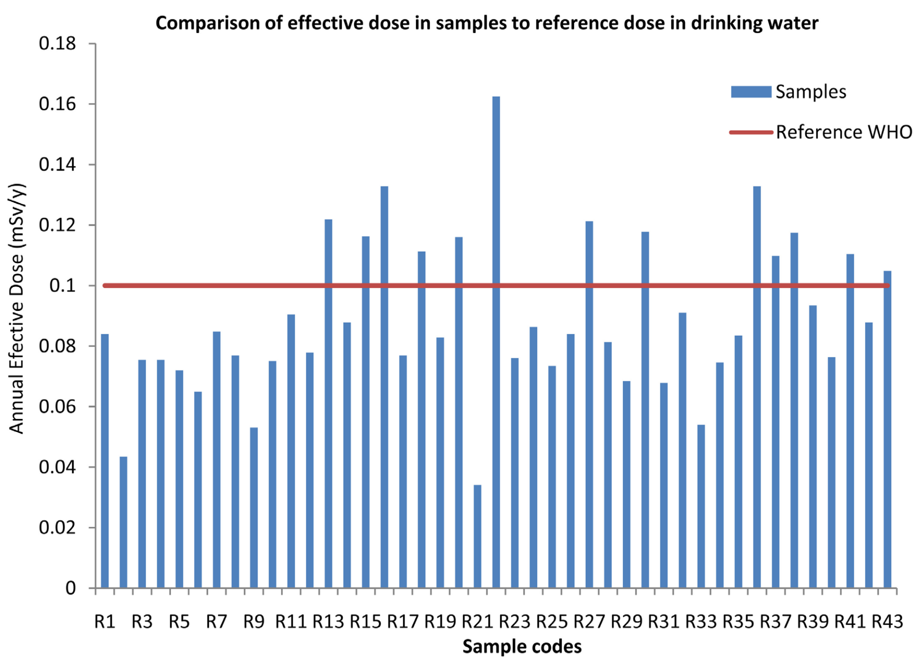

Figure 2. Annual effective dose in tap water samples from the district of Abidjan.

2.4. Gross Alpha and Beta Activity Determination

The gross α and β activities of the water samples were estimated according to

Saleh et al., as shown by Equation (1) [21].

$$A_{\alpha,\beta} = \frac{N}{60 \times \frac{Eff_{\alpha,\beta}}{100} \times V_s} \tag{1}$$

N is the separately net gross alpha or beta count rate (cpm), $Eff_{\alpha,\beta}$ is separately gross alpha or beta counting efficiency (in percent), V_s is the volume of sample aliquot (in L) and 60 is the conversion factor.

2.5. Effective Dose Equivalent Due to Ingestion

The effective dose equivalent (DRw), the total effective equivalent dose (TEED) and lifetime risk index using concentrations of gross alpha and beta activity were calculated using ICRP (1991), UNSCEAR (2000) and Karahan *et al.* [22] [23] [24].

$$DRw_{(\alpha,\beta)} = Aw_{(\alpha,\beta)} \times DCF_{(\alpha,\beta)} \times 730 \tag{2}$$

where $DRw_{(\alpha,\beta)}$ is the dose equivalent effective (Sv/year), $Aw_{(\alpha,\beta)}$ is activity (Bq/L), a daily water intake of 2 L/Day according to WHO [1] results in annual consumption rate of 730 L/year, $DCF_{(\alpha,\beta)}$ is the dose conversion factor for ingestion of the individual natural radionuclides for adult, $\alpha = 2.80 \times 10^{-4}$ mSv·Bq^{-1} and $\beta = 6.90 \times 10^{-4}$ mSv·Bq^{-1} [8].

3. Results and Discussion

3.1. Gross Alpha and Beta Activity Concentrations in Samples

The measured activity concentrations of gross alpha in tap water samples of different locations in the district of Abidjan are gathered in **Table 1**. The observed gross alpha activities found in the collected samples varied from 0.001 ± 0.002 to 0.063 ± 0.050 Bq/l with an average of 0.013 ± 0.012 Bq/l. The highest gross alpha activity in the water was found in sample R18 and the lowest alpha activity was found in sample R10. The gross alpha activity in water sample is primarily comprised uranium decay products such as ^{226}Ra and ^{40}K. WHO recommended the parameter of gross alpha activity concentration to be 0.1 Bq/l. If the gross alpha activity does not exceed 0.1 Bq/l, it can be assumed that the annual total indicative dose is less than 0.1 mSv per year. In the present study, the obtained results show that the measured activity concentrations of gross alpha in all tap water samples were less than 0.1 Bq/l which is the limit recommended by WHO.

For gross beta activity concentration in the tap water samples, **Table 1** showed various values ranging from 0.067 ± 0.080 to 0.320 ± 0.120 Bq/l with an average of 0.174 ± 0.076 Bq/l.

The highest concentration was found in sample R22 and the lowest in sample R21. This high activity concentration could be due to the geological setting of the underground water source. However, the results obtained also showed that the measured activity concentrations of gross beta in all tap water samples are less than 1.0 Bq/l which is the limit recommended by WHO.

Compared with other values of gross alpha and beta activities in tap water in other countries, it is observed, as shown in (Table 2), that the results of the present study are lower than values of gross alpha concentration found in tap drinking water samples in countries like Italy, Nigeria, Jordan and Malaysia. It is also shown than gross beta activity obtained in the present study was lower than the one found in tap water in Jordan, Malaysia but higher than the beta activity measured in Turkey, Italy, Nigeria and Bangladesh Dhaka.

Table 1. Gross alpha and beta activity concentrations of tap water samples.

Sample Codes	Activity concentration (Bq/L)	
	Gross Alpha	Gross Beta
R01	0.003 ± 0.002	0.167 ± 0.060
R02	0.010 ± 0.004	0.083 ± 0.060
R03	0.010 ± 0.020	0.147 ± 0.030
R04	0.010 ± 0.003	0.147 ± 0.100
R05	0.010 ± 0.006	0.140 ± 0.080
R06	0.017 ± 0.002	0.123 ± 0.070
R07	0.007 ± 0.010	0.167 ± 0.100
R08	0.010 ± 0.004	0.150 ± 0.075
R09	0.057 ± 0.035	0.083 ± 0.070
R10	0.001 ± 0.002	0.150 ± 0.081
R11	0.020 ± 0.004	0.173 ± 0.072
R12	0.007 ± 0.003	0.153 ± 0.062
R13	0.010 ± 0.020	0.240 ± 0.100
R14	0.007 ± 0.010	0.173 ± 0.061
R15	0.007 ± 0.020	0.230 ± 0.072
R16	0.007 ± 0.005	0.263 ± 0.080
R17	0.010 ± 0.003	0.150 ± 0.065
R18	0.063 ± 0.050	0.197 ± 0.080
R19	0.007 ± 0.030	0.163 ± 0.061
R20	0.013 ± 0.006	0.227 ± 0.150
R21	0.003 ± 0.005	0.067 ± 0.080
R22	0.013 ± 0.020	0.320 ± 0.120
R23	0.013 ± 0.006	0.147 ± 0.081
R24	0.007 ± 0.010	0.170 ± 0.101
R25	0.010 ± 0.002	0.143 ± 0.081
R26	0.020 ± 0.006	0.160 ± 0.060

Continued

R27	0.007 ± 0.004	0.240 ± 0.075
R28	0.007 ± 0.030	0.160 ± 0.065
R29	0.010 ± 0.005	0.133 ± 0.040
R30	0.007 ± 0.002	0.233 ± 0.007
R31	0.007 ± 0.010	0.133 ± 0.019
R32	0.047 ± 0.008	0.163 ± 0.070
R33	0.020 ± 0.006	0.100 ± 0.025
R34	0.023 ± 0.015	0.140 ± 0.033
R35	0.010 ± 0.006	0.163 ± 0.051
R36	0.007 ± 0.010	0.263 ± 0.110
R37	0.007 ± 0.020	0.217 ± 0.150
R38	0.013 ± 0.030	0.230 ± 0.090
R39	0.010 ± 0.020	0.183 ± 0.100
R40	0.007 ± 0.008	0.150 ± 0.080
R41	0.010 ± 0.005	0.217 ± 0.075
R42	0.007 ± 0.020	0.173 ± 0.080
R43	0.017 ± 0.030	0.203 ± 0.150
Range	**0.001 - 0.063**	**0.067 - 0.320**
Average	**0.013 ± 0.012**	**0.174 ± 0.076**

3.2. Annual Effective Dose and Total Equivalent Effective Dose of Samples

The annual alpha and beta effective dose due to intake of water was determined by averaging the individual annual committed effective doses contributed by the major alpha and beta emitters in the U-238 and Th-232 series of the naturally occurring radionuclides [17]. The calculated effective doses are shown in (**Table 3**).

The equivalent gross alpha effective dose due to water intake in the district varied from 0.0002 ± 0.0004 mSv/year found in sample R10 to 0.0129 ± 0.0102 mSv/year found in R18, with an average of 0.0027 ± 0.0025 mSv/year.

As for the annual beta effective dose due to intake of water, the lowest value of 0.0335 ± 0.0400 mSv/year was found in sample R21 while the highest one of 0.1598 ± 0.0600 mSv/year was found in R22, with an average value of 0.0863 ± 0.0369 mSv/year. Summing the two equivalent gross effective doses, the total annual effective dose due to intake of tap water samples found varied from 0.0341 ± 0.0761 mSv/year to 0.1624 ± 0.0410 mSv/year, with an average value of 0.0890 ± 0.0394 mSv/year. The lowest annual effective dose was found in sample

R21 while the highest one was obtained in R22. It thus follows that greater risk is associated with tap water from R22, than at the other areas of the district.

The recommended reference dose level (RDL) of the committed effective dose, equal to 0.1 mSv from 1 year's consumption of drinking water [31] was however exceeded in thirteen out of the forty three samples (**Table 2**), meaning 30% of the total samples (**Figure 2**). This result shows that the water is not safe for consumption in some locations of the district of Abidjan.

Table 2. Comparison gross alpha and beta activities in the present with others in tap water in the world.

Country	Activity concentration (Bq/l)		References
	Gross alpha	Gross alpha	
Turkey	0.0002 - 0.015	0.0252 - 0.2644	[25]
Italy	<0.007 - 0.349	<0.025 - 0.273	[26]
Jordan Amman	<0.05 - 0.2495	<0.188 - 0.327	[27]
Jordan Aqaba	0.04 ± 0.02	0.71 ± 0.03	[28]
Bangladesh Dhaka	0.0037 ± 0.0015	0.0604 ± 0.023	[3]
Nigeria	0.0058 - 0.174	0.0147 - 0.2225	[29]
Malaysia	0.012	0.234	[30]
Cote d'Ivoire	**0.001 - 0.063**	**0.067 - 0.320**	**Present study**

Table 3. Annual effective dose and total equivalent effective dose of the samples.

Sample Codes	Annual effective dose (mSv/year)		Total equivalent effective dose (mSv/year)
	DRw_α	DRw_β	
R01	0.0006 ± 0.0004	0.0834 ± 0.0300	0.0840 ± 0.0304
R02	0.0020 ± 0.0008	0.0414 ± 0.0300	0.0435 ± 0.0308
R03	0.0020 ± 0.0041	0.0734 ± 0.0150	0.0754 ± 0.0191
R04	0.0020 ± 0.0006	0.0734 ± 0.0050	0.0754 ± 0.0056
R05	0.0020 ± 0.0012	0.0699 ± 0.0400	0.0719 ± 0.0411
R06	0.0035 ± 0.0004	0.0614 ± 0.0350	0.0649 ± 0.0354
R07	0.0014 ± 0.0020	0.0834 ± 0.0500	0.0848 ± 0.0520
R08	0.0020 ± 0.0008	0.0749 ± 0.0374	0.0769 ± 0.0383
R09	0.0117 ± 0.0072	0.0414 ± 0.0350	0.0531 ± 0.0383
R10	0.0002 ± 0.0004	0.0749 ± 0.0404	0.0751 ± 0.0421
R11	0.0041 ± 0.0008	0.0864 ± 0.0360	0.0905 ± 0.0409
R12	0.0014 ± 0.0006	0.0764 ± 0.0310	0.0778 ± 0.0368

Continued

R13	0.0020 ± 0.0041	0.1198 ± 0.0500	0.1219 ± 0.0316
R14	0.0014 ± 0.0020	0.0864 ± 0.0305	0.0878 ± 0.0540
R15	0.0014 ± 0.0041	0.1148 ± 0.0360	0.1163 ± 0.0325
R16	0.0014 ± 0.0010	0.1313 ± 0.0340	0.1328 ± 0.0400
R17	0.0020 ± 0.0006	0.0749 ± 0.0325	0.0769 ± 0.0410
R18	0.0129 ± 0.0102	0.0984 ± 0.0340	0.1113 ± 0.0331
R19	0.0014 ± 0.0061	0.0814 ± 0.0305	0.0828 ± 0.0502
R20	0.0027 ± 0.0012	0.1133 ± 0.0749	0.1160 ± 0.0366
R21	0.0006 ± 0.0010	0.0335 ± 0.0400	0.0341 ± 0.0761
R22	0.0027 ± 0.0041	0.1598 ± 0.0600	0.1624 ± 0.0410
R23	0.0027 ± 0.0012	0.0734 ± 0.0404	0.0761 ± 0.0640
R24	0.0014 ± 0.0020	0.0849 ± 0.0504	0.0863 ± 0.0417
R25	0.0020 ± 0.0004	0.0714 ± 0.0404	0.0734 ± 0.0525
R26	0.0040 ± 0.0012	0.0799 ± 0.0300	0.0839 ± 0.0409
R27	0.0014 ± 0.0008	0.1198 ± 0.0375	0.1213 ± 0.0312
R28	0.0014 ± 0.0061	0.0799 ± 0.0325	0.0813 ± 0.0383
R29	0.0020 ± 0.0010	0.0664 ± 0.0200	0.0685 ± 0.0386
R30	0.0014 ± 0.0004	0.1163 ± 0.0035	0.1177 ± 0.0210
R31	0.0014 ± 0.0020	0.0664 ± 0.0095	0.0678 ± 0.0039
R32	0.0096 ± 0.0016	0.0814 ± 0.0350	0.0910 ± 0.0115
R33	0.0041 ± 0.0012	0.0499 ± 0.0125	0.0540 ± 0.0366
R34	0.0047 ± 0.0031	0.0699 ± 0.0165	0.0746 ± 0.0137
R35	0.0020 ± 0.0012	0.0814 ± 0.0255	0.0834 ± 0.0195
R36	0.0014 ± 0.0020	0.1313 ± 0.0550	0.1327 ± 0.0267
R37	0.0014 ± 0.0041	0.1084 ± 0.0749	0.1098 ± 0.0570
R38	0.0027 ± 0.0061	0.1148 ± 0.0500	0.1175 ± 0.0790
R39	0.0020 ± 0.0041	0.0914 ± 0.0500	0.0934 ± 0.0511
R40	0.0014 ± 0.0016	0.0749 ± 0.0400	0.0763 ± 0.0540
R41	0.0020 ± 0.0016	0.1084 ± 0.0375	0.1104 ± 0.0416
R42	0.0014 ± 0.0010	0.0864 ± 0.0400	0.0878 ± 0.0440
R43	0.0035 ± 0.0061	0.1014 ± 0.0749	0.1049 ± 0.0810
Average	**0.0027 ± 0.0025**	**0.0863 ± 0.0369**	**0.0890 ± 0.0394**

4. Conclusions

This study is the first of its kind in the area of study to determine the radioactivity levels of tap drinking water using concentrations of gross alpha and gross beta activity. The concentrations ranged from 0.001 ± 0.002 to 0.063 ± 0.050 Bq/l with an average of 0.013 ± 0.012 Bq/l and from 0.067 ± 0.080 to 0.320 ± 0.120 Bq/l with an average of 0.174 ± 0.076 Bq/l respectively for gross alpha and gross beta activities show the radioactivity levels lower than recommended levels established by WHO. Unfortunately, the effective dose calculation indicated that the doses of more than 30% of the total samples exceeded the guideline value, 0.1 mSv per year. This result shows the radiological health hazards related to the consumption of tap water from these locations in the District of Abidjan.

However, the data gathered in this study provided baseline radiometric values of tap water as well as drinking water in this region that can be used to evaluate the possible changes in the future.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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