World Journal of Nuclear Science and Technology, 2024, 14, 86-96
https://www.scirp.org/journal/wjnst
ISSN Online: 2161-6809
ISSN Print: 2161-6795

Gross Alpha and Beta Activities and Related Lifetime Risks Assessment Due to Ingestion of Drinking Water from Different Sources in the District of Abidjan, Cote d'Ivoire

Ponaho Claude Kezo[1,2], Issa Konate[2], Dabo Salif Ignace Agba[2,3]

[1]Laboratory of Environmental Science and Technology, University Jean Lorougnon Guede (UJLoG), Daloa, Côte d'Ivoire
[2]Laboratory of Environmental and Solar Energy Sciences, University Felix Houphouet Boigny (UFHB), Abidjan, Côte d'Ivoire
[3]Laboratory of Fundamental and Applied Physics, University Nangui Abrogoua (UNA), Abidjan, Côte d'Ivoire
Email: ponaho04@yahoo.fr

How to cite this paper: Kezo, P.C., Konate, I. and Agba, D.S.I. (2024) Gross Alpha and Beta Activities and Related Lifetime Risks Assessment Due to Ingestion of Drinking Water from Different Sources in the District of Abidjan, Cote d'Ivoire. *World Journal of Nuclear Science and Technology*, **14**, 86-96.
https://doi.org/10.4236/wjnst.2024.141004

Received: November 2, 2023
Accepted: January 26, 2024
Published: January 29, 2024

Abstract

Drinking good quality water is essential for better health. It is therefore essential to assess the radiological quality of all water consumed in the District of Abidjan in order to prevent related hazards. Thus, the objective of this study was to assess the risk of cancer due to the ingestion of alpha and beta emitting radionuclides in the different types of water consumed in the region. A total of 63 water samples with 43 tap water samples, 5 bottled mineral water and 15 sachet water samples was collected and taken to GAEC laboratory for analysis. The low background Gas-less Automatic Alpha/Beta counting system (Canberra iMatic^{TM}) was used to determine alpha and beta activity concentrations. Activity concentrations of both gross alpha and gross beta obtained in water sample were respectively lower than the WHO recommended limits of 0.1 Bq/l and 1 Bq/l. Also, the annual effective dose and total equivalent effective dose found in mineral bottled water samples were higher than in other types of water. The assessment of radiological lifetime risk has shown values of cancer risk due to ingestion alpha and beta emitters lower than recommended limit. These results indicate that there is no health hazard associated to consumption of water in the District of Abidjan.

Keywords

Gross Alpha and Beta Activities, Drinking Water, Effective Dose, Radiological Lifetime Risks

1. Introduction

Water is one of the most significant human resources; its quality is extremely essential and it is one of the major parameters in environmental studies. Water physical, chemical, and radioactive properties should be well known to evaluate its aptness for human intake [1]. Studies have shown the existence of radioactive isotopes due to the presence of natural decay series of uranium, thorium and actinium and other isotopes such as ^{40}K [2]. They have also shown the hazard of the gradually exposure of these dissolved radionuclides emitted from water to living tissues [3] [4] [5] [6]. 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 [7].

In fact, the district of Abidjan is the main economic pole of the country. It attracts people from various parts of the country and the sub-region in search of improving their living conditions. The diversity of social strata led to consumption of several types of drinking water according to their economic condition. These types of drinking water provided by various sources such as aquifers, manufactures and production conditions include tap water, bottled mineral water and sachets, contain radioactivity. Thus, work to evaluate the radiological quality should be done almost frequently in order to preserve the health of populations.

Unfortunately, very few works concerning the radiological quality of water have been carried out in the District of Abidjan [8] [9] [10] [11]. Meanwhile, human activities continue to degrade water resources [12] [13].

These anthropogenic activities can increase the natural radioactivity concentration in water and then the risk of cancer of the population after consuming water. Therefore, it was necessary to analyze all the types of water consumed in that area in order to assess the associated radiological risk.

Thus, the most common radiometric methods of drinking water analysis for routine monitoring using the screening methods based on the measurement of gross alpha and gross beta activity [14] according to ISO methods [15] [16] were adopted in this work.

Thus, the objective of this present study is to assess radiological lifetime risks using gross alpha and beta activities in the different types of drinking water in the district of Abidjan.

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 [17].

In geological and hydrogeological plans, it 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 [18]. This basin is a Cretaceous to Quaternary basin with enormous potential in groundwater [19].

The (**Figure 1**) below shows the study area with tap water sampling points.

2.2. Collection and Preparation of Samples

Three different types of drinking water were collected in the area, namely tap water, mineral bottled water and sachet water. For tap water, 43 samples were collected from 13 townships in the District like shown in (**Figure 1**). 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 (1M) to prevent adherence of the radionuclides to the walls of the containers. For mineral bottled water, 5 samples of 1.5 liters from five different manufactures were collected in the market. As for the sachet water, 45 samples with three (3) of fifteen (15) different branches of most consumed sachet water were collected from market.

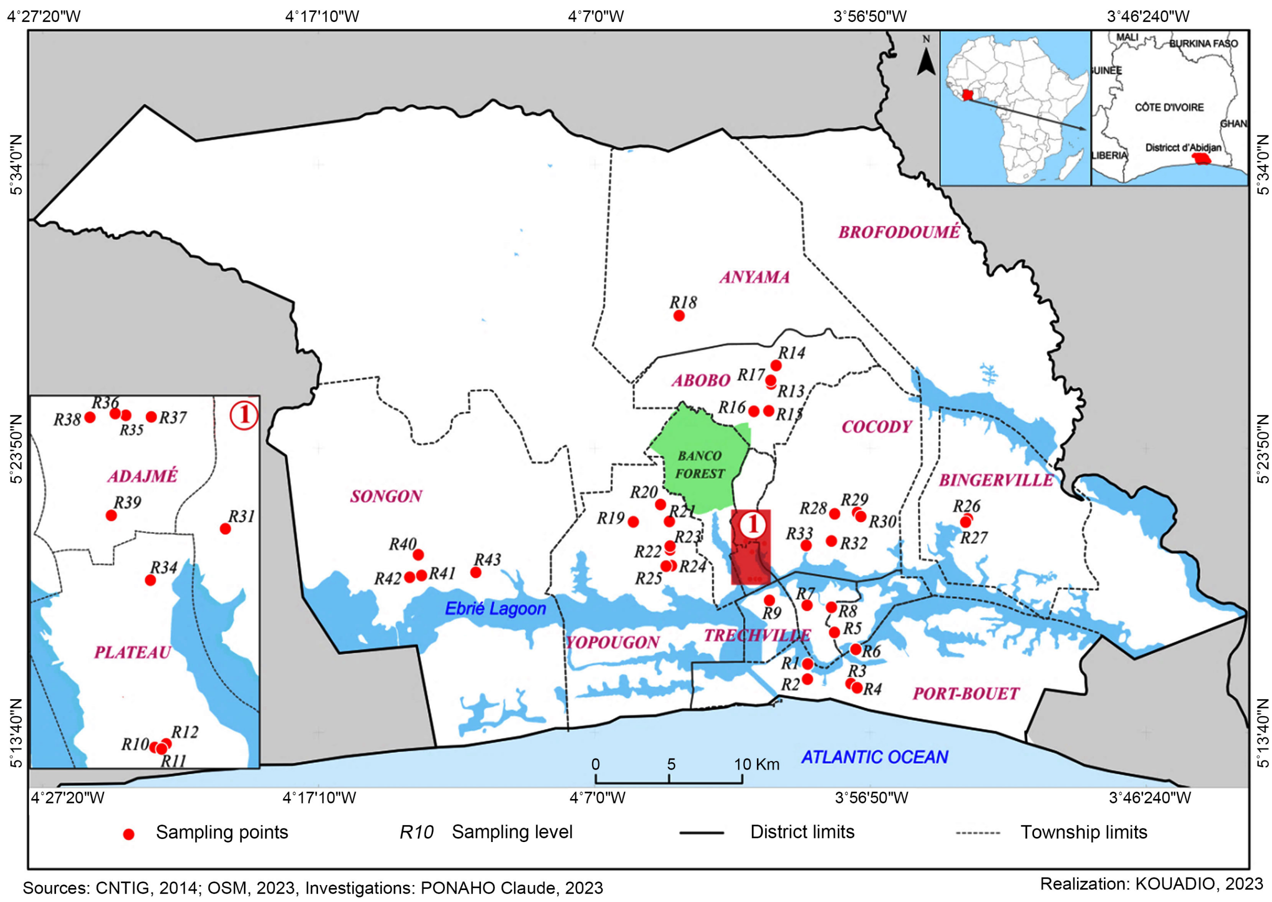

Figure 1. Tap water sampling points in the study area.

The collected samples were taken to Ghana Atomic Energy Commission (GAEC) Lab for preparation and gross alpha and beta analysis.

Before analysis, 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.

After heating, the small amounts remaining in the beakers were dissolved with few drops of nitric acid (HNO_3) (1M) 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. 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 Method

The prepared samples were counted to determine alpha and beta activity concentrations 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, below shows the Automatic Alpha/Beta counting system (Canberra iMatic™), used in this work.

2.4. Gross Alpha and Beta Activity Determination

The gross α and β activities of the water samples were estimated according to [20], as shown by equation below.

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

$A_{\alpha,\beta}$ is gross α or β activities, 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.

Figure 2. Picture of the automatic Alpha/Beta counting system (Canberra iMatic™).

2.5. Effective Dose Equivalent and Total Effective Equivalent Dose

The effective dose equivalent (DRw) and the total effective equivalent dose ($TEED$) due to ingestion of gross alpha and beta radionuclides were calculated using [21] [22] and [23].

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

where $DRw_{(\alpha,\beta)}$ is the dose equivalent effective (Sv/year), $Aw_{(\alpha,\beta)}$ is gross α or β activity (Bq/L), a daily water intake of 2 L/day according to [24], 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, $\alpha = 2.80 \times 10^{-4}$ mSvBq^{-1} and $\beta = 6.90 \times 10^{-4}$ mSvBq^{-1} [7].

The total effective equivalent dose ($TEED$), considered as a total dose due to ingestion of radionuclides in water, is calculated by summing the effective doses due to both alpha and beta radionuclides in water. The $TEED$ in the water samples were given by the equation below:

$$TEED_{(\alpha,\beta)} = DRw_{(\alpha)} + DRw_{(\beta)}$$

2.6. Radiological Lifetime Risk Assessment

Considering the population life expectancy in Cote d'Ivoire equals to 57 years [25], the lifetime cancer risk is determined by the following equation.

$$RL = DRw_{(\alpha,\beta)} \times DL \times RF$$

where RL is the radiological lifetime risk, DL is duration of life (57 years) and RF is risk factor recommended as 7.3×10^{-2} Sv^{-1} [22].

3. Results and Discussion

3.1. Gross Alpha and Beta Activity Concentrations in Samples

Gross alpha and beta activities measured in all the three types of drinking water consumed in the District of Abidjan are presented in **Table 1**.

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

Type of sample	Number	Activity concentration (Bq/L)			
		Gross Alpha		Gross Beta	
		Range	Mean	Range	Mean
Tap	43	0.001 - 0.063	0.013 ± 0.012	0.067 - 0.320	0.174 ± 0.076
Mineral bottled	5	0.001 - 0.020	0.007 ± 0.005	0.150 - 0.270	0.203 ± 0.040
Sachet	15	0.003 - 0.017	0.010 ± 0.002	0.147 - 0.260	0.197 ± 0.080

According to **Table 1**, the observed gross alpha activities found in the collected samples varied from 0.001 to 0.060 Bq/l with an average of 0.013 ± 0.012 Bq/l, form 0.001 to 0.020 Bq/l with an average value of 0.007 ± 0.005 Bq/l and from 0.003 to 0.017 Bq/l with an average value of 0.010 ± 0.002 Bq/l respectively in tap water, mineral bottled water and sachet water.

For the gross beta activities, they varied from 0.067 to 0.320 Bq/l with an average value of 0.174 ± 0.076 Bq/l, from 0.150 to 0.270 Bq/l with average of 0.203 ± 0.040 Bq/l and from 0.147 to 0.260 Bq/l with an average value of 0.197 ± 0.080 Bq/l respectively in tap water, mineral bottled water and sachet water.

Comparing the different values of activity measured in the water samples, it is shown that the lowest gross alpha activity of 0.001 Bq/l was found in tap water and mineral water samples, while the highest gross alpha activity's value was measured in a sachet water sample. The results in **Table 1** also showed a lowest value of gross beta activity of 0.060 Bq/l in tap water and the highest beta activity of 0.150 Bq/l was found in mineral bottled water sample.

This variation in radionuclide concentrations could be explained by several factors such as the difference in the origins of the waters, the human activities preceding production, the poor conservation of the product etc. Indeed, the difference in geological formations of the waters could lead to a variation in the concentrations of terrestrial radionuclides such as U-238, Th-238 and K-40 from which the alpha and beta emitters present in the waters originate.

The gross alpha activity in water sample is primarily comprised uranium decay products such as ^{226}Ra and ^{40}K and gross beta activity in water is primarily comprised thorium decay products.

Gross alpha and beta activities founded in water samples in this study were compared with WHO recommended values. According to WHO recommendation, if the gross alpha activity and gross beta activity respectively do not exceed 0.1 Bq/l, and 1 Bq/l in a drinking water sample, it can be assumed that the water sample is of good quality. The comparison is presented in (**Figure 3**) which showed that activity concentrations of both gross alpha and gross beta in all types of water were respectively lower than the WHO recommended limits of 0.1 Bq/l and 1 Bq/l. Thus, all the samples are of good quality.

The gross alpha and beta activities obtained in this work were also compared with different values in other countries and shown in (**Table 2**).

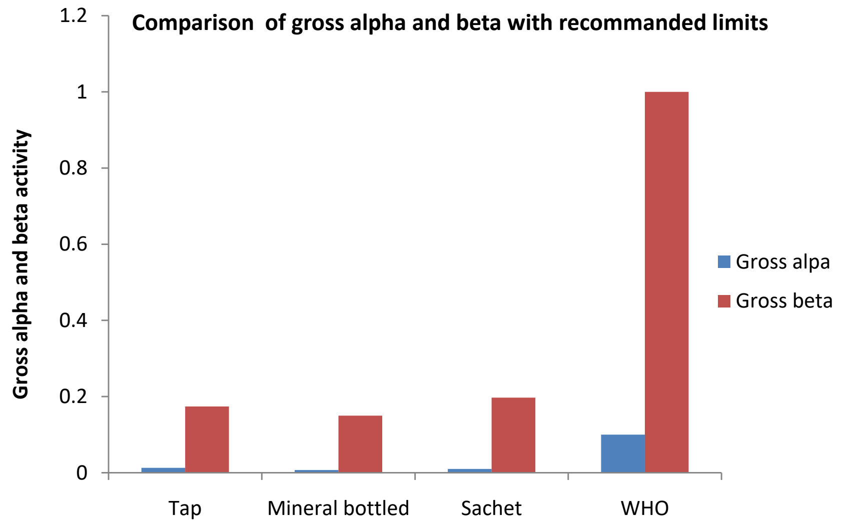

Figure 3. Comparison of the measured gross alpha and beta with WHO recommended limits.

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

Country	Type of water	Activity concentration (Bq/l)		References
		Gross alpha	Gross beta	
Turkey	Tap	0.0002 - 0.015	0.0252 - 0.2644	[26]
Italy	Tap	<0.007 - 0.349	<0.025 - 0.273	[27]
Jordan	Mineral	31.46	50.14	[28]
Jordan	Tap	0.04 ± 0.02	0.71 ± 0.03	[29]
Nigeria	Sachet	0.007 - 0.080	0.120 - 0.98	[30]
Niger State	Sachet	0.002 - 0.024	0.072 - 0.558	[31]
Bangladesh	Mineral	0.730 - 0.96	65.54 - 77.29	[32]
Nigeria	water	0.10 - 4.00	3.2 - 43.7	[33]
Cote d'Ivoire	Tap	0.001 - 0.063	0.067 - 0.320	Present study
Cote d'Ivoire	Bottled	0.001 - 0.020	0.150 - 0.270	Present study
Cote d'Ivoire	Sachet	0.003 - 0.017	0.147 - 0.260	Present study

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

The annual 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 [34]. The calculated effective doses were shown in (**Table 3**).

The equivalent gross alpha effective dose due to water intake in the district varied with the water type. For tap water, the equivalent gross alpha effective dose varied from 0.0002 to 0.0129 mSv/year with a mean value of 0.0027 mSv/year.

For mineral bottled and sachet water, the equivalent gross alpha effective doses varied from 0.0002 to 0.0041 mSv/year and from 0.0006 to 0.0035 mSv/year respectively with average values of 0.0014 mSv/year and 0.0020 mSv/year.

For the annual beta effective dose due to intake of water, the values varied from 0.0414 to 0.1598 mSv/year, from 0.0751 to 0.1362 mSv/year and from 0.0734 to 0.1298 mSv/year respectively for tap water, mineral bottled and sachet water with respective average values of 0.0863 mSv/year, 0.1014 mSv/year and 0.0984 mSv/year.

The total effective equivalent doses (TEED), calculated by summing the effective doses due to both alpha and beta radionuclides in water were also shown in **Table 3**. The TEED values varied from 0.0340 to 0.1624 mSv/year, from 0.0751 to 0.1362 mSv/year and from 0.0769 to 0.1313 mSv/year respectively for tap, mineral bottled and sachet water. The mineral bottled water samples were found to have the highest average value of TEED while the lowest average value was found in tap water samples.

3.3. Radiological Lifetime Risk

For risk assessment, the total equivalent effective doses were used and the nominal probability coefficient of 7.3×10^{-2} Sv^{-1} recommended by ICRP [21] was adopted. The risk levels from the direct ingestion of gross alpha and gross beta radionuclides in drinking water from the District of Abidjan were estimated as shown in **Table 4**.

All the values of risk level estimated in water samples were lower than the acceptable risk of 10^{-4} [35]. These results are in agreement with those found in our previous studies on measurements of natural radionuclides in drinking water in the area. This indicates that the consumption of the types of water analyzed would be safe for the population of the District of Abidjan.

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

Sample Codes	Annual effective dose (mSv/year)				Total equivalent effective dose TEED (mSv/year)	
	DRw_α		DRw_β		Range	Mean
Tap	0.0002 - 0.0129	0.0027	0.0414 - 0.1598	0.0863	0.0340 - 0.1624	0.0890
Mineral	0.0002 - 0.0041	0.0014	0.0749 - 0.1348	0.1014	0.0751 - 0.1362	0.1028
Sachet	0.0006 - 0.0035	0.0020	0.0734 - 0.1298	0.0984	0.0769 - 0.1313	0.1004

Table 4. Radiological lifetime risk in the different drinking water types.

Sample type	Radiological lifetime risk RL ($\times 10^{-4}$)	
	Range	Mean
Tap	0.0085 - 0.536	0.112
Mineral bottled	0.0085 - 0.170	0.058
Sachet	0.0255 - 0.145	0.087

4. Conclusions

The objective of this study was to assess the radiological risk due to alpha and beta particle emitters in different types of water consumed in the District of Abidjan.

Analysis of samples using a low background Gas-less Automatic Alpha/Beta counting system, has shown that activity concentrations of both gross alpha and gross beta in all types of water were respectively lower than the WHO recommended limits of 0.1 Bq/l and 1 Bq/l. Therefore, the annual effective dose and total equivalent effective dose calculated were also lower than the recommended values.

The radiological lifetime risk assessment gave values of risk varying from 8.5×10^{-7} to 5.36×10^{-5}, from 8.5×10^{-7} to 1.70×10^{-5} and from 2.55×10^{-6} to 1.45×10^{-5} respectively in tap, mineral bottled and sachet water. These results show the low level of cancer risk related to water consumption in the district.

Acknowledgements

The authors would like to thank the Radiation Protection Institute's (RPI) at the Ghana Atomic Energy Commission (GAEC) for the use of their facilities.

Conflicts of Interest

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

References

[1] Al-Shboul, K.F., Alali, A.E., Batayneh, I.M. and Al-Khodire, H.Y. (2017) Radiation Hazards and Lifetime Risk Assessment of Tap Water Using Liquid Scintillation Counting and High-Resolution Gamma Spectrometry. *Journal of Environmental Radioactivity*, **178-179**, 245-252. https://doi.org/10.1016/j.jenvrad.2017.09.005

[2] Ferdous, M.J., *et al.* (2012) Gross Alpha and Gross Beta Activities of Tap Water Samples from Different Locations of Dhaka City. *Sri Lankan Journal of Physics*, **13**, 1-8. https://doi.org/10.4038/sljp.v13i1.3917

[3] Alam, M.N., Kamal, M.I., Ghose, M., Islam, S. and Anwaruddin, M. (1999) Radiological Assessment of Drinking Water of the Chittagong Region of Bangladesh. *Radiation Protection Dosimetry*, **82**, 207-214. https://doi.org/10.1093/oxfordjournals.rpd.a032626

[4] Gruber, V., Maringer, F.J. and Landstetter, C. (2009) Radon and Other Natural Radionuclides in Drinking Water in Austria: Measurement and Assessment. *Applied Radiation and Isotopes*, **67**, 913-917. https://doi.org/10.1016/j.apradiso.2009.01.056

[5] Amrani, D. and Cherouati, D.E. (1999) Health Effects from Radon-222 in Drinking Water in Algiers. *Journal of Radiological Protection*, **19**, 275-279. https://doi.org/10.1088/0952-4746/19/3/402

[6] Collman, G.W., Loomis, D.P. and Sandler, D.P. (1991) Childhood Cancer Mortality and Radon Concentration in Drinking Water in North Carolina. *British Journal of Cancer*, **85**, 626-629. https://doi.org/10.1038/bjc.1991.143

[7] WHO (2004) Guidelines for Drinking Water Quality. 3rd Edition, World Health

Organisation, Geneva.

[8] Kezo, P.C., Monnehan, G.A., Faanu, A., Gogon, B.D.L.H., Koua, A.A., Dali, T.P.A. and Djagouri, K. (2016) 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. *Research Journal of Environmental and Earth Sciences*, **8**, 56-62. https://doi.org/10.19026/rjees.8.3066

[9] Kezo, P.C., Monnehan, G.A., Gogon, B.D.L.H., Koua, A.A., Dali, T.P.A. and Koua, A.A. (2017) Analyse radiologique des eaux minérales produites en Côte d'Ivoire par la technique de spectrométrie gamma. *Revue Ivoirienne des Sciences et Technologie*, **30**, 65-76.

[10] Kezo, P.C. and Konate, I. (2020) Assessment of Radiological Risks Due to Natural Radioactivity in Tap Water from the District of Abidjan, Côte d'Ivoire. *International Journal of Applied Research*, **6**, 25-30.

[11] Kezo, P.C., Konate, I. and Dali, T. (2023) Public Effective Dose Assessment Using Gross Alpha and Beta Radioactivity Levels of Tap Drinking Water in the District of Abidjan, Cote d'Ivoire. *Journal of Environmental Protection*, **14**, 127-138. https://doi.org/10.4236/jep.2023.143009

[12] Ble, L.O., Degny, G.S. and Douampo, A.D. (2020) Evaluation de la vulnérabilité à la pollution des eaux souterraines du district d'Abidjan. *Revue Ivoirienne des Sciences et Technologie*, **36**, 91-103. https://revist.net/REVIST_30/REVIST_30_4.pdf

[13] Soro, N., Ouattara, L., Dongo, K., Kouadio, K.E., Ahoussi, K.E, Soro, G., Oga, M.S., Savané, I. and Biémi, J. (2010) Déchets municipaux dans le District d'Abidjan en Côte d'Ivoire: Sources potentielles de pollution des eaux souterraines. *International Journal of Biological and Chemical Sciences*, **4**, 364-384. https://doi.org/10.4314/ijbcs.v4i6.64952

[14] Jobbágy, V., Kávási, N., Somlai, J., Dombovári, P., Gyöngyösi, C. and Kovács, T. (2011) Gross Alpha and Beta Activity Concentrations in Spring Waters in Balaton Upland, Hungary. *Radiation Measurements*, **46**, 195-163. https://doi.org/10.1016/j.radmeas.2010.08.004

[15] ISO 9696 (2007) Water Quality-Measurement of Gross Alpha Activity in Non-Saline Water-Thick Source Method.

[16] ISO 9697 (2008) Water Quality-Measurement of Gross Beta Activity in Non-Saline Water-Thick Source Method.

[17] RGPH (2021) Recensement Général de la Population et de l'Habitat (RGPH) Principaux résultats préliminaires. Secrétariat Technique Permanent du Comité Technique du RGPH.

[18] Tastet, J.P. (1979) Environnements sédimentaires et structuraux quaternaires du littoral du Golfe de Guinée: Côte d'Ivoire, Togo, Bénin. PhD. Thèse, d'Etat ès Sciences, Université de Bordeaux 1, Bordeaux, 1-181.

[19] Jourda, J.P. (1987) Contribution à l'étude géologique et hydrogéologique de la région du Grand Abidjan (Côte d'Ivoire). PhD Thèse, 3ème Cycle, Université Scientifique, Technique et Médicale, Grenoble, 1-319.

[20] Saleh, H. and Shayeb, M.A. (2014) Natural Radioactivity Distribution of Southern Part of Jordan (Maan) Soil. *Annals of Nuclear Energy*, **65**, 184-189. https://doi.org/10.1016/j.anucene.2013.10.042

[21] ICRP (1991) 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. *Annals of the ICRP*, **21**, 1-3.

[22] UNSCEAR (2000) Sources and Effects of Ionizing Radiation. United Nations Scien-

tific Committee on the Effects of Atomic Radiations Report to the General Assembly. United Nations, New York.

[23] Karahan, G., Taskin, H., Bingoldag, N., Kapdan, E. and Yilmaz, Y.Z. (2018) Environmental Impact Assessment of Natural Radioactivity and Heavy Metals in Drinking Water around Akkuyu Nuclear Power Plant in Mersin Province. *Turkish Journal of Chemistry*, **42**, 735-747. https://doi.org/10.3906/kim-1710-83

[24] WHO (2011) Guidelines for Drinking Water Quality. 4th Edition, World Health Organization, Geneva.

[25] Ministère de l'Economie, des Finances et de la Souveraineté Industrielle et Numérique (2023) Situation Economique et Financière, Côte d'Ivoire. https://www.tresor.economie.gouv.fr/Pays/CI/situation-economique-et-financiere

[26] Damla, N., Cevik, U., Karahan, G. and Kobya, A.I. (2006) Gross Alpha and Gross Beta Activities in Tap Waters in Eastern Black Sea Region of Turkey. *Chemosphere*, **62**, 957-960. https://doi.org/10.1016/j.chemosphere.2005.05.051

[27] Rusconi, R., Forte, M., Badalamenti, P. and Bellinzona, S. (2004) The Monitoring of Tap Waters in Milanno, Planning, Methods and Results. *Radiation Protection Dosimetry*, **111**, 373-376. https://doi.org/10.1093/rpd/nch057

[28] Ismail, A.M., Kullab, M.K. and Saq'an, S.A. (2009) Natural Radionuclides in Bottled Drinking Water in Jordan and Their Committed Effective Doses. *Journal of Physics*, **2**, 47-57.

[29] Bonotto, D.M., Bueno, T.O., Tersari, B.W. and Silva, A. (2009) The Natural Radioactivity in Water by Gross Alpha and Beta Measurements. *Radiation Measurements*, **44**, 92-101. https://doi.org/10.1016/j.radmeas.2008.10.015

[30] Gado, A.A., Muthukumar, M., Gwani, M., Jonathan, L.A., Kazuga, S., Umar, A.B., Jafar, A.B. and Anbazhagi, M. (2018) Determination of Gross Alpha, Beta Radioactivity in Sachet Drinking Water. *Research Journal of Physical Sciences*, **6**, 1-7.

[31] Kolo, M.T., Baba-Kutigi, A.N., Olarinoye, I.O. and Sharifat, I. (2009) Survey of Gross Alpha and Gross Beta Radioactivity in Sachet Water Hawked in Minna, Niger State. *Journal of Science*, *Education and Technology*, **2**, 404-413.

[32] Ferdous, J., Begum, A., Sharmin, N.J. and Ahsan, M.H. (2016) Study of Gross Alpha and Gross Beta Activity in Bottled Water in Dhaka City of Bangladesh. *Asian Journal of Water*, *Environment and Pollution*, **13**, 59-64. https://doi.org/10.3233/AJW-160008

[33] Agbalagba, E., Egarievwe, S., Odesiri-Eruteyan, E. and Drabo, M. (2021) Evaluation of Gross Alpha and Gross Beta Radioactivity in Crude Oil Polluted Soil, Sediment and Water in the Niger Delta Region of Nigeria. *Journal of Environmental Protection*, **12**, 526-546. https://doi.org/10.4236/jep.2021.128033

[34] Ogundare, F.O. and Adekoya, O.I. (2015) Gross Alpha and Beta Radioactivity in Surface Soil and Drinkable Water around a Steel Processing Facility. *Journal of Radiation Research and Applied Sciences*, **8**, 411-417. https://doi.org/10.1016/j.jrras.2015.02.009

[35] United States Environmental Protection Agency (1998) Version Health Risks from Low-Level Environmental Exposure to Radionuclides. Federal Guidance Report No. 13, Washington DC, 38-41.