Journal of Environmental Protection, 2023, 14, 1006-1015
https://www.scirp.org/journal/jep
ISSN Online: 2152-2219
ISSN Print: 2152-2197

Total Indicative Dose Determination in Water from the North Riviera Well Field of SODECI in Abidjan, Cote d'Ivoire

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How to cite this paper: Achi, E.Z.T.K., Gogon, B.D.L.H., Oka, N.G.L., Koua, A.A. and Goffri, M.C.K. (2023) Total Indicative Dose Determination in Water from the North Riviera Well Field of SODECI in Abidjan, Cote d'Ivoire. *Journal of Environmental Protection*, **14**, 1006-1015.
https://doi.org/10.4236/jep.2023.1412055

Received: November 1, 2023
Accepted: December 17, 2023
Published: December 20, 2023

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Abstract

The Uranium-238 (^{238}U), Thorium-232 (^{232}Th) families and Potassium-40 (^{40}K) are of terrestrial origin and contribute generally to an individual's external exposure through our presence in this environment. They also contribute to the internal exposure through the ingestion of products and beverages such as water that are close to the earth. The aim of this work is to determine the committed effective dose or Total Indicative Dose (TID) due to gamma radioactivity of the borehole water from the Nord Riviera (NR) well field operated by the Côte d'Ivoire Water Distribution Company (SODECI) for the supply of drinking water to part of the population of Abidjan. In addition, the populations, with their habits, could use these borehole waters directly as drinking water. To this end, water samples from the seven (07) functional boreholes were collected and analyzed on a gamma spectrometry chain, equipped with an HPGe detector in the laboratory of the Radiation Protection Institute (RPI) of the GHANA Atomic Energy Commission (GAEC). The results of the specific activities of ^{238}U, ^{232}Th and ^{40}K obtained were transcribed into TID. As the natural radioactivity of the borehole water is high [1], the TIDs calculated from the activity results of the natural radionuclides ^{238}U, ^{232}Th, and ^{40}K vary for the seven boreholes from 0.150 to 0.166 mSv/yr with an average of 0.161 ± 0.034 mSv/yr. The TID of the control tower, where the borehole water is mixed and treated for household use, is equal to 0.136 ± 0.03 mSv/yr. The TIDs obtained are therefore all slightly greater than the WHO reference dose value of 0.1 mSv/yr. But all remain below the UNSCEAR reference dose of 0.29 mSv/yr.

Keywords

North Rivera (NR) Well Field, Borehole Water, Natural Radioactivity, Gamma Spectrometry, Total Indicative Dose, Committed Annual Effective Dose

1. Introduction

The earth's crust is largely responsible for the formation and support of naturally occurring radioactive emitters, as far as the terrestrial elements are connected. The presence and distribution of radioactivity in groundwater is largely dependent on factors such as the local geological characteristics of the source, soil or rock through which the water flows [2] [3]. Sometimes they also depend on the influence of several nearby anthropogenic activities that may constitute important pollution sources.

In Côte d'Ivoire and particularly in the greater Abidjan region, water resources are dependent on underground reserves, which are mainly contained in the sandy-clay formations of the Continental Terminal (CT) and sandy Quaternary. The CT aquifer develops in the Akouédo zone. It is exploited by SODECI through the North Riviera (NR) well field for the supply of drinking water to part of the city of Abidjan. It should also be noted that some inhabitants in the area still use this groundwater directly for drinking and other daily needs via wells. It is therefore necessary to evaluate the effective dose that could be committed by the natural radioactive activity contained in this groundwater.

The aim of this work is to determine the dosimetric impact of the natural gamma radioactivity of the borehole water on the population of the communes supplied by the NR well field and the local population that uses this water directly.

As part of this study a sampling at the seven functional boreholes and the control or treatment tower took place in July 2018 at the NR well field. The calculated committed effective doses were obtained by taking into account the specific activities of the primary radioelements ^{238}U, ^{232}Th, and ^{40}K.

2. Overview of the Study Area

The samples were collected from the NR well field of SODECI, in the town of Cocody, precisely in the Akouédo zone. It is composed of 10 boreholes, 7 of which were operating continuously with an average flow rate of 250 m^3/hour/borehole. The well field is located at the north of the former Akouédo landfill site, around 5 km away. Groundwater sampling was carried out in the functional boreholes, on July 25, 2018.

The samples were collected from the boreholes in the order of their geographical positions which are F02, F03, F09, F10, F16, F18, F20 and then in the control tower (**Figure 1**).

All groundwater from different boreholes is mixed and treated in control tower before being distribute for household consumption. It should be noted

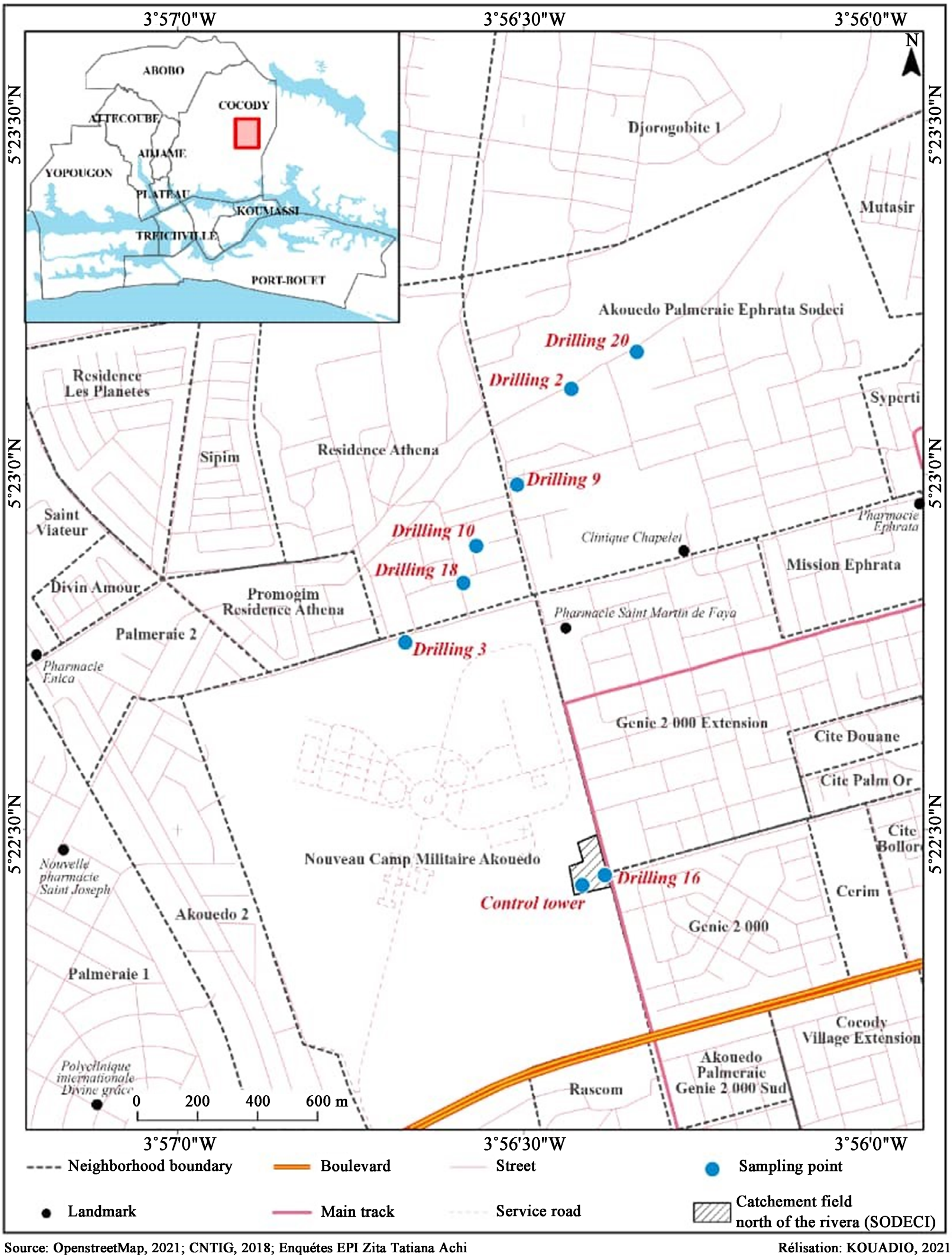

Figure 1. Borehole water withdrawal points at the NR wellfield.

that all boreholes are at least 120 m deep (source: SODECI).

The geological profile of the area is made up of sandy clay, medium sand and coarse sand resting on a granitic and schistose base [4] (**Figure 2**).

The water table that develops in the Akouedo zone is the CT aquifer. Côte d'Ivoire integrated water resources management master plan shows that this aquifer is essentially composed of sandy clay and sand (**Figure 3**) [6].

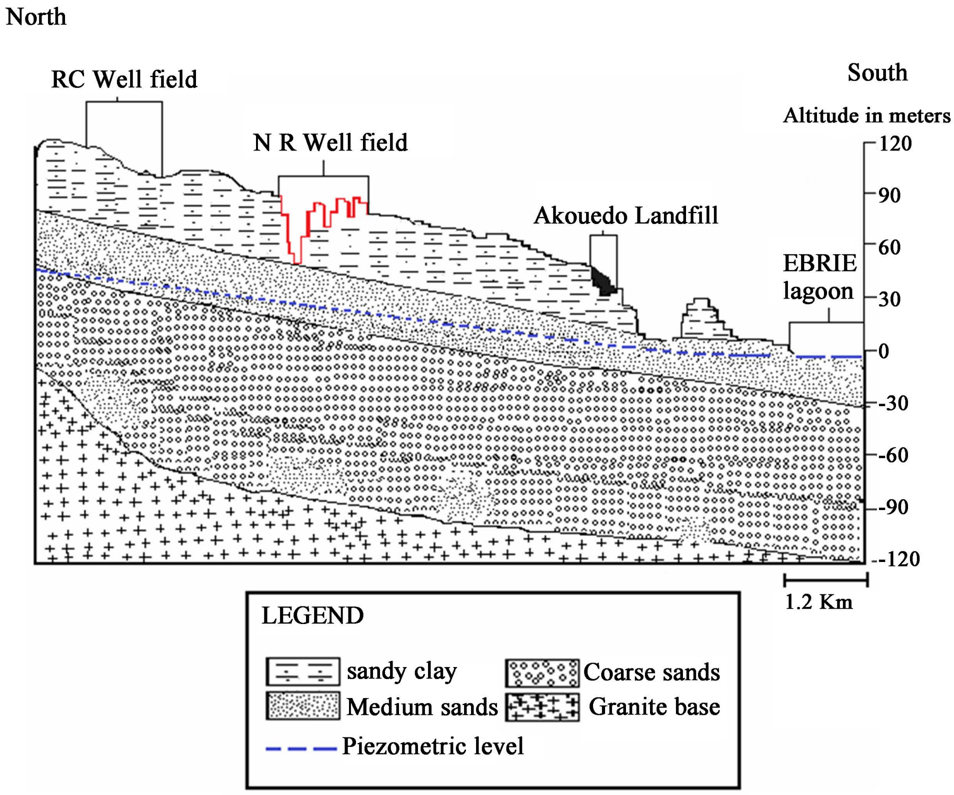

Figure 2. Geological profile of the Akouedo area [5].

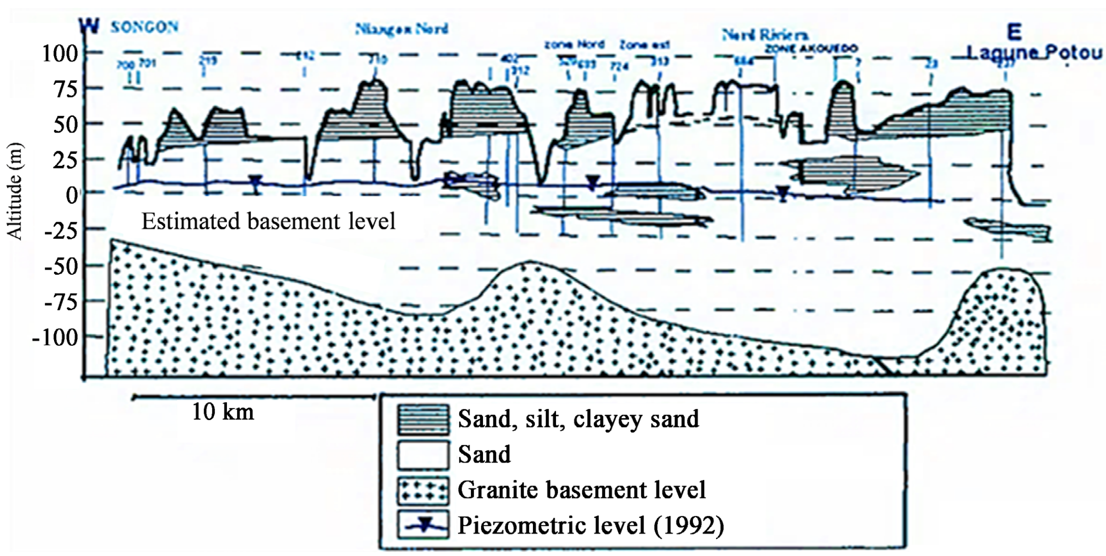

Figure 3. West-East geological profile of the Abidjan sedimentary basin aquifer [5].

3. Material and Method

3.1. Sampling Method

As the boreholes were equipped with pumps, the water was sample directly into 1.5 L polyethylene bottles previously washed with nitric acid, then with distilled water and finally with the sample to be taken. During sampling, physical parameters such as temperature, conductivity and pH were measured. The bottles were filled to the brim and the caps screwed on to prevent any gas exchange with the atmosphere. Finally, the labeled water samples were stored in a cooler at a temperature below 6˚C sent to the Radiation Protection Institute (RPI) laboratory of the GHANA Atomic Energy Commission (GAEC) for preparation and analysis.

Table 1 summarizes all the samples collected, coded in addition to their GPS location.

3.2. Sample Analysis Method

Sample preparation and radionuclide analysis were performed in the laboratory of the Radiation Protection Institute (RPI) at GAEC.

The samples were homogenized and transferred into one-liter marinelli beakers without filtration. The marinellis were previously washed with distilled water, dried and rinsed with acetone to avoid any contamination. In order to maintain the radioactive balance between parents and short-lived progeny, the homogenized samples were hermetically sealed. Then they were weighed, stored for 1 month and analyzed using a high purity germanium detector calibrated in energy and efficiency with a multi-gamma standard source. The gamma-ray spectrometry system used for the analysis consists of an N-type Hyper Pure Germanium detector. The relative efficiency of the detector is 25% with an energy resolution of 1.8 keV on the 1332 keV photopic of ^{60}Co.

3.3. Activity Concentration

The detector has been calibrated in terms of energy and efficiency with a standard

Table 1. Borehole water sample codes.

Borehole water samples	Sample code	Geographical GPScoordinates	
		Point X	Point Y
Drilling 02	F02	−3.940513	5.385342
Drilling 03	F03	−3.94452	5.379404
Drilling09	F09	−3.941827	5.383102
Drilling 10	F10	−3.942809	5.381667
Drilling 16	F16	−3.939799	5.374182
Drilling 18	F18	−3.943129	5.380795
Drilling 20	F20	−3.938946	5.386214
Control tower	TC	−3.940293	5.374087

source composed of different gamma-emitting radionuclide of well-know concentrations. These energies are defined in the energy range from 122 KeV to 1836.063 KeV (**Table 2**) thus covering all the low, medium and high energies of the spectrum.

After background subtraction, the radionuclide activity A, expressed in Bq/L is defined by the following equation:

$$A = \frac{N_{net}(E)}{\varepsilon(E) \cdot t \cdot I_{\lambda} \cdot M} \quad (1)$$

$N_{net}(E)$: the net peak area;

$\varepsilon(E)$: efficounting efficiency for E energy;

I_{γ}: the probability of emission of a gamma ray of energy E;

t: the counting time in seconds;

M: sample volume (L).

3.4. Internal Exposure Dose

The recommended drinking water limits, in terms of radioisotope content, are calculated so that the annual dose to an individual from drinking water does not exceed 0.1 mSv [2]. Thus, the final assessment of a water is based on the calculated dose indicator and the Total Indicative Dose (TID) [7].

The TID is the committed effective dose resulting from an intake, for one year, of all natural and artificial radionuclides detected in a water supply, excluding radon and its short-lived progeny.

For this estimate of committed effective doses, as recommended by the model used by the WHO, the following were taken into account:

- the annual water consumption equivalent to 730 L·year^{-1} for an adult over 17 years old,
- the volumetric activities of radionuclides ^{238}U, ^{232}Th and ^{40}K in borehole water,
- the effective dose coefficients per unit of intake for an adult prescribed by the WHO 2004 [8].

The dose is thus calculated from the following formula:

Table 2. Composition of the mixture of radionuclides contained in the standard source.

Radionuclides	Energies (keV)
Cobalt-57	122
Cerium-139	165.864
Pewter-113	391.69
Cesium-137	661.66
Yttrium-88	898.042
Cobalt-60	1173.237
Cobalt-60	1332.501
Yttrium-88	1836.063

$$E = 730 \times \left(\mathrm{DCF_U} \times A_\mathrm{U} + \mathrm{DCF_{Th}} \times A_\mathrm{Th} + \mathrm{DCF_K} \times A_\mathrm{K} \right) \quad (2)$$

With A_{U}, A_{Th}, A_{K} the concentrations of the measured activities,

DCF_i (i = U, Th, K) the conversion factors for water.

Conversion factors for water or committed effective dose per unit of intake of radionuclide i ingested by an adult according to the WHO (2004) are:

$$\mathrm{DCF_U} = 4.5 \times 10^{-5}\ \mathrm{mSv/Bq};$$
$$\mathrm{DCF_{Th}} = 2.3 \times 10^{-4}\ \mathrm{mSv/Bq};$$
$$\mathrm{DCF_K} = 6.2 \times 10^{-6}\ \mathrm{mSv/Bq}.$$

4. Results and Discussion

The natural radionuclides measured during the analysis of the samples are ^{238}U, ^{232}Th and ^{40}K. These samples have activities of the elements measured that are higher than the limit values given in the literature [1]. Thus, using these specific activities, the committed effective doses of the said radionuclides were obtained (**Table 3**).

It can be seen that the annual effective doses due to ingestion of radionuclides in all samples show annual effective dose values slightly above the dose reference value of 0.1 mSv/yr established by the WHO (**Figure 4**).

It is truly indicative when calculating the TID for borehole water samples, as only the water from the control tower distributed to households is likely to be consumed.

The natural radioactivity of the water is above the quality reference. However, we note that the annual effective dose values of the groundwater samples ranging from 0.150 to 0.166 mSv/yr are higher than that of the control tower (0.136 mSv/yr) where all water is treated. This could be due to the treatment at the control tower. Indeed, most radionuclides can be effectively removed in water treatment facilities [9].

It should be noted that if the dose is between 0.1 mSv/year and 0.3 mSv/year

Table 3. Radiological parameters and committed effective doses of the different samples.

Samples codes	Radionuclide activity Bq/L			E or TID (mSv/yr)
	^{238}U	^{232}Th	^{40}K	
F02	0.51 ± 0.14	0.70 ± 0.16	5.68 ± 0.59	0.160 ± 0.034
F03	0.48 ± 0.15	0.74 ± 0.16	5.36 ± 0.56	0.164± 0.034
F09	0.55± 0.17	0.72 ± 0.19	5.87 ± 0.60	0.165± 0.040
F10	0.48 ± 0.15	0.74 ± 0.16	5.36 ± 0.56	0.164± 0.034
F16	0.45 ± 0.18	0.70 ± 0.14	5.35 ± 0.66	0.156 ± 0.032
F18	0.49 ± 0.17	0.78 ± 0.18	4.14 ± 0.53	0.166 ± 0.038
F20	0.46 ±0.12	0.66 ± 0.13	5.49 ± 0.56	0.150 ± 0.028
TC	0.50 ±0.15	0.60 ± 0.14	4.24 ±0.40	0.136 ± 0.030

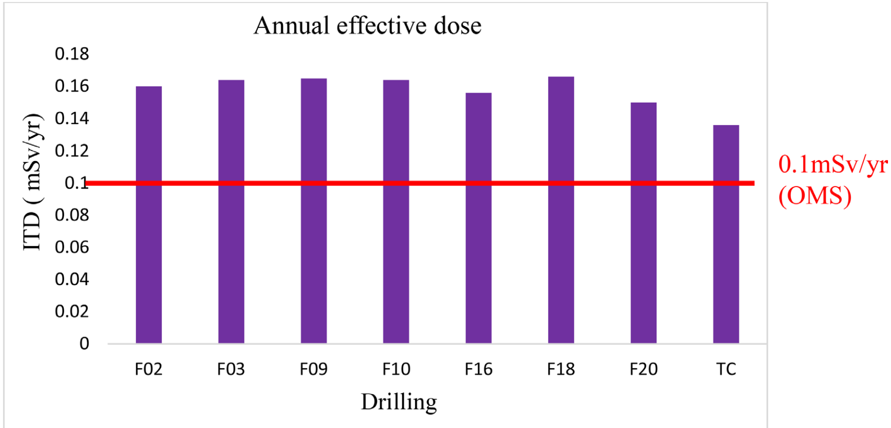

Figure 4. Annual effective dose or indicative total dose.

(which is the case for our samples), groundwater remediation is not mandatory [8]. On the other hand, it is mandatory to inform consumers who may use this water directly, in particular from boreholes (wells) for drinking or washing [10]. Nevertheless, dilution with another available ressource can help reduce the dose of these water [11].

In terms of health impact, the International Commission on Radiological Protection's (ICRP) conservative assumption is that there is no exposure threshold below which there is no risk [12].

Indeed, experience has shown that in practice the annual dose of 0.1 mSv/year exceeded indicates that the screening level of gross alpha activity of 0.5 Bq/L is also been exceeded [8]. Alpha particles emitted by uranium ingested in water could lead to the massive destruction of the deoxyribonucleic acid (DNA) molecule [13]. High concentrations of uranium in drinking water may increase the risk of kidney damage in humans [14]. Risks to the esophagus and stomach are also advanced [10].

With regard to the water at the control tower, it is possible that after treatment of the water from the boreholes, the effective doses are below the guide value (TID < 0.1 mSv/year), making the water fit for consumption. It is true that the communes of Treichville, Marcory, Koumassi and Port-bouet in southern Abidjan supplied by the RN wellfield [15] have effective dose values below the reference value of 0.1 mSv/year [13]. In fact, certain water treatments can lead to a significant reduction in natural radioactivity. These include, among others, coagulation/flocculation, iron removal/demanganization, decarbonation with lime, decantation/filtration, filtration on a support covered with metal oxides etc [11] [16].

However, the doses measured in the water samples are all below the reference dose of 0.29 mSv/year established by UNSCEAR 2000 [17]. Consequently, the consumption of these waters would be without serious danger to the population [13].

5. Conclusions

The present study enabled us to calculate the Total Indicative Doses from the results of the activities of the natural radionuclides ^{238}U, ^{232}Th and ^{40}K, measured during the analysis of the borehole water samples at the laboratory of the Institute of Radiation Protection at GAEC. The borehole water from the NR well field is used by the Côte d'Ivoire Water Distribution Company (SODECI) to supply drinking water to part of the population of Abidjan. The results of the analyses showed a high natural radioactivity [1].

The TIDs calculated from the natural radionuclide activity results of ^{238}U, ^{232}Th and ^{40}K for the seven boreholes vary from 0.150 to 0.166 mSv/yr with an average of 0.161 ± 0.034 mSv/yr. That of the mixing tower where the borehole water is treated for distribution to households is equal to 0.136 ± 0.03 mSv/yr and is lower than the TID of the borehole water due to the treatment provided. The calculated TID are slightly higher than the WHO reference dose value of 0.1 mSv/yr. Although the natural radioactivity of the borehole and control tower water is slightly higher than the TID quality reference, corrective actions are not necessarily justified. Also, their consumption, even from wells, would not be a serious danger for the population according to the UNSCEAR.

Acknowledgements

This work was funded by the Academy of Sciences, Arts and Cultures of Africa (ASCAD). The authors are grateful for the financial support for this work.

Conflicts of Interest

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

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