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# Preliminary Study of Natural Radioactivity in the Lake Bosumtwi Basin

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**Abstract:** The concentrations of $^{238}U$, $^{232}Th$, and $^{40}K$ in water from Lake Bosumtwi and bore-holes in selected towns around the Bosumtwi basin of the Ashanti region of Ghana have been determined. The concentrations were determined for water samples from 24 boreholes and 12 points across the lake using a High-Purity Germanium (HPGe) γ-ray spectrometry. The water samples from the lake were found to contain acceptable levels of radionuclides with mean activity concentrations of 7.9, 89.7 and 0.6 mBq/L for $^{238}U$, $^{40}K$, and $^{232}Th$, respectively. The water samples from the boreholes recorded mean activity concentrations of 7.7, 85.5, and 3.3 mBq/L for $^{238}U$, $^{40}K$ and $^{232}Th$, respectively. The annual effective dose calculated for the lake varied from 0.244 to 1.121 μSv with an average of 0.763 μSv and that calculated for the boreholes varied from 0.296 to 2.173 μSv with an average of 1.166 μSv. The radionuclides concentrations in water from the bore-holes and that of the lake, which serve as sources of water supply to the surrounding communities are negligible and pose no radiological hazards to the public.

**Key words:** Borehole water, bosumtwi, effective dose, lake water, radioactivity

## INTRODUCTION

Rivers are the most important freshwater resource for man. Social, economic and political development has been largely related to the availability and distribution of freshwaters contained in riverine systems. Water quality problems have intensified through the ages in response to the increasing growth of populations and industrial centers. Polluted water is an important vehicle for the spread of diseases. In developing countries 1.8 million people, mostly children, die every year as a result of water-related diseases (WHO, 2004; Bush and Mayer, 1982).

Ghana's water resources have been under increasing threat of pollution in recent years due to rapid demographic changes, which have coincided with the establishment of human settlements lacking appropriate sanitary infrastructure. The qualities of these water bodies vary widely depending on location and environmental factors. Among the factors determining the qualities of natural waters, ground waters in particular, have the chemical composition of the rocks with which they interact; soil formations and the length of time that the water body has been trapped underground (Van der Merwe, 1962).

To monitor the water resources and ensure sustainability, national guideline (Ghana Water Company Limited guideline) and permissible limit (Ghana Water Company Limited permissible limits) and international criteria and guidelines established for water quality standards (WHO, 1984, 1993) are being used. Many settlements have developed with no proper water supply and sanitation services. People living in these areas, often utilize the lake water for drinking, recreation and irrigation, which creates a situation that may pose a serious health risk to the people.

A number of factors influence water chemistry. Gibbs (1970) proposed that rock weathering, atmospheric precipitation, evaporation and crystallization control the chemistry of surface water. The influence of geology on chemical water quality is widely recognized (Gibbs, 1970; Langmuir, 1997). The influence of soils on water quality is very complex and can be ascribed to the processes controlling the exchange of chemicals between the soil and water (Hesterberg, 1998; APHA, 1975; Cotruvo, 1988). Apart from natural factors influencing water quality, human activities such as industrial and agricultural practices impact negatively on river water quality. It is, therefore, important to carry out water quality assessments (radiological) for sustainable

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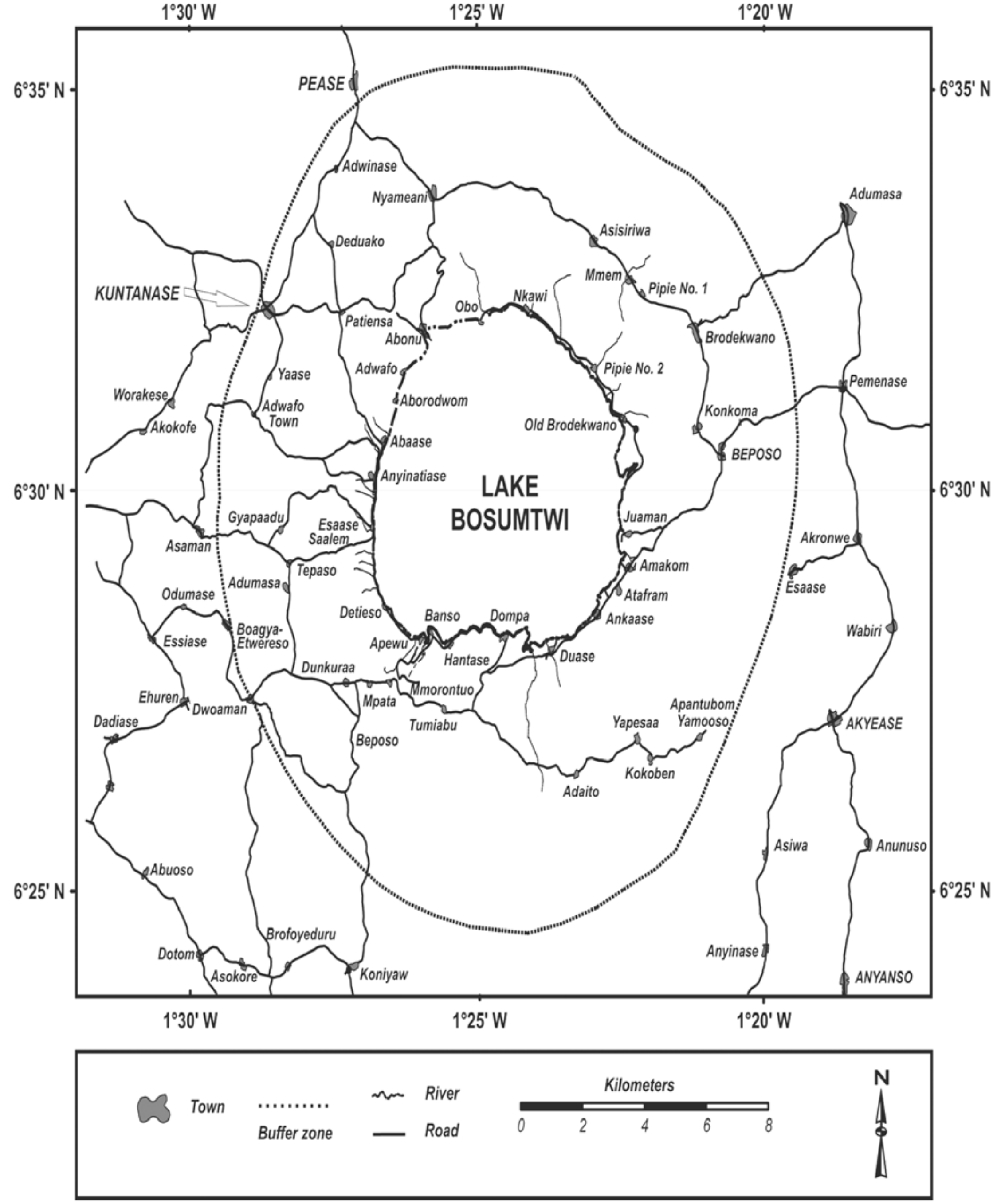


Fig. 1: The Bosumtwi forest reserve

management of water bodies (Kempster *et al.*, 1997; Kelter *et al.*, 1997).

The present study focuses on using the World Health Organization (WHO) guideline and permissible limits, and international criteria and guidelines established for radiological water quality standards, to assess the water qualities from the lake and selected boreholes in the surrounding towns and villages in the Lake Bosumtwi catchment area. The towns and villages around the lake are potential tourist centers in the Region.

**Description of the study area:** Lake Bosumtwi is a natural inland freshwater lake in the Ashanti Region of Ghana. It is located about 30 km south-east of Kumasi in the Northern tip of the Adansi mountains in the forest zone of Ghana. The lake exhibits a radial drainage system of 106 $km^2$, a diameter of about 11 km at its widest part and a maximum depth of 78 m. Lake Bosumtwi covers an area of about 52 $km^2$ (Turner *et al*., 1995).

The lake has no outlet, although it has apparently overflowed in recent geologic past (Turner *et al*., 1996a). The most important controls on the water balance of the lake are rainfall directly onto, and water evaporating directly from, the surface of the lake (Turner *et al*., 1996a). Of lesser importance is the runoff contributed by the lake's surrounding watershed. It is reasonable to assume, when considering the hydrogeological conditions that little or no groundwater enters or leaves the basin. According to Turner *et al*. (1996a, b), the lake level is very sensitive to small changes in rainfall and other climatic parameters, such as annual mean temperature and evaporation (Lissewski, 2003).

The lake is one of the main sources of livelihood for 24 communities living around and they heavily depend on the fish catch for their income and food (protein). Besides fishing, they depend on the aquatic resource for drinking water and irrigation water for agricultural activities.

The lake also provides the basis for other social and economic opportunities such as transportation and tourism. The Bosumtwi Forest Reserve, which is near the Ankaase community at Lake Bosumtwi (Fig. 1), and has an area of 140 $km^2$, is a legally protected area consisting of semi-deciduous tropical rainforest and provides a typical natural environment that attracts eco-tourism.

Fig. 1: The Bosumtwi forest Reserve

**Hydro-geological setting:** The Bosumtwi impact structure is exposed in 2.1 Gyr Precambrian metasedimentary and metavolcanic rocks in the forest zone of southern Ghana (06°30 N, 01°25 W). It is a well-preserved 1.07 Myr complex impact crater 10.5 km in diameter with a pronounced rim. The crater is almost completely filled by Lake Bosumtwi, which is ~8 km in diameter and up to 78 m deep at its center. Bosumtwi is associated with one of only four known tektite strewn fields (the Ivory Coast tektites) (Koeberl *et al*., 1997; Karp *et al*., 2002). Details on the geology of Bosumtwi and the controversies surrounding the acceptance of the impact origin, and on a recent drilling project that was supported by the International Continental Scientific Drilling Program (ICDP), the Ghana Geological Survey Department, Kwame Nkrumah University of Science and Technology (KNUST), and various funding organizations in Austria, Canada, and the USA, are reported by Koeberl and Reimold (2005).

## METHODOLOGY

**Sampling and sample preparation:** Sampling and sample preparation methods adopted followed standard guidelines proposed in literature (Barcelona *et al*., 1985; APHA, 1975).

A total number of 24 water samples were collected from boreholes within 24 communities around Lake Bosumtwi and 12 water samples from selected points in the lake for analysis. The lake is an important source of livelihood for the 24 communities living around and they rely on it for fishing as a source of income, protein and domestic chores. Water from boreholes was also sampled for analysis. Precise information on depth and casing lengths of the boreholes were unavailable. The samples were measured during the period when the weather conditions during the sampling period were fairly stable. The pH, temperature and conductivity of the water samples were measured on the field during the sampling period using a portable water-analysis kit. The stability and precision of the measurements were found to be nominal and within 5% of the mean of data for pH, temperature and conductivity.

Water was collected into 1.5 L polyethylene plastic bottles and a few drops of hydrochloric acid added to bring the pH to an appreciable level of 2 in order to prevent adherence of the radionuclides to the walls of the containers. The bottles were filled to the brim without any head space to prevent trapping of gas. The bottles were tightly covered with the lids and labeled appropriately. The samples were transported to the laboratory and prepared into 1 L Marinelli beakers and stored in a refrigerator prior to analysis.

**Analysis of water samples:** The samples were analyzed using an ORTEC high resolution gamma-spectrometry system. The spectrometer consists of a High Purity Germanium (HPGe) detector coupled to a desk top computer provided with a Canberra S100 Multichannel Analyzer (MCA) and with a Maestro-32 Multi-Channel Buffer (MCB) configuration software for spectrum acquisition and evaluation. The detector crystal has a diameter of about 36 mm and thickness of about 10 mm. The crystal is housed in an aluminium canister with a 0.5 mm thick beryllium entrance window. A lead shield, built with 5 cm thick lead brick surrounds the detector to prevent it from external background radiation reaching the detector. The detector is coupled to a Canberra 1510 signal processing unit which contains the power supply, amplifier and analogue to digital converter. Digitized counts are collected in a Canberra S100 multi-channel analyzer. The detector is cooled with liquid nitrogen at -196ºC (77 K) provided in a 25 L Dewar. The ambient temperature around the detector was 16ºC during the period of measurement. The relative efficiency of the detector is 25% with energy resolution of 1.8 keV at gamma ray energy of 1332 keV of $^{60}Co$.

The energy and efficiency calibrations of the detector were performed using mixed radionuclide standard of density of 1.0 g/cm$^3$ in a 1.0 L Marinelli beaker manufactured by Deutscher Kalibrierdienst (DKD-3), QSA Global GmBH, Germany. Photopeak efficiency calibration was performed by acquiring a spectrum of the calibration standard until the count rate at the peak of total absorption could be calculated with statistical uncertainty of less than 1% at a confidence level of 95%.

The net count rate was determined at the photopeaks for all the energies used for the determination of the efficiency of the calibration standard at the time of measurement. The efficiency at each energy was plotted as a function of the peak energy and extrapolated to determine the efficiencies at other peak energies for the measurement geometry using the relationship:

$$\ln \epsilon ( E_y ) = 0.206 - 0.487 ( \ln E_y ) \qquad (1)$$

where 0.206 and 0.487 are calibration constants for the geometry used and $E\gamma$ is the gamma energy.

Background counts were taken for the same period and density corrections made where appropriate. The samples were counted for 86400 seconds. The specific activity concentrations of $^{238}U$, $^{232}Th$ and $^{40}K$ in Bq/L for the water samples respectively were determined. The $^{238}U$ activity was determined by taking the mean activity of the two separate photo peaks of the daughter nuclides: $^{214}Pb$ at 352.0 keV and $^{214}Bi$ at 609.3 keV, $^{232}Th$ was determined using photo peaks of $^{228}Ac$ at 911.1 keV and the photopeak of $^{212}Pb$ at 583.1 keV and $^{40}K$ was directly determined using 1460.8 keV photopeak. The activity concentrations (Bq/kg) of $^{40}K$, $^{238}U$ and $^{232}Th$, respectively were computed using the following relationship (Beck *et al*., 1972).

$$A_{sp} = N_{sam} / P_E . \epsilon . T_c . M \qquad (2)$$

where; $N_{sam}$ - background corrected net counts of the radionuclide in the sample, $P_E$ - gamma ray emission probability (gamma yield), $\epsilon$ - total counting efficiency of the detector system, $T_c$ - sample counting time, and M - mass of sample (kg) or volume (L).

The annual effective dose (mSv), from ingestion of radionuclide consumed in water was calculated on the basis of the mean activity concentrations of the radionuclides. The daily water consumption rate was considered to be 2 L per day and the conversion factor or dose per unit intake by ingestion for naturally occurring radionuclides for adult members of the public is $4.5\times10^{-5}$ mSv/Bq for $^{238}U$, $2.3\times10^{-4}$ mSv/Bq for $^{232}Th$ and $6.2\times10^{-6}$ mSv/Bq for $^{40}K$ were used. The annual committed equivalent dose, $H_{ing}(W)$, was computed from the expression (ICRP, 1996):

$$H_{ing} (W) = \Sigma^3_{j=1} DCF_{ing} (U,Th, K).A_{sp}.I_w \qquad (3)$$

where; $DCF_{ing}(U, Th, K)$- Dose conversion coefficients of the radionuclides in Sv/Bq, $A_{sp}$ - Specific activity concentrations of radionuclides in the water samples in Bq/L, $I_w$- water consumption rate in litres per year, assuming 2L average water intake per day for 365 days/year will be 730 L/year.

## RESULTS AND DISCUSSION

The activity concentrations of $^{238}U$, $^{40}K$, and $^{232}Th$, temperature, pH and conductivity of water in the lake and the boreholes water in the surrounding towns of the lake are shown in Table 1 and 2, and water sampling points shown in Fig. 1.

The activity concentration in the lake for $^{238}U$, $^{40}K$, and $^{232}Th$ varied from 1.4 to 17.5 mBq/L with an average of 7.9 mBq/L, 33.3 to 120.0 mBq/L with an average of 89.7 mBq/L and 0.3 to 1.0 mBq/L with an average of 0.6 mBq/L, respectively. The activity concentration in the boreholes for $^{238}U$, $^{40}K$, and $^{232}Th$ varied from 0.9 to 21.5 mBq/L with an average of 7.7 mBq/L 19.2 to 154.9 mBq/L with an average of 85.5 mBq/L and 0.4 to 9.5 mBq/L with an average of 3.3 mBq/L, respectively.

The annual effective doses due to intake of radionuclides were calculated using the World Health Organization consumption rates of 2 L of water per day (WHO, 2004) which corresponds to 730 L/year. The annual effective dose calculated for the lake varied from 0.244 to 1.121 μSv with an average of 0.763 μSv and that calculated for the boreholes varied from 0.296 to 2.173 μSv with an average of 1.166 μSv.

According to the WHO Guidelines (WHO, 2004) radiological quality of drinking water estimated that the total annual effective dose from all radionuclides except for tritium and radon should not exceed 100 μSv. The calculated annual effective dose for this study is much below this limit.

Table 1: $^{238}U$, $^{40}K$, and $^{232}Th$ concentrations and annual effective doses in samples of water from different points in the lake

| Location | Acitivity concentration (mBq/L) $^{238}U$ | $^{232}Th$ | $^{40}K$ | Annual committed dose (μSv) | Temp. (ºC) | pH | Conductivity (μS/cm) |
|---|---|---|---|---|---|---|---|
| $LW_1$ | 1.6 | 0.3 | 33.3 | 0.244 | 26.9 | 7.2 | 947 |
| $LW_2$ | 16.9 | 0.7 | 103.3 | 1.121 | 27.3 | 7.0 | 698 |
| LW3 | 1.9 | 1.0 | 101.5 | 0.682 | 27.5 | 7.3 | 792 |
| $LW_4$ | 4.5 | 0.9 | 100.1 | 0.742 | 28.0 | 6.9 | 264 |
| $LW_5$ | 5.6 | 0.9 | 45.1 | 0.529 | 26.8 | 6.3 | 278 |
| $LW_6$ | 12.2 | 0.8 | 84.5 | 0.911 | 27.1 | 7.0 | 365 |
| $LW_7$ | 3.3 | 0.5 | 102.5 | 0.654 | 28.2 | 7.1 | 512 |
| $LW_8$ | 4.5 | 0.7 | 74.5 | 0.602 | 28.1 | 7.5 | 671 |
| $LW_9$ | 15.4 | 0.3 | 120.0 | 1.079 | 29.0 | 7.4 | 237 |
| $LW_{10}$ | 17.5 | 0.6 | 98.7 | 1.098 | 28.8 | 7.4 | 187 |
| $LW_{11}$ | 1.4 | 0.3 | 125.4 | 0.655 | 29.3 | 7.6 | 319 |
| $LW_{12}$ | 9.9 | 0.7 | 87.5 | 0.833 | 27.6 | 6.9 | 912 |
| Average | 7.9 | 0.6 | 89.7 | 0.763 | 27.9 | 7.1 | 515 |

Table 2: $^{238}U$, $^{40}K$, and $^{232}Th$ concentrations and annual effective doses in samples of water from different boreholes in the Bosumtwi basin

| Location | Activity concentration (mBq/L) $^{238}U$ | $^{232}Th$ | $^{40}K$ | Annual committed dose (μSv) | Depth (m) | Temp. (ºC) | pH | Conductivity (μS/cm) |
|---|---|---|---|---|---|---|---|---|
| $BH_1$ | 0.9 | 9.5 | 67.4 | 1.867 | NA | 35.0 | 7.0 | 475 |
| $BH_2$ | 8.6 | 1.9 | 63.2 | 0.882 | NA | 28.0 | 6.8 | 390 |
| $BH_3$ | 6.5 | 0.4 | 42.3 | 0.459 | NA | 23.7 | 7.6 | 458 |
| $BH_4$ | 7.2 | 1.5 | 50.9 | 0.708 | NA | 25.0 | 7.2 | 295 |
| $BH_5$ | 16.9 | 6.5 | 78.9 | 1.953 | NA | 22.8 | 6.9 | 540 |
| $BH_6$ | 9.5 | 1.5 | 45.8 | 0.753 | NA | 24.9 | 7.5 | 430 |
| $BH_7$ | 5.4 | 8.6 | 86.5 | 1.955 | NA | 22.5 | 6.9 | 509 |
| $BH_8$ | 7.5 | 5.6 | 152.3 | 1.835 | NA | 22.3 | 7.5 | 257 |
| $BH_9$ | 2.9 | 7.4 | 109.0 | 1.780 | NA | 21.6 | 6.5 | 325 |
| $BH_{10}$ | 15.8 | 7.4 | 154.9 | 2.407 | NA | 23.1 | 6.4 | 294 |
| $BH_{11}$ | 2.5 | 1.0 | 12.4 | 0.296 | NA | 23.8 | 6.8 | 198 |
| $BH_{12}$ | 4.2 | 4.7 | 98.7 | 1.339 | NA | 25.5 | 6.8 | 231 |
| $BH_{13}$ | 3.1 | 2.6 | 85.4 | 0.902 | NA | 26.4 | 7.1 | 288 |
| $BH_{14}$ | 2.2 | 0.5 | 37.2 | 0.321 | NA | 22.0 | 6.6 | 199 |
| $BH_{15}$ | 17.3 | 1.4 | 101.7 | 1.246 | NA | 23.9 | 6.4 | 360 |
| $BH_{16}$ | 17.2 | 3.0 | 100.2 | 1.495 | NA | 23.8 | 7.2 | 265 |
| $BH_{17}$ | 4.9 | 1.2 | 94.7 | 0.770 | NA | 25.1 | 6.6 | 258 |
| $BH_{18}$ | 1.0 | 1.4 | 35.8 | 0.419 | NA | 24.6 | 7.1 | 793 |
| $BH_{19}$ | 4.3 | 1.2 | 95.2 | 0.762 | NA | 23.3 | 7.5 | 364 |
| $BH_{20}$ | 3.3 | 0.9 | 19.2 | 0.334 | NA | 22.7 | 7.3 | 268 |
| $BH_{21}$ | 4.2 | 1.4 | 154.2 | 1.060 | NA | 25.4 | 6.4 | 268 |
| $BH_{22}$ | 4.6 | 1.0 | 98.8 | 0.752 | NA | 24.0 | 6.7 | 369 |
| $BH_{23}$ | 12.4 | 7.5 | 124.1 | 2.173 | NA | 24.7 | 7.5 | 702 |
| $BH_{24}$ | 21.5 | 1.1 | 142.6 | 1.515 | NA | 23.2 | 7.4 | 176 |
| Average | 7.7 | 3.3 | 85.5 | 1.166 | | 24.5 | 6.9 | 363 |

NA: not available

Physicochemical parameters of water such as temperature, pH and conductivity were also measured in order to find the impact of these parameters on the concentration of the radionuclides in water. However, no correlation was found between the radionuclide concentrations and temperature, pH and conductivity.

## CONCLUSION

Lake Bosumtwi is the largest natural lake in West Africa. The level of radionuclide concentration in water from Lake Bosumtwi and bore-holes in selected towns in the Bosumtwi basin of Ashanti region of Ghana was determined. Concentration of $^{238}U$, $^{232}Th$ and $^{40}K$ was determined for the water samples from boreholes and points across the lake. The mean activity concentrations for water samples from the lake were found to be 7.9, 89.7 and 0.6 mBq/L for $^{238}U$, $^{40}K$, and $^{232}Th$, respectively. For the boreholes it was found to be 7.7, 85.5 and 3.3 mBq/L for $^{238}U$, $^{40}K$ and $^{232}Th$, respectively. The annual effective dose calculated for the lake water varied from 0.244 to 1.121 μSv with an average of 0.763 μSv and that for the boreholes varied from 0.296 to 2.173 μSv with an average of 1.166 μSv. The radionuclides concentrations of the bore-hole water supply and in the lake are negligible and pose no radiological hazards to the public.

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