Journal of Radioanalytical and Nuclear Chemistry (2023) 332:797–807
https://doi.org/10.1007/s10967-023-08809-4

Assessment of natural radioactivity in industrial line production waters from major industrial cities of Thailand

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Received: 27 October 2022 / Accepted: 27 January 2023 / Published online: 10 February 2023

Abstract
Five hundred water samples used in industrial line production were analyzed for gross alpha (GA), gross beta (GB) and tritium. GA activity concentrations in 6 of 500 analyzed samples could be detected and their mean concentrations ranged from 0.129 to 0.285 Bq l^{-1}, which were lower than the reference dose of 0.5 Bq l^{-1}. GB activity concentrations in all samples cloud be detected and 5 samples exceeded the reference value (1.0 Bq l^{-1}). The measured concentration of tritium showed to be lower than the minimum detectable activity (MDA). The water are safe for drinking and other used in industrial activities.

Keywords Gross alpha · Gross beta · Tritium · Activity concentration · Industrial line water

Introduction

Radioactivity in the environment originates from natural such as the leaching from rocks through the both erosion and dissolution [1], and anthropogenic activities such as nuclear accidents, nuclear weapons [2], uranium mining and processing, manufacture of fertilizers derived from phosphate rock, drilling, transportation, processing and burning of fossil fuels [3]. The radioactivity in drinking water arises mainly by the radionuclides of the natural decay chains of ^{238}U, ^{232}Th and ^{40}K. Their activity concentration depends on the origin of the water. Most of radionuclides found in drinking water occur naturally at very low levels and are not considered a public health concern. However, radionuclides can be released into the environment from human activities as aforementioned, which results in the increase of radioactivity level in drinking water. These radionuclides emit alpha and beta radiations which are less penetrating unlike gamma ray that has the highest penetrating power. However, if alpha and beta particles enter into the body either through inhalation or ingestion, they cause far more detrimental because of their ionizing power [4]. Exposure to high levels of these radionuclides in long periods of time may develop serious health risk such as cancer [1], anemia, cataracts (in particular, bone, liver, and breast cancer) [5]. Meanwhile, tritium is a pure beta emitter with a maximum energy of 18.6 keV and with a half live of 12.6 years [3]. It occurs naturally by the interaction of cosmic rays with the atmosphere, and can be produced by human activities such as nuclear weapon testes and nuclear reactors as provide electricity activities [6].

Therefore, there is the need to measure, monitor and limit the concentration of alpha, beta and tritium in drinking water. The World Health Organization (WHO)'s guidelines recommends the limits of gross alpha and gross beta radioactivity concentration in drinking water below 0.5 and 1.0 Bq l^{-1} [7], respectively. The essence of the evaluation gross alpha and gross beta activities is to ensure that the reference dose level (RDL) of 0.1 from 1 year's consumption of drinking water is not exceeded. These Guidelines provide a generally applicable approach to drinking water safety and described the application of the Guidelines in some commonly specific circumstances such as supply in portable water and food industry. Meanwhile, European regulation, the European directive 98/83/EC [8] recommends the limits of gross alpha and gross beta radioactivity concentration in drinking water below 0.1 and 1.0 Bq l^{-1}, respectively. For

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tritium activity concentration in drinking water, the acceptable level should be less than 100 Bq l^{-1}.

In Thailand, there are many food production and non-food industries. Most industrial zones are located in the Eastern (Chachoengsao and Rayong) and Central (Samut Sakhon and Bangkok Metropolis) region of Thailand. However, the northern (Chiangmai), the northeastern (Khon Kaen) and the southern (Songkhla) regions have many large and modern factories such as food and agro-industries. The non-food industries such as oil and gas, coal fired power plants, cement and fertilizer production may induce high concentration of radionuclide into process water. Measuring water quality including radionuclide substances in the process and waste water discharge is very important before releasing them into the environment. In addition, the radionuclides may cause external exposure to workers employed in oil and gas operations. Meanwhile, the presence of radionuclides in surface water, that used in portable water and food/beverage production may cause of human internal exposure. Significance measures may have to be taken in order to ensure that water palatable and safe. The radioactive concentrations in industrial line process in Thailand are quite rare. Therefore, the aim of this study is to evaluate gross alpha, gross beta and tritium activity concentrations in supplied water including from industrial line processing in major industry cities, Thailand including tap water, raw water, consumption water, drinking water, deep well, reclaimed water, waste water, soft water and others. The assessment of the radiological risks for individuals exposed to alpha and beta radiation emitted from radionuclides in those water samples were also estimated.

Materials and methods

Location of sampling sites

A total of 500 samples of supplied water were collected from (1) food production and processing (2) portable water and (3) others or non-food industries in 7 major industry cities of Thailand during 2021 including Chiangmai (the northern Thailand), Khon Kaen (the northeastern Thailand), Samut Sakhon and Bangkok Metropolis (the central Thailand), Chachoengsao and Rayong (the eastern sThailand). The location of sampling sites is shown in Fig. 1. The water sources included tap water (95 samples), raw water (116 samples), consumption water (105 samples), drinking water (30 samples), deep well (19 samples), reclaimed water (17 samples), waste water (95 samples), soft water (2 samples) and others (21 samples).

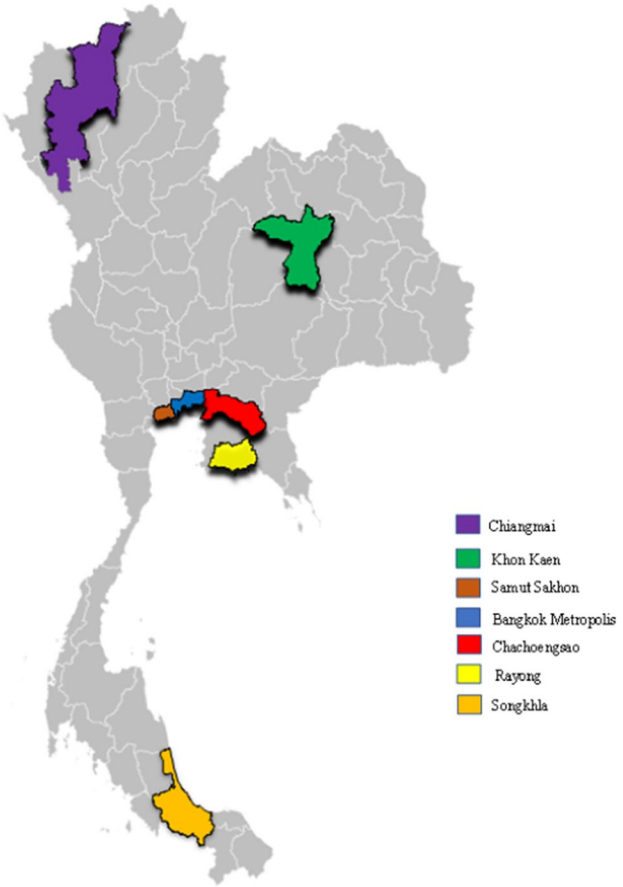


Fig. 1 Sampling locations. (Color figure online)

Gross alpha and gross beta radioactivity measurement

The measurement of the GA and GB activity was carried out according to the technique described by EPA 900.0 [9]. Each water samples were acidified to pH = 1 with concentrated nitric acid (conc. HNO_3) to reduce the growth of microorganisms and avoid the collection of organic materials and changes in the state of the ions that are in the samples. An appropriate volume of samples (about 250 ml) was taken into the beaker. The solution was evaporated to near dryness on a hot plate and then quantitatively transferred into a tarred 2-inch stainless steel counting planchet. The sample residue was dried under infrared lamp for 30 min and subsequently dried in an oven at 105 °C for 10 min, allowed to cool down in a desiccator, weighted and counted for 4800 s.

The GA and GB counting were carried out using a Berthod LB770 low background alpha/beta counter (Berthold Technologies GmbH & Co. KG, Germany) with an argon-methane mixture (90% argon and 10% methane).

For background measurement and detector efficiency calibration, an empty planchet was counted for 2400 s to determine the background of each detector. ^{241}Am (specific activity 8.799 kBq/g) and ^{90}Sr (specific activity 0.3711 MBq/g) standard sources were used to calibrate the system for alpha and beta energy counting efficiency, respectively. The counting efficiencies for the system were 14.50% for alpha and 50.16% for beta as shown in Table 1. The calibration standard source was made on 28.04.2019. The uncertainty of the calibration standard source was also done and the obtained results were acceptable with $Z < 2$ for both alpha and beta. The self absorption curve of alpha and beta were constructed by adding the same ^{241}Am/^{90}Sr solutions in distilled water and increasing amounts of $CaCO_3$ substrate (0–200 mg). The solutions were prepared with the same analyzed sample preparation procedure as mentioned above. The sample thickness ranged from 0 to 10 mg/cm^2, approximately.

For quality control, the accuracy and reliability of the measurements were verified using two spiked ^{241}Am and ^{90}Sr standard sources as known their activities for GA and GB, respectively. The actual activity of GA and GB in the prepared standard were 5 Bq and 20 Bq. The results of the measured activity of GA and GB in the prepared standard solutions were different of below 5% compared to their actual activities. The validation of the measurement method was also done by analysis certified reference material, IAEA-TEL-2019-03. All obtained results were within acceptable values for alpha 4.2 Bq kg^{-1} and for beta 17.32 Bq kg^{-1}.

The GA and GB activity concentrations of the water samples were estimated via the following equation:

$$A_{\alpha,\beta}\left(\text{Bq l}^{-1}\right) = \frac{(I_s - I_b)}{\varepsilon \times V \times 60} \quad (1)$$

where $A_{\alpha,\beta}$ is the gross alpha or gross beta activity concentration, I_s is the gross alpha or gross beta counting rate of the sample (cpm), I_b is the gross alpha or gross beta counting rate of the background (cpm), ε is the gross alpha or gross beta counting efficiency, V is the volume of sample (l) and 60 is the conversion factor from cpm to cps.

The minimum detectable activity (MDA) for GA and GB measurements that could be achieved with the detection system can be computed as follows:

$$\text{MDA}_{\alpha,\beta}\left(\text{Bq l}^{-1}\right) = \frac{\frac{1.96^2}{2t_s} \times \left[1 + \sqrt{1 + \frac{4t_s^2}{1.96^2}} \times R_b \times \left(\frac{1}{t_s} + \frac{1}{t_b}\right)\right]}{\varepsilon \times V \times 60} \quad (2)$$

where MDA $_{\alpha,\beta}$ is the minimum detectable activity for gross alpha or gross beta measurement, t_s is the time of the measurement used to accumulate the sample count (min), t_b is the time of the measurement used to accumulate the background count (min), R_b is the mean background count rate (cpm).

Tritium radioactivity measurement

Tritium activity concentrations were quantified according to the technique described by EPA Method 906.0 [10] using a Hidex 600 SL automatic liquid scintillation counter (LabLogic Systems, UK). The distillation process was usually applied to the sample to avoid misestimation caused by quenching, chemical luminescence and other radioactive substance. In the distillation process, 100 ml of each water sample was placed in a distillation volumetric flask of 250 and then 0.1 of $KMnO_4$ and 0.5 g of NaOH were added. The first 20 ml fraction of the distillate was discarded and the next 30 ml fraction was collected. An aliquot 5 ml of the sample was mixed with 10 ml liquid scintillation cocktail (Ultima Gold, Perkin Elmer) in 20 ml polyethylene scintillation vials. The vials were shaken well for 2 min and then was kept in the dark for 24 h in order to reduce chemical quenching before the LSC measurements. The tritium counting was done for 3 cycles of 180 min. A quench correction curve as the relationship between the counting efficiency and quench index parameters (QIP) i.e., TDCR was generated for efficiency determination of each measurement. The quenched tritium standard set (Eckert and Ziegler Analytics, USA) was measured by the LSC for 60 min with three measurements per vial. The obtained results were used to construct quench curves, which were subsequently used for the counting efficiency and absolute activity or disintegrations per minute (DPM)

Table 1 Analysis procedures, efficiency and the minimum detectable activity (MDA) of the methods used to measure natural radionuclide in water samples

Assay	Radiochemical procedure	Detector	Efficiency (%)	MDA (Bq l^{-1})
Gross alpha	Evaporation in planchet	Gas-flow proportional counter	14.50*	0.018
Gross beta	Evaporation in planchet	Gas-flow proportional counter	50.16*	0.012
Tritium	Distillation	Liquid Scintillation counter	30.0	9.4

*Counting efficiency as a function of mass thickness for alpha and beta particle. Efficiency shown in the table are at 2.0 mg/cm^2 for alpha and 5.0 mg/cm^2 for beta

[11]. The tritium activity concentration of each measuring sample was calculated according to the following equation:

$$A_T\left(\mathrm{Bq\,l^{-1}}\right) = \frac{(C_s - C_{BKG})}{\varepsilon \times V \times 60} \quad (3)$$

where A_T is the tritium activity concentration, C_s is the counting rate of the sample (cpm), C_{BKG} is the counting rate of the background (cpm), ε is the counting efficiency, V is the volume of sample (l) and 60 is the conversion factor from cpm to cps.

The MDA for tritium measurement was evaluated using the following equation:

$$\mathrm{MDA_T}\left(\mathrm{Bq\,l^{-1}}\right) = \frac{4.65 \times \left(\sqrt{\frac{C_{BKG}}{t_b}}\right)}{\varepsilon \times V \times 60} \quad (4)$$

where $\mathrm{MDA_T}$ is the minimum detectable activity for tritium measurement and t_b is the counting time of the background (min).

^{40}K radioactivity measurement

One litre of each water sample was acidified with 2 ml of conc. HNO_3, filled into Marinelli beaker and then hermetically sealed. The water samples were measured using a gamma muti channel analyzer equipped with a lead shield (100 mm) high purity germanium coaxial detector (HPGe) system. The detector has a relative efficiency of 30% and energy resolution of 1.89 keV at 1332 keV of ^{60}Co source. Energy calibration and relative efficiency calibration of the spectrometer were carried out using Marinelli calibration standard source containing of ^{137}Cs (662. keV) and ^{60}Co (1172.37, 1332.50 keV). The ^{40}K activity was determined from its 1460.75 keV Y-line. The sample was counted for 30,000 s for activity measurements. The ^{40}K activity concentrations were calculated according to the following equation:

$$A_{40_K}\left(\mathrm{Bq\,l^{-1}}\right) = \frac{N_{(cps)}}{\varepsilon \times V \times P_\gamma(E)} \quad (5)$$

where A_{40_K} is the ^{40}K activity concentration, $N_{(cps)}$ is the net count per second (cps), ε is the energy detector efficiency, V is the sample volume (l) and $P_\gamma(E)$ is the opportunity to decay and emit gamma ray energy.

Results and discussion

Table 1 shows the radiochemical procedures and detection systems used to determine the radiochemical parameters. The minimum detectable activities (MDA) for GA, GB and tritium were 0.018, 0.012 and 9.4 Bq l^{-1} which were lower than the maximum contamination limits recommended established in the WHO Guideline and the EC Directive 98/83/EC. These MDA values were adequate for determine activity concentrations.

The GA activity concentrations in water samples are gathered in Table 2. The water samples were grouped according to their sources and the errors shown in the results were the 1σ statistical counting errors. The relative error for all measurements were below 1%. As can be seen in Table 2, the measured GA activities were lower than the MDA for almost all water samples. The mean GA activities of raw water, consumption water and deep well were 0.285 ± 0.027, 0.129 ± 0.025 and 0.275 ± 0.027 Bq l^{-1}, respectively. The highest GA activity concentration was found in raw water, which might be due to rich granite deposit in the area. The GA activity values in 4 samples from raw water, in 1 sample from deep well and in 1 sample from consumption water were found to be higher than the Maximum Contamination Level Goals (MCLG) set by the EC Directive (0.1 Bq l^{-1}). As according to the Directive, these samples needed to be further analysis for specific radionuclide i.e. $^{226\,+228}$Ra. However, if the WHO Guideline was applied, 1 sample from raw water was observed to be higher than the maximum contamination

Table 2 Gross alpha activity concentration in water samples

Water sample (no. of samples)	Gross alpha activity concentration (GA) (Bq l^{-1})		
	Min	Max	Mean
Tap water (95)	< 0.018	–	< 0.018
Raw water (116)	0.145 ± 0.026	0.609 ± 0.032	0.285 ± 0.027
Consumption water (105)	0.129 ± 0.025	0.129 ± 0.025	0.129 ± 0.025
Drinking water (30)	< 0.018	–	< 0.018
Deep well (19)	0.275 ± 0.027	0.275 ± 0.027	0.275 ± 0.027
Reclaimed water (17)	< 0.018	–	< 0.018
Waste water (95)	< 0.018	–	< 0.018
Soft water (2)	< 0.018	–	< 0.018
Others (21)	< 0.018	–	< 0.018

level (0.5 Bq l^{-1}). In our case, this water sample is from non-food industry, which is not required strictly controlled and it is not a source of drinking water. Therefore, no need further analysis for ^{226}Ra and ^{228}Ra activity concentrations. In case if water samples are a source of drinking water, the recommended method for measurement the activity of ^{226}Ra and ^{228}Ra concentrations is according to the technique described by EPA 903.1 [12] and EPA 904.0 [13], respectively.

Table 3 shows the GB activity concentration in water samples. As shown in Table 3, all water samples exceeded the MDA values. The GB activity concentrations ranged 0.117–0.073 Bq l^{-1} in tap water, 0.134–2.494 Bq l^{-1} in raw water, 0.105–0.864 in consumption water, 0.112–0.650 Bq l^{-1} in drinking water, 0.209–0.369 Bq l^{-1} in deep well, 0.122–0.443 Bq l^{-1} in reclaimed water, 0.137–2.895 Bq l^{-1} in waste water, 0.132–0.134 Bq l^{-1} in soft water and 0.121–0.400 Bq l^{-1} in others. Figure 2 presents the variation of gross beta concentration in various supplied water samples. As can be seen in Fig. 2, the GB activity concentrations in the total 95 tap water samples, 105 consumption water samples, 30 drinking water samples, 19 deep well samples, 17 reclaimed water samples, 2 soft water samples and 21 others samples were below the Maximum Contaminated Level Goal (MCLG) recommended in the Directive and the WHO Guideline (1 Bq l^{-1}). Meanwhile, in the total 116 raw water samples, there were 2 samples whose GB activity concentration was exceeded 1 Bq l^{-1}. In addition, in the total 95 waste water samples, there were 3 samples whose GB activity concentration was higher than 1 Bq l^{-1}. The relatively high GB activity concentrations in waste water samples were found in Rayong (the eastern Thailand), which might be attributed to the presence of radioactive elements in crude oil and coal from the industries such as petroleum and coal-fired power plants. Meanwhile, the high GB activity concentrations in raw water samples were observed in the northern and southern areas, which might be due to rich of granite rock and high potential of tin and tungsten deposits in the areas, respectively.

GB measurements include a contribution from the presence of the primary radionuclide ^{40}K, a beta emitter that occurs naturally in a fix ratio to stable potassium. Therefore, if the level of GB activity concentration exceeded 1 Bq l^{-1}, ^{40}K is analyzed and then subtracted from the GB activity concentrations. In our case, there were 2 samples from waste water and 3 samples from raw water significantly exceeded 1 Bq l^{-1}. For the raw water, the ^{40}K activity concentrations ranged from 3.52 to 5.90 Bq l^{-1} and their GB activity concentrations were below the MCLG after subtraction. Meanwhile, the waste water does not require additional further determination of ^{40}K due to they are suitable treated before discharge to environment.

The tritium activity concentrations in the samples are summarized in Table 4. The tritium activity concentration values of all samples were lower than the MDA (< 9.4 Bq l^{-1}) and well below the MCLG set by the EC Directive (100 Bq $l.^{-1}$

Comparison of GA, GB and tritium activity concentrations of supplied water sample with those of other countries are shown in Tables 5, 6 and 7, respectively. The average GA activity concentration of drinking water from this study (< 0.018 Bq l^{-1}) was lower than that of China (0.029 Bq l^{-1}) as reported by Sang et al. [14], northeast China (0.24 and 0.23 Bq l^{-1}) as reported by Shi et al. [15], Italy (0.05 and 0.04 Bq l^{-1}) as reported by Verde et al. [1], Iran (0.052 Bq l^{-1}) as reported by Abbasi and Mirekhtiary [16] and Saudi Arabia (0.0194 Bq l^{-1}) as reported by Amin [17]. Meanwhile, the GA activity concentrations from Nigeria (0.018 Bq l^{-1}) as reported by Okunola et al. [18] and Serbia (0.001–0.013 Bq l^{-1}) as reported by Jankovic' et al. [3] were similar to those of this study. For well water, the average GA activity concentration from Thailand (0.275 Bq l^{-1}) was found to be higher than that of Nigeria as reported by Okunola et al. [18]. In case of tap water, the average GA activity concentration from this study (< 0.018 Bq l^{-1}) was in the range of the result obtained from Nigeria, 0.014 Bq l^{-1} [18], however it showed to be lower than that obtained from Hungary, 0.076 Bq l^{-1} [19]. The

Table 3 Gross beta activity concentration in water samples

Water sample (no. of samples)	Gross beta activity concentration (GB) (Bq l^{-1})		
	Min	Max	Mean
Tap water (95)	0.117 ± 0.022	0.730 ± 0.058	0.271 ± 0.025
Raw water (116)	0.134 ± 0.022	2.494 ± 0.232	0.306 ± 0.029
Consumption water (105)	0.105 ± 0.022	0.864 ± 0.048	0.257 ± 0.027
Drinking water (30)	0.112 ± 0.022	0.650 ± 0.058	0.219 ± 0.024
Deep well (19)	0.209 ± 0.023	0.369 ± 0.028	0.284 ± 0.025
Reclaimed water (17)	0.122 ± 0.022	0.443 ± 0.031	0.228 ± 0.024
Waste water (95)	0.137 ± 0.022	2.895 ± 0.147	0.444 ± 0.032
Soft water (2)	0.132 ± 0.022	0.134 ± 0.022	0.133 ± 0.022
Others (21)	0.121 ± 0.022	0.400 ± 0.029	0.207 ± 0.024

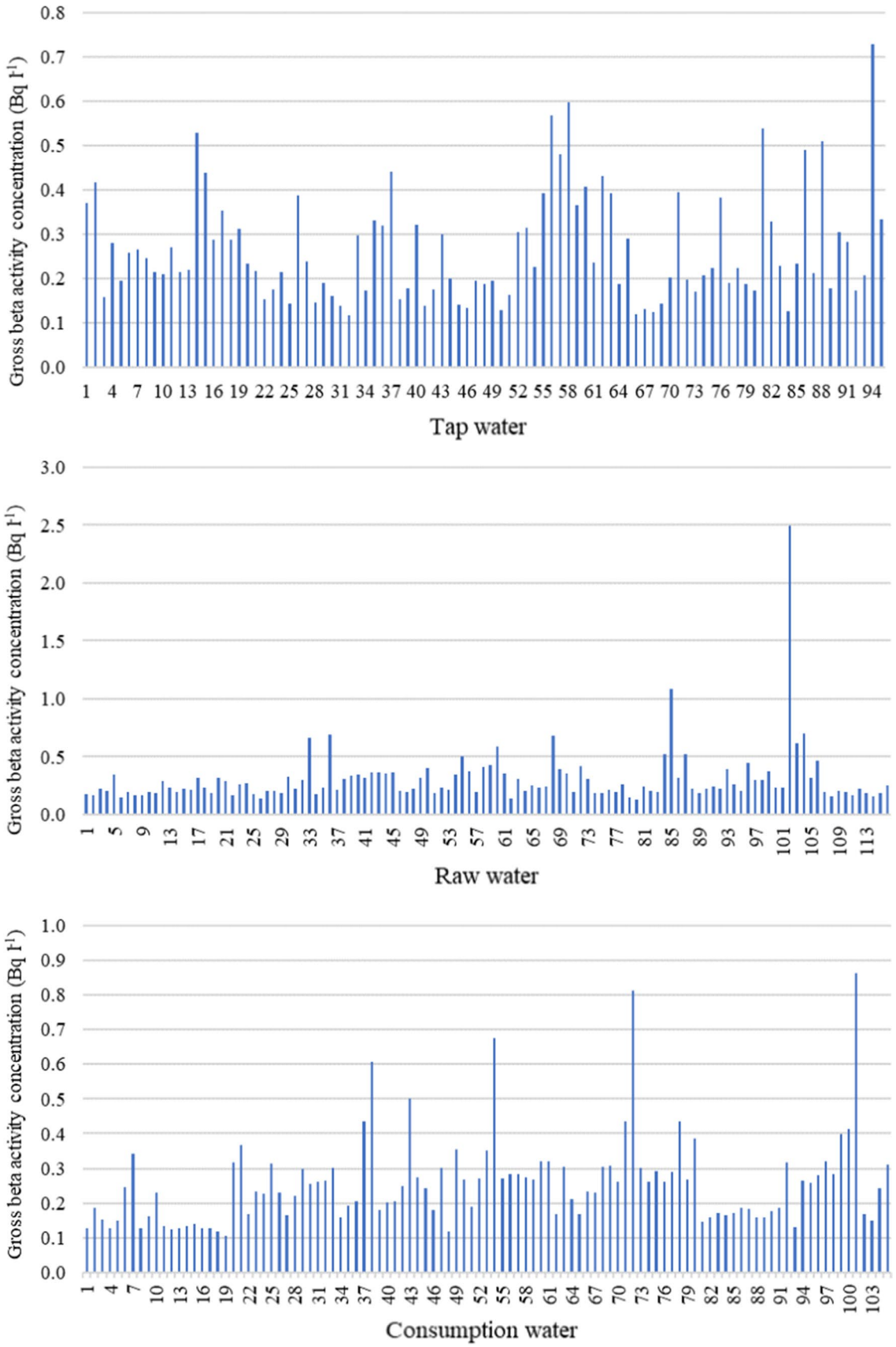
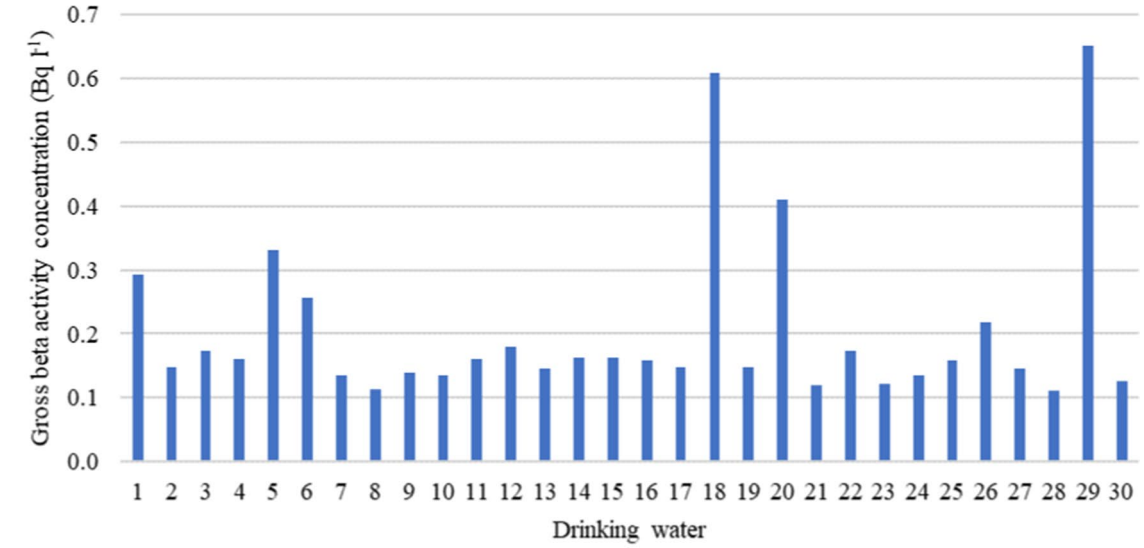
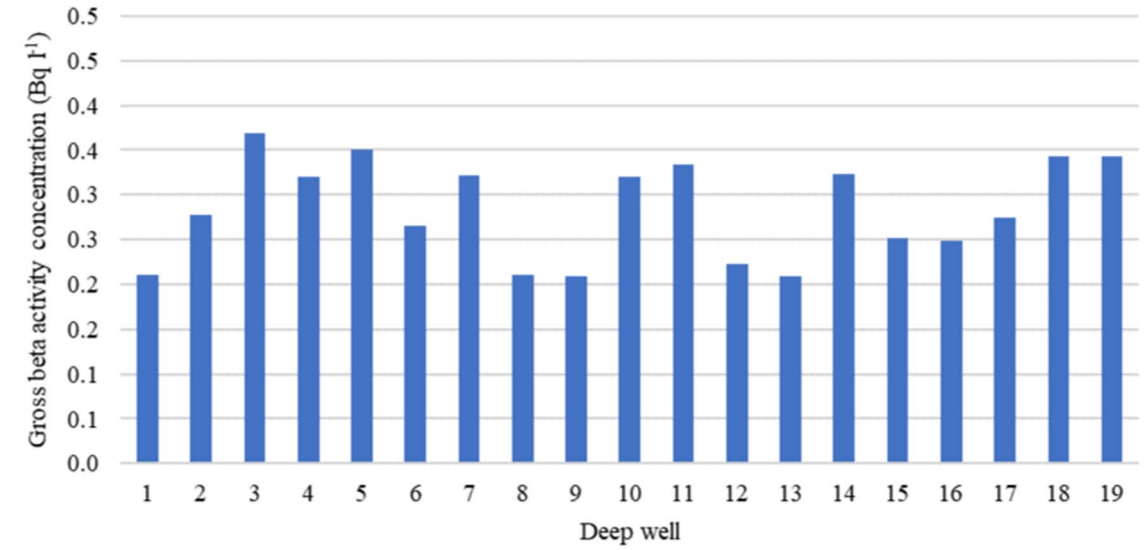


Fig. 2 The variation of gross beta concentration in various supplied water samples. (Color figure online)





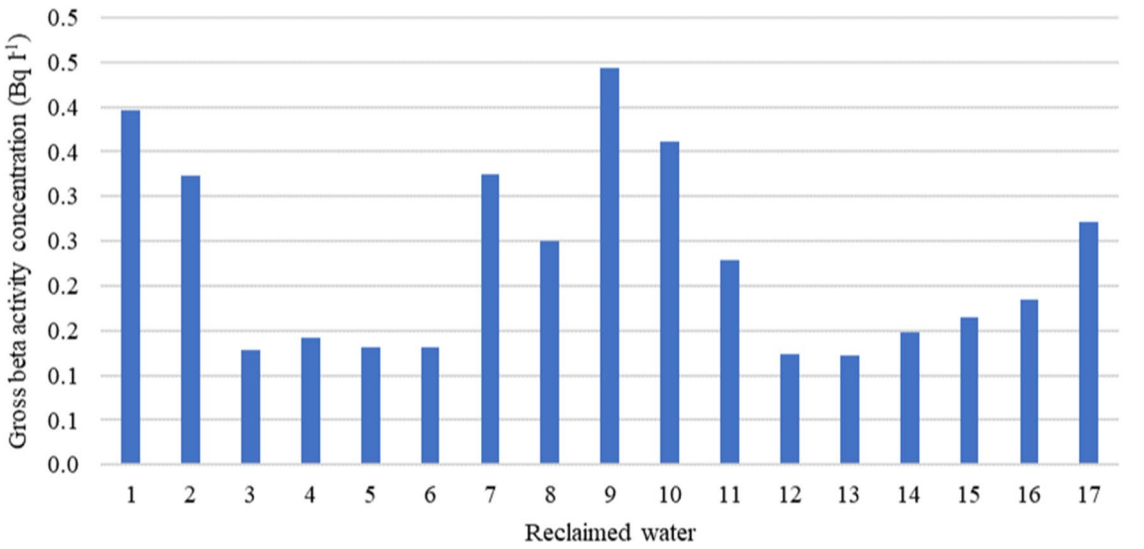


Fig. 2 (continued)

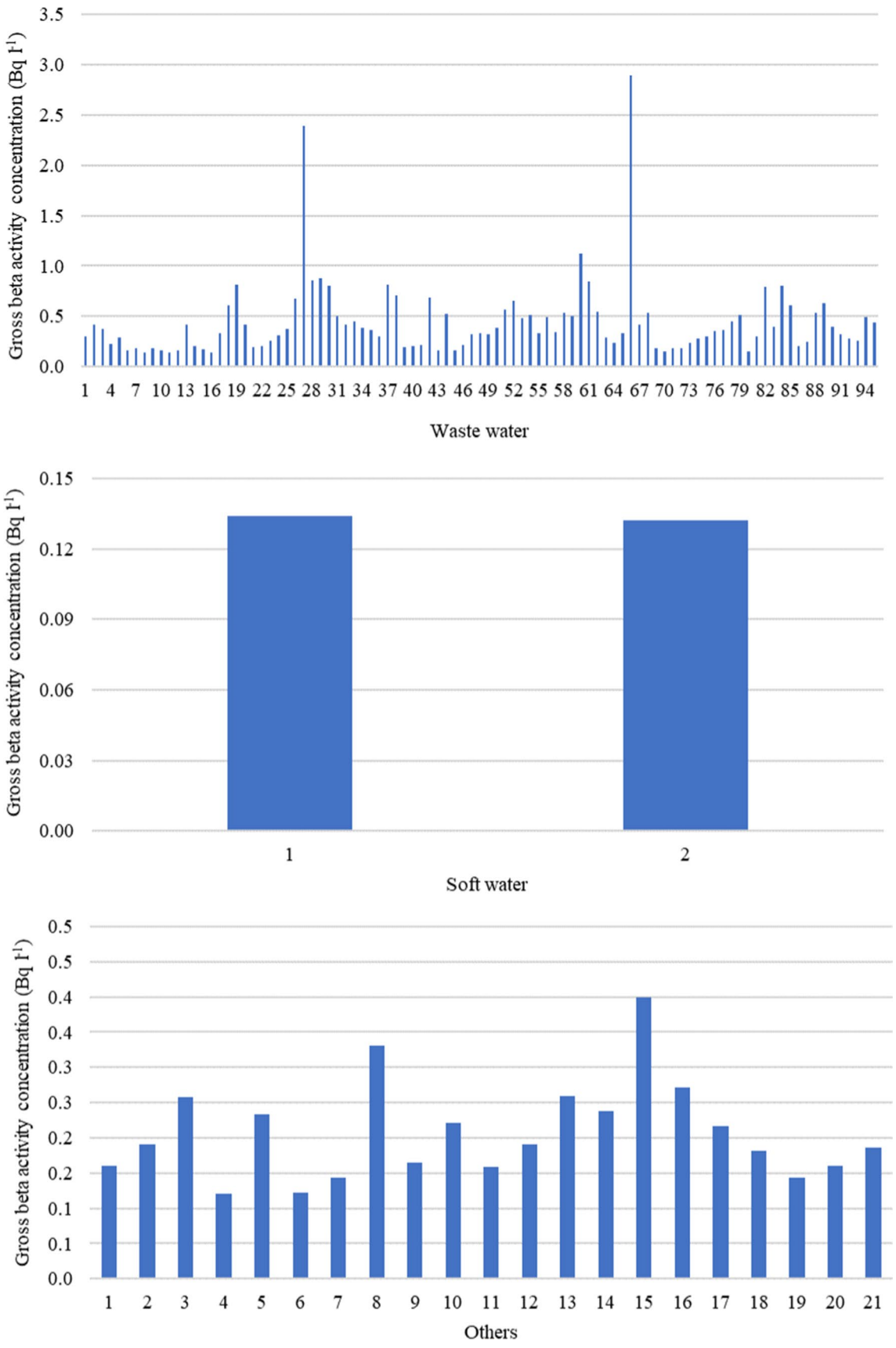


Fig. 2 (continued)

Table 4 Tritium activity concentration in water samples

Water sample (no. of samples)	Tritium activity concentration (GB) (Bq l^{-1})		
	Min	Max	Mean
Tap water (95)	–	<9.4	<9.4
Raw water (116)	–	<9.4	<9.4
Consumption water (105)	–	<9.4	<9.4
Drinking water (30)	–	<9.4	<9.4
Deep well (19)	–	<9.4	<9.4
Reclaimed water (17)	–	<9.4	<9.4
Waste water (95)	–	<9.4	<9.4
Soft water (2)	–	<9.4	<9.4
Others (21)	–	<9.4	<9.4

average GA activity concentration of waste water obtained from this study (<0.018 Bq l^{-1}) was also obviously lower than that obtained from Nigeria, 0.504 Bq l^{-1} [20].

As shown in Table 6, the average GB activity concentration of drinking water of 0.219 Bq l^{-1} was slightly lower than those measured in northeast China (0.30 and 0.29 Bq l^{-1}) as reported by Shi et al. [15] and Italy (0.33, 0.26 and 0.30 Bq l^{-1}) as reported by Verde et al. [1]. Meanwhile, the average GB activity concentrations of drinking water obtained from Nigeria, 1.287 Bq l^{-1} [18] and Saudi Arabia, 0.540 Bq l^{-1} [17] were obviously higher than those obtained from this study. The average GB activity concentration of drinking water from this study also showed to be higher than those measured in China, 0.091 Bq l^{-1} [14], Serbia, 0.041–0.173 Bq l^{-1} [3], Iran 0.110 Bq l^{-1} [16]. For well water, the average GB activity concentration from this study (0.284 Bq l^{-1}) was significantly lower than that of Nigeria as reported by Okunola et al. [18]. The average GB activity concentration of tap water measured in this study was (0.271 Bq l^{-1}) was obviously lower than that of Nigeria (0.711 Bq l^{-1}) as reported by Okunola et al. [18], but it was higher than Hungary (0.095 Bq l^{-1}) as reported by Jobbágy et al. [19]. In case of waste water, the average GB activity concentration from this study was found clearly lower than that of Nigeria (16.24 Bq l^{-1}) as reported by Idoko et al. [20].

Result for tritium activity concentration of drinking water obtained from this study (9.4 Bq l^{-1}) was in range of those Italy (8.49, 5.80 and 5.11 Bq l^{-1}) as reported by Verde et al. [1] and Serbia (0.023–0.046 Bq l^{-1}) as reported by Jankovic' et al. [3].

The annual effective dose values in drinking water samples were calculated using the following equation [16]:

$$D = A \times \mathrm{IR} \times \mathrm{ID} \times 2(\text{for both } \propto \text{ and } \beta) \quad (6)$$

where D is the annual effective dose (Sv $year^{-1}$), A is the activity concentration of $\propto/\beta$ particles (Bq l^{-1}), IR is the intake of water for a person in 1 year (730 l) and ID is the $d_{\propto}$ or d_{β} ingestion effective dose factor (3.58×10^{-7} Sv Bq^{-1}). It was found that the annual effective dose for 1 year of the population of age group > 17 in all samples were less than the recommended limit (0.1 mSv y^{-1}).

Table 5 Comparison of the gross alpha activity concentration in water samples with those reported in other countries

Country	Type	Range (Bq l^{-1})	Average value (Bq l^{-1})	References
China	Drinking water	0.0005–0.49	0.029	[14]
China (northeast)	Drinking water (wet season)	–	0.24	[15]
China (northeast)	Drinking water (dry season)	–	0.23	[15]
Nigeria	Drinking water	0.001–0.038	0.018	[18]
	Well water	0.005–0.012	0.009	[18]
	Tap water	0.002–0.037	0.014	[18]
Nigeria	Waste water	0.006–1.433	0.504	[20]
Italy	Drinking water (Monti Lattari)	0.005–0.08	0.05	[1]
	Drinking water (Ausino)	0.0006–0.09	0.04	[1]
	Drinking water (Vesuviano)	0.001–0.09	0.04	[1]
Serbia	Drinking water	0.001–0.013	–	[3]
Iran	Drinking water	0.012–0.115	0.052	[16]
Hungary	Tap water	–	0.076	[19]
Saudi Arabia	Drinking water	0.06–0.45	0.194	[17]
Thailand	Drinking water	–	<0.018	This study
Thailand	Well water	–	0.275	This study
Thailand	Tap water	–	<0.018	This study
Thailand	Waste water	–	<0.018	This study

Table 6 Comparison of the gross beta activity concentration in water samples with those reported in other countries

Country	Type	Range (Bq l^{-1})	Average value (Bq l^{-1})	References
China	Drinking water	0.005–1.26	0.091	[14]
China (northeast)	Drinking water (wet season)	–	0.30	[15]
China (northeast)	Drinking water (dry season)	–	0.29	[15]
Nigeria	Drinking water	0.185–2.685	1.287	[18]
	Well water	0.035–1.511	0.527	[18]
	Tap water	0.008–2.014	0.711	[18]
Nigeria	Waste water	5.038–28.53	16.24	[20]
Italy	Drinking water (Monti Lattari)	0.03–0.43	0.33	[1]
	Drinking water (Ausino)	0.0032–0.48	0.26	[1]
	Drinking water (Vesuviano)	0.10–0.48	0.30	[1]
Serbia	Drinking water	0.041–0.173	–	[3]
Iran	Drinking water	0.023–0.332	0.110	[16]
Hungary	Tap water	–	0.095	[19]
Saudi Arabia	Drinking water	0.05–2.95	0.540	[17]
Thailand	Drinking water	0.112–1.087	0.219	This study
Thailand	Well water	0.209–0.369	0.284	This study
Thailand	Tap water	0.117–1.073	0.271	This study
Thailand	Waste water	0.137–2.895	0.444	This study

Table 7 Comparison of tritium activity concentration in water samples with those reported in other countries

Country	Type	Range (Bq l^{-1})	Average value (Bq l^{-1})	References
Italy	Drinking water (Monti Lattari)	1.06–20.00	8.49	[1]
	Drinking water (Ausino)	0.13–21.20	5.80	[1]
	Drinking water (Vesuviano)	0.83–12.19	5.11	[1]
Serbia	Drinking water	0.023–0.046	–	[3]
Thailand	Drinking water	–	< 9.4	This study

Conclusions

Gross alpha (GA), gross beta (GB) and tritium activity concentrations in supplied water in industrial pipeline production of food production and processing, portable water, and non-food industries were analyzed. Most of samples (raw water, consumption water, drinking water, deep well, reclaimed water, waste water, soft water and others) presented the GA and GB activities lower than the permissible limit recommended by WHO, but in 1 sample the elevated levels of GA activity (> 0.5 Bq l^{-1}) and in 5 samples the GB activity (> 1.0 Bq l^{-1}) were achieved. The high GB activity values were found in raw water and waste water samples, which may relate to a source of rock, mineral deposits and industrial processes. The measured tritium activity values in all water samples were below the MDA (< 9.4 Bq l^{-1}). The annual effective dose values obtained for all water samples were lower than 0.1 mSv recommended dose for radionuclides in drinking water. The data obtained in this study can provide an information for the authorities and the consumers regarding the radiological quality of drinking water. It is useful for the purpose of the prevention of unnecessary exposure of humans to natural radiation. Based on this study, quality inspection of supplied water should be continued and the impact of coal processing and exploration, as well as source soil and rock in the potential area on GA, GB and tritium activity will be further evaluated.

Acknowledgements The authors gratefully acknowledge the financial support from the Thailand Institute of Nuclear Technology (Public Organization).

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