# Natural Radioactivity in Drinking Water of Drilled Wells in Zanjan, Northwestern Iran

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## Abstract

**Background:** Many radioactive compounds may be released into the environment and hence into the drinking water supplies due to the human activities. Radionuclides can also enter the food chain if the contaminated water is used for drinking or irrigation purposes.

**Objective:** To estimate the annual effective dose of natural radioactive materials like $^{226}Ra$ and $^{40}K$ in drinking water of wells in Zanjan, nortwestern Iran.

**Methods:** 82% of drinking water in Zanjan comes from drilled wells. Water samples from the main sites of drinking water from different parts of Zanjan were collected. The amount of $^{226}Ra$ and $^{40}K$ were measured by gamma-ray spectrometry using a NaI (Tl) detector. The annual effective dose of the radioactive materials was calculated for children (2–7 years old) and adults (≥17 years old) with annual water intake of 350 and 500 L, respectively. The annual effective dose received by residents of the city due to consumption of the contaminated drinking water was also calculated.

**Results:** The mean±SD concentrations of $^{226}Ra$ and $^{40}K$ were 32.4±7.8 and 20.5±27.4 Bq/L, respectively. The mean±SD annual effective dose received by residents of the city due to consumption of the contaminated drinking water was 7.13±1.76 and 4.59±1.12 mSv/y for children and adults, respectively.

**Conclusion:** The level of radioactive compounds in water of drilled wells in Zanjan is significantly higher than the ICRP permissible limit of 1 mSv/y.

## Keywords

Natural radioactivity; $^{226}Ra$; $^{40}K$; Drinking water; Drilled wells; Annual effective dose

## Introduction

The environmental radiation originates from a number of naturally occurring radioactivity and human-made sources. The radioactive materials exist everywhere in the environment (*e.g.*, uranium, thorium and potassium-40) and the largest proportion of human exposure to radiation comes from natural sources [1]. Many of the radioactive compounds may be released into the environment and hence into the drinking water supplies due to the human activities [1]. The existence and distribution of natural radioactivity in water depends on the local geological characteristics of the soil or rocks. Elevated levels of natural radioactivity in drinking water are associated with increasing the potential health hazards for the residents. Therefore, measuring the radioactivity in drinking water is of great interest in environmental studies [2-5].

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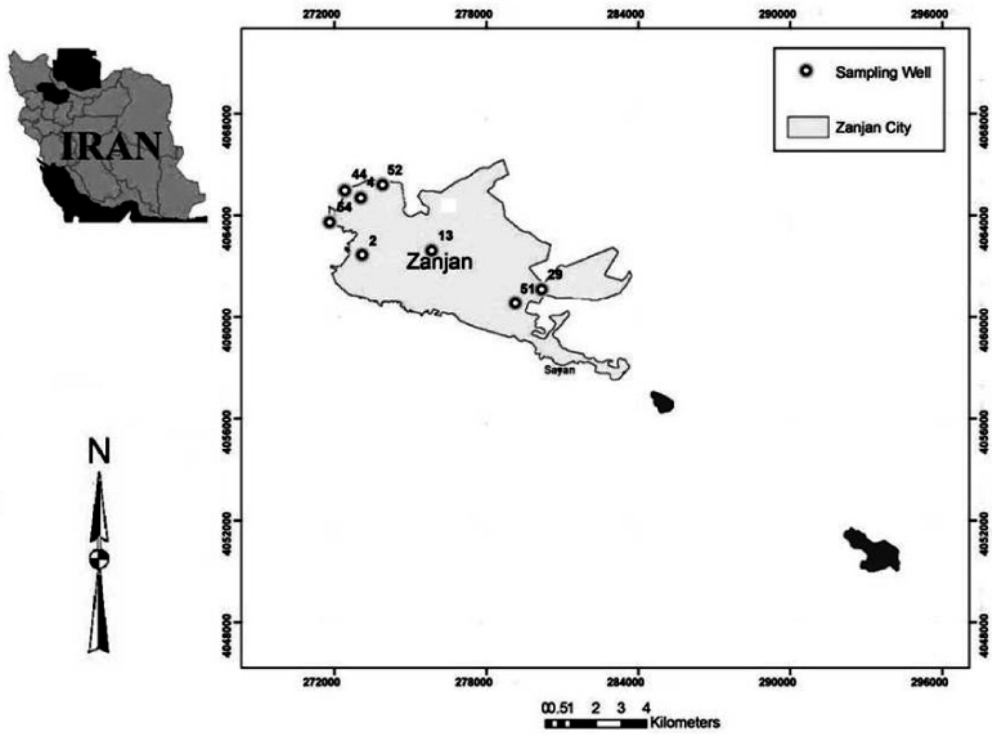


**Figure 1:** Map of Zanjan displaying the locations of the drilled wells

Zanjan province is located in the plateau of Northwest of Iran. The province is about 1600 m above the sea level with a total area of 22,150 km$^2$. It is situated between the longitudes of 47° 48′ 54″ and 49° 49′ 30″ E and the latitudes of 35° 49′ 59″ and 37° 48′ 54″ N. One of the prominent features of magmatic highlands in North of Zanjan province is the existence of large granitic and granodioritic bodies in Tarom mountains. Mineralization of gold, copper, lead, zinc and kaolin are associated with these hydrothermal alteration halos. Zanjan has around 385,000 inhabitants. The total annual water consumption in Zanjan is 37,000,000 m$^3$, more than 82% of which (30,000,000 m$^3$) comes from water cavern in Zanjan plain from drilled wells. The objective of this study was to estimate the annual effective dose of $^{226}$Ra and $^{40}$K in Zanjan drinking water of drilled wells. The annual effective dose estimation was also done for children and adults using the measured activity concentrations of $^{40}$K and $^{226}$Ra and the corresponding ingested dose conversion factors.

## Materials and Methods

The main sites of drinking water (10 sites) were selected from different parts of Zanjan. The sampling regions are indicated in the geological map of Zanjan (Fig. 1).

Three samples of water were taken from the taps connected to the electrical pumps established in each of the wells. The water samples were poured into plastic bottles which had previously been washed with pure water and rinsed with hydrochloric acid to prevent the contamination. For analysis, about 0.5 L of each sample was poured into a Marinelli beaker and sealed well to prevent radon gas leakage. The samples were left for one month to ensure that radon and its daughters achieve a secular equilibrium. The radioactivity measurements were then carried out by γ-ray spectrometry using a NaI (Tl) detector (3.81 in diameter and 5.08 in thickness, type 658/2A Harshow Co, and 2048 channel analyzer SENSOR-CASSY model with an energy resolution of 7.5 % at the energy peak of 662 keV). The samples were placed into the active volume of the NaI

(Tl) detector and measured for a counting time of 10,800 sec. The detector was shielded using a 1-cm thick lead plate. The standard of $^{137}Cs$ was used for energy calibration. The measurements for determining the background were carried out by using 0.5 L of pure, double distilled water. These determinations were done by using the same geometry and measurement time for the water samples (Marinelli geometry and 10,800 sec measurement time). The $^{226}Ra$ activities were determined by using one of the radon's daughters after achieving the secular equilibrium. The energy peak at 609.3 keV corresponding to $^{214}Bi$ was used. The $^{40}K$ activities were calculated by using its γ peak at 1460 keV. The annual effective dose due to the intake of the radionuclides present in water of drilled wells was calculated by the following equation:

$$D = C \times I \times E$$

where $D$ (Sv/y) is the annual effective dose of the radioactive compound due to the ingestion of radionuclides from drinking water, $C$ (Bq/L) is the activity concentration of radionuclides in the drinking water, $I$ (L/y) is the annual intake of drinking water and $E$ (Sv/Bq) is the ingested dose conversion factor for the radionuclide [1]. The conversion factor varies with each radioisotope and the age of the individual. The annual effective dose has been calculated for two age groups—children (2–7 years old) and adults (≥17 years old) with annual water intake of 350 and 500 L, respectively [6]. The detection limit ($DL$) of the measurement system, which was necessary to calculate the lowest detectable activity concentration of the radionuclides in the samples, was achieved by using the following equation [7, 8]:

$$DL = 1.64\ \delta/\varepsilon \times P \times t \times w$$

where $DL$ (Bq/L) is the detection limit, $\delta$ is the square root of the number of counts for the background spectrum, $\varepsilon$ is the efficiency of the NaI (Tl) detector used for the measurements, $P$ is the emission probability of the γ decay, $t$ (s) is the measurement time, and $w$ (L) is the volume of the water sample. The lowest detectable concentrations obtained for $^{226}Ra$ and $^{40}K$ assuming a 95% confidence interval, measurement time of 10,800 sec, and a sample volume of 1 L, were 4 and 1 Bq/L, respectively. The measurements below these values were not detectable by the detector and were indicated as "ND" in the results section.

## Results

The concentrations of $^{226}Ra$ and $^{40}K$ in water samples taken from the main sites in Zanjan are shown in Table 1. The concentration of $^{226}Ra$ and $^{40}K$ varied from 21 to 43 Bq/L, and from ND to 70 Bq/L with a mean±SD of 32.4±7.8 and 20.5±27.4 Bq/L, respectively.

Table 2 shows the annual effective dose (mSv/y) due to the ingestion of radionuclides in drinking water for children (2–7 years old) and adults (≥17 years old). The values varied from 4.54 to 9.75 mSv/y and from 2.92 to 6.18 mSv/y for children and adults, respectively. The mean annual effective doses due to the ingestion of $^{226}Ra$ were 6.98 and 4.52 mSv/y for children and adults, respectively.

## Discussion

The measurement of natural radioactivity in drinking water is one of the most important issues in health physics. The objective of this study was to measure the activity concentrations of $^{226}Ra$ and $^{40}K$ in drinking water of drilled wells in Zanjan, which led to the determination of the annual effective dose of radioactive materials in the water consumed in this area. The results showed that the concentrations of $^{226}Ra$ in all samples examined were higher than the recommended limit of 1 Bq/L [1]. This was also greater than the value reported by Hosseini, *et al*, for Zahedan [9]. The annual effective dose due to the intake of $^{40}K$ ranged from 0.007 to 0.51 mSv/y and from 0.003 to 0.22 mSv/y for children and adults, respectively. The mean concentration of $^{40}K$ (20±8 Bq/L) in the drinking water from drilled wells in Zanjan was greater than that reported in drinking water of some other parts of the world [7]. The mean annual effective dose due to ingestion of $^{40}K$ in two studied age groups were 0.15 mSv/y in children and 0.07 mSv/y in adults, which were lower than the average worldwide reported value of 0.17 mSv/y [6]. Totally, the mean±SD annual effective doses calculated in this study were 7.13±1.76 and 4.59±1.12 mSv/y for children and adults, respectively. The total annual effective dose due to the ingestion of $^{226}Ra$ and $^{40}K$ in both studied age groups exceeded the recommended limit of 1 mSv/y for the general population [1].

It can be seen that much of the total annual effective dose is attributed to $^{226}Ra$. In our previous study, the mean±SD concentration of $^{226}Ra$ in the soil samples of Zanjan was 90±9 Bq/kg, which was more than the limit of 35 Bq/kg reported by UNSCEAR [10]. Consequently, it was found that the annual effective dose of the radioactive compounds for Zanjan residents due to the intake of $^{226}Ra$ and $^{40}K$ was higher than the recommended limit given by WHO [1]. Presence of such high levels of radioactive substances in Zanjan underlines conduction of more research on the health status of its inhabitants.

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