Wolters Kluwer
Medknow
ISSN 0972-0464

Radiation Protection and Environment

विकिरण संरक्षण एवं पर्यावरण

Vol. 39/ Number 1 / January-March 2016
Vol. 1-19 Published under the title
BULLETIN OF RADIATION PROTECTION

Publication of INDIAN ASSOCIATION FOR RADIATION PROTECTION (IARP)
www.iarp.org.in

A study of radon concentration in drinking water samples of Amritsar city of Punjab (India)

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Abstract

Radon concentration has been estimated in drinking water samples of 17 selected locations in Amritsar city of Punjab, India. RAD7, an electronic solid state radon monitor has been used to evaluate the radon concentration in collected drinking water samples. The corresponding annual mean effective dose for ingestion and inhalation was calculated according to parameters introduced by UNSCEAR (2000) report. The radon concentration in drinking water samples has been found to vary from 0.53 ± 0.11 to 11.20 ± 1.40 Bql^{-1}. The values of radon concentration in these samples were found below the recommended limit proposed by USEPA (1991) and European Commission (2001). The range of calculated annual effective dose varied between 1.45 and 30.57 μSvy^{-1}. These values lie well within the safe limit prescribed by the WHO (2003) and European council (2005). The purpose of this study was to assess the radiological risk, if any, to human health due to consumption of drinking water that is available at Amritsar city.

Keywords: Drinking water samples, effective dose, RAD7, radon

INTRODUCTION

Environmental radiation originates from a number of naturally occurring and human-made sources.[1] Naturally occurring radionuclides are created in the upper atmosphere and are found in the earth's crust. As they decay, they produce daughter products that are mostly short lived and more radioactive. The largest proportion of human exposure to radiation comes from natural sources and from inhalation or ingestion of radioactive materials, i.e., uranium, thorium, and potassium. The largest fraction of natural radiation exposure comes from radon, a radioactive gas.[2] Underground rock containing natural uranium continuously releases radon into water in contact with it. Radiation exposure can occur by ingesting, inhaling, injecting, or absorbing radioactive materials. The International Commission on Radiological Protection (ICRP) suggests that radionuclides in water are absorbed more easily than radionuclides incorporated in food.[3] Once ingested, the radioactive particles ionize the nearby atoms in the body as the radiation travel through a cell or other material. Radon being the daughter product of uranium is expected in higher levels in rocks containing uranium. When groundwater percolates through rocks rich in uranium, it is expected to have high level of radon gas in groundwater. Radiological hazards may be possible due to the presence of large content of radioactive substances in drinking water. Such hazards from drinking water are rarely of public health significance.

Inhalation of radon gases is the second most important cause of lung cancer after smoking and the majority of radon-induced lung cancers are caused by low and moderate radon concentrations rather than by high

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Access this article online

Quick Response Code:

Website: www.rpe.org.in

DOI: 10.4103/0972-0464.185155

How to cite this article: Kumar A, Kaur M, Sharma S, Mehra R. A study of radon concentration in drinking water samples of Amritsar city of Punjab (India). Radiat Prot Environ 2016;39:13-9.

radon concentrations because in general, less people are exposed to high indoor radon concentrations.[4] It has been measured in water in many parts of the world, mostly for the risk assessments due to consumption of drinking water.[5-13] It is odorless, tasteless, and colorless, and therefore cannot be detected by the human senses. It is a radioactive inert and heaviest gas among all noble gases. Because it is denser than air, radon gas in the environment tends to settle in lower areas where the air is still and can concentrate in poorly vented rooms and basements. It is the only alpha emitting radioactive gas and its alpha-emitting decay products are responsible for its carcinogenicity. It is produced after the alpha decay of radium, which is further the decay product of U-238.[14] This means the concentration of radon depends on the concentration of U-238 in any source. When radium decays, it produces an alpha particle with 4.78 MeV energy and recoiling Rn-222 with recoil energy of 86 KeV.[15] Radon has three isotopes, i.e., (i) Rn-219 or "actinon" is a part of U-235 decay chain. It is never encountered in indoor air due to its short half-life (3.4 s). (ii) Rn-220 or "thoron" is a part of Thorium-232 decay chain; its half-life is more than actinon but <1 min (54 s). (iii) Rn-222 or familiar "radon" is a part of the U-238 decay chain. Its half-life is 3.8 days. Due to its longer half-life, it is detected in indoor air, outdoor air, soil gas, and water samples. As radon decays, it produces a new radioactive element called radon daughters or decay products, i.e., Po-218 (3.05 min), Pb-214 (26.8 min), Bi-214 (19.9 min), Po-214 (164 μs), and Pb-210 (22 years).

Ingesting drinking water that contains radon also presents, depending on its level, a possible risk to human health. Levels of radon are generally higher in groundwater than in surface water. Although radon in drinking water does not pose a direct health risk,[16,17] the main concern is that the levels of radon in indoor air of dwellings can be enhanced partially by radon derived from water supply.[18] It is hazardous to inhale radon, since it emits alpha particles. Radon in water may, therefore, present dual pathways of exposure for individuals through drinking water and inhalation of air containing radon released from groundwater.

Many studies have been done to measure radon in water in different regions of Punjab[19-23] from the health hazard point of view. In the present study, a survey of radon measurement has been carried out in drinking water sources in Amritsar city of Punjab. The aim of the study is to draw a general picture of radon activity of drinking water in Amritsar city of Punjab and to evaluate doses to the population resulting from the ingestion and inhalation of radon from water for health risk assessments.

Study area

The present study was carried out in Amritsar city, Punjab state, India, shown in Figure 1. Amritsar is located in the Northern part of Punjab state and lies between 31° 28′ 30″–32° 03′ 15″ north latitude and 74° 29′ 30″–75° 24′ 15″ east longitude. Soils in the western part of the city are coarse loamy, calcareous, whereas in the central part of the city, soils are fine loamy, calcareous, and are well drained.

METHODOLOGY

Ground water samples were collected from different sources such as hand pumps and submersible pumps as these are the main sources of water in Amritsar city, Punjab. Radon concentrations in the collected samples were determined immediately so that no decay of radon takes place. They were stored in 250 ml vial in such a way that no air particles remain in vial. This makes it possible to calculate radon concentration only due to water rather than combination of air and water. These water samples were analyzed using RAD7 (Durridge Company Inc., USA), which is an online radon monitor for calculating the radon concentration (Durridge Company). RAD7 is a continuous radon gas monitor. It is based on solid state silicon detector. It contains a hemisphere dome in the middle of device, called internal cell.[24] The volume of internal cell is 0.7 L. At the center of the hemisphere, silicon alpha detector is placed. It is a sophisticated and versatile measuring device capable of complex measurements of radon in soil, air, and water. It is a simplest, easiest, and portable computer-driven electronic instrument to use. The task of RAD7 is divided into two categories.

Purging of RAD7

Before using RAD7, the first step is to do purging to remove undesired moisture and humidity from the

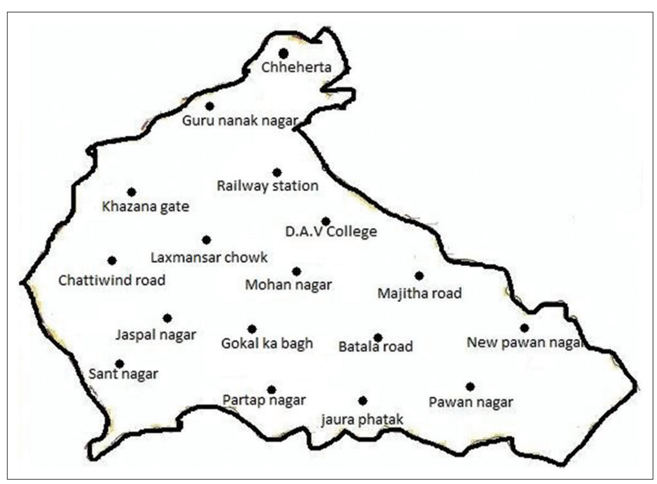

Figure 1: Map showing the surveyed area during the present study

measurement chamber. This can be done by connecting gas purifier to RAD7 instrument with tubes. The Drierite gas purifier is an all-purpose drying unit for the efficient and rapid drying of air. It is used to maintain a dry atmosphere in storage spaces, vaults, and commercial packages. In the present study, we are using Indicating Drierite. Indicated Drierite is impregnated with cobalt chloride. It is blue when dry and changes to pink upon absorption of moisture. The need of purging is only to obtain relative humidity <10% so that we can collect accurate result. Purging can be simply done by just connecting the inlet of RAD7 at the bottom of desiccant drying unit and outlet of RAD7 at the top of desiccant drying unit as shown in Figure 2. If relative humidity becomes <10%, it implies that RAD7 is now ready for use.[25]

Determination of radon concentration

Radon concentration was estimated using RAD7 whose schematic diagram is shown in Figure 3.[9,10,16] Set RAD7 at Wat250 mode for finding radon in water samples. The RAD7's pump will run for 5 min. During the 5 min of pumping, more than 95% of the available radon is removed from the water. This removed radon gas is sucked through filter into the inlet and reaches the measurement chamber. The voltage of 2000–2500 V is applied between detector and hemisphere, creating an electric field throughout the volume of cell. This electric field drifts the positively charged particles onto the detector. Inside the chamber, Rn-222 decays into a

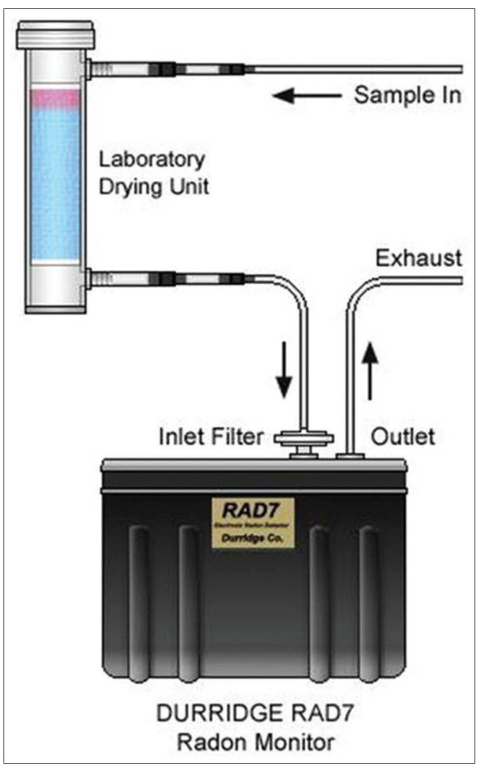

Figure 2: The purging process of RAD7

positively ionized Po-218. This positively ionized Po-218 will be accelerated toward the detector. The produced Po-218 has a half-life of 3 min. When the short-lived Po-218 nucleus decays upon the detector's active surface, its alpha particle (6 MeV) energy has 50% probability of entering the detector, producing an electrical signal proportional in strength to the energy of alpha particle. This signal is amplified electronically and transformed into a digital signal. This signal will be further processed by a microprocessor that helps to produce the spectrum. The radon concentration in internal cell of RAD7 can be calculated by the following differential equations:[26]

$$\frac{dC(t)}{dt} = -\lambda C(t) \quad (1)$$

$$\frac{dC_{PO}(t)}{dC} = \lambda_{PO} C(t) - \lambda_{PO} C_{PO}(t) \quad (2)$$

where C (t) is the radon concentration in the internal cell of RAD7, λ is the density constant of radon, C_{Po} (t) is Po-218 concentration, and λ_{Po} is Po-218 decay constant and equals to 0.00379 s^{-1}. After certain duration of pumping, the radon concentration in internal cell of RAD7 equals to that of the environment C_0. Equation 2 becomes as follows:

$$dC_{PO}(t)\, dt = \lambda_{PO} C_0 - \lambda_{PO} C_{PO}(t) \quad (3)$$

The initial condition is:

$$C_{Po}(0) = 0 \quad (4)$$

The solution of Equation 3 is:

$$C_{PO}(t) = C_0 (1 - e^{-\lambda_{PO} t}) \quad (5)$$

If the time is much longer than the half-life of Po-218, Equation 5 becomes:

$$C_{Po}(t) = C_0 \quad (6)$$

Radon concentration can be calculated from Equation 6 and this is the measurement principle of RAD7.

Evaluation of mean annual effective dose

The dose due to radon can be divided into two parts, first is dose from ingestion and second is dose from inhalation. The annual mean effective dose for ingestion and inhalation was calculated according to parameters introduced by UNSCEAR report[27] as shown below:

$$\text{Ingestion dose (mSv)} = Rn^{222} \text{ conc. } (Bq l^{-1}) \times 60\ l y^{-1} \times 10^{-3}\ m^3 l^{-1} \times 3.5\ nSv\ Bq^{-1} \quad (7)$$

$$\text{Inhalation dose (mSv)} = Rn^{222} \text{ conc. } (Bq l^{-1}) \times 10^{-4} \times 7000\ h y^{-1} \times 0.4 \times 9\ nSv\ (Bq\ h\ m^{-3})^{-1} \quad (8)$$

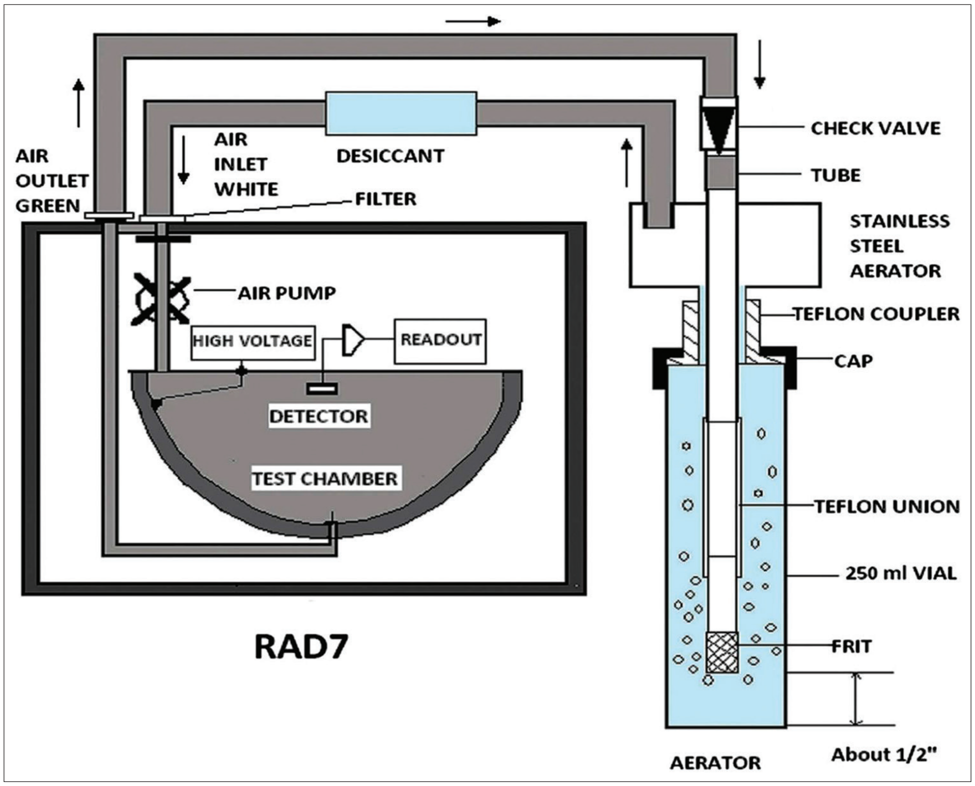

Figure 3: Schematic diagram of RAD H_2O assembly

RESULTS AND DISCUSSION

The results of radon concentration in water samples taken from 17 locations of Amritsar city are shown in Table 1. The results show that the higher activity of radon was 11.20 ± 1.40 Bql^{-1} in DAV College and low activity was 0.53 ± 0.11 Bql^{-1} in Partap Nagar with a mean value of 03.75 Bql^{-1}. Figure 4 shows the frequency chart of mean radon concentration in the studied dwellings. Since the distribution of radon in water samples has been found to be lognormal, geometric mean and standard deviation values have been calculated and represented in Table 1. The positive value of mean radon concentration in studied samples showed a platykurtic distribution with a well-defined central peak. The mean concentration of radon is slightly positively skewed meaning that majority of the data are lower than the average values. The US Environment Protection Agency has suggested that the maximum allowed concentration level of radon concentration in water is 11 Bql^{-1}.[28] The recommended limit of the protection of the public against exposure to radon in drinking water supplies (2001/928/Euratom) recommends action level of 100 Bql^{-1} for public water supplies.[29] ICRP has suggested the maximum contamination level of radon concentration in water samples as 0.6 Bql^{-1}.[30]

The values of radon concentration obtained in groundwater were compared with other regions of Punjab reported by other researchers. Kumar *et al*. have reported a radon concentration range of 1.4–4.9 Bql^{-1} in the water samples of Fazilka district, Punjab.[9] The values of radon concentration in groundwater samples of Bathinda district and Kapurthala district of Punjab varies from 0.9–5.1[19] to 0.23–2.1 Bql^{-1}.[20] The value of radon concentration varies from 2.56 to 7.75 Bql^{-1} in environs of NITJ, Punjab, reported by Badhan *et al*.[21] Some researchers also found the value of radon concentration in Pathankot,[16] Ropar, Hoshiarpur,[22] and Gurdaspur.[23] A few values of radon concentration in groundwater samples of Amritsar city are higher than other districts except Pathankot district as reported in Table 2. The average radon concentration increases as one move from Amritsar to Pathankot, i.e., from Punjab plains toward Siwalik Himalayas. It is well established that Himalayas' rivers and streams which charge underground water table in Punjab, contain anomalous values of radon concentration. The occurrence of radon in groundwater is reasonably related to the uranium content of the bedrocks and it can easily enter into the interacting groundwater by the effect of lithostatic pressure.[31] The comparatively higher value of radon concentration in Amritsar city, though the level itself is very low, may be correlated to varying uranium content in drinking water samples reported by Singh *et al*.[32] All values of radon concentration in groundwater samples of Amritsar city were well within the permissible limit suggested by the USEPA[28] and European Commission,[29] and hence it

Table 1: Radon concentration and annual effective dose in water samples at different locations

Serial number	Sample locations	Co-ordinates of locations	Sources of water	Radon concentration in water samples (Bq/l)				Annual effective dose (µSv/y)		
				Minimum	Maximum	Mean	SD	Inhalation	Ingestion	Total
1	Jaspal Nagar	31°36′31′′ 74°53′36′′	SP*	00.66	09.94	00.78	00.12	01.97	00.16	02.13
2	Batala Road	31°37′29′′ 75°16′18′′	HP*	01.27	01.71	01.50	00.24	03.78	00.32	04.10
3	Gokal ka Bagh	31°37′11′′ 74°53′50′′	SP	01.51	02.28	01.87	00.37	04.71	00.39	05.10
4	Joura Phatak	31°37′47′′ 74°53′35′′	SP	01.80	02.87	02.20	01.40	05.54	00.46	06.00
5	Pawan Nagar	31°38′15′′ 74°53′44′′	SP	02.58	03.15	02.80	00.24	07.06	00.59	07.64
6	Chheharta	31°37′35′′ 74°47′21′′	HP	02.73	03.44	03.09	00.31	07.79	00.65	08.44
7	Laxmansar Chowk	31°36′57′′ 74°52′32′′	SP	04.20	07.03	05.50	10.22	13.86	01.15	15.01
8	Khazana Gate	31° 37′03′′ 74°51′45′′	SP	08.65	10.69	09.44	00.88	23.78	01.98	25.76
9	D.A.V College	31°38′02′′ 74°52′20′′	SP	09.90	12.69	11.20	01.40	28.22	02.35	30.57
10	Sant Nagar	31°36′45′′ 74°51′51′′	SP	05.88	09.39	07.84	10.52	19.77	01.65	21.42
11	New Pawan Nagar	31°38′14′′ 74°53′44′′	SP	04.10	05.40	04.80	00.58	12.09	01.01	13.10
12	Guru Nanak Nagar	31°39′45′′ 75°01′59′′	HP	02.98	03.51	03.15	00.24	07.94	00.66	08.60
13	Chatiwind Road	31°36′36′′ 75°09′11′′	HP	02.06	03.49	02.75	00.21	05.67	00.47	06.14
14	Railway Station	31°37′59′′ 74°52′02′′	SP	02.05	02.86	02.43	00.37	06.12	00.51	06.63
15	Majita Road	31°39′28′′ 74°53′20′′	HP	02.08	02.43	02.25	00.15	05.67	00.47	06.14
16	Mohan Nagar	31°37′15′′ 75°05′36′′	SP	01.51	02.01	01.70	00.23	04.28	00.36	04.64
17	Partap Nagar	31°37′09′′ 74°54′04′′	SP	00.37	00.64	00.53	00.11	01.34	00.11	01.45
Mean				03.19	04.91	03.75	01.62	09.45	00.79	10.24
SD				02.58	03.52	02.96	03.21	07.51	00.63	08.13
GM				02.35	03.77	02.79	00.49	06.96	00.57	07.54
Kurtosis				01.91	−0.28	01.18	05.19	01.17	01.17	01.17
Skewness				01.57	01.01	01.41	02.54	01.42	01.42	01.42

*SP: Submersible pump, HP: Hand pump, SD: Standard deviation, GM: Geometric mean

is safe for drinking purposes. Only 5% (one sample) of water sample was found to lie well below within the safe limit suggested by the ICRP.[30] The reason for variation in radon concentration in some areas may be due to the depth of water sources.

The annual effective dose in the stomach and lungs per person was also evaluated in this study. The values of the annual effective dose per person caused by different water samples in this study are in Table 1. The average annual effective dose from ingestion of radon in drinking water was 0.79 µSvy^{-1} and that of inhalation of water-borne radon was 9.45 µSvy^{-1}. Hence, the annual effective dose due to inhalation of water-borne radon was higher than those from radon ingestion from water. As normally expected for any radionuclide associated with internal hazard, the dose due to inhalation of radon is higher as compared to ingestion. The estimated total annual effective dose ranged from 1.45 to 30.57 µSvy^{-1}. The value of skewness and kurtosis for total annual effective dose is almost same as mean radon concentration. This means the distribution curve for total annual effective dose

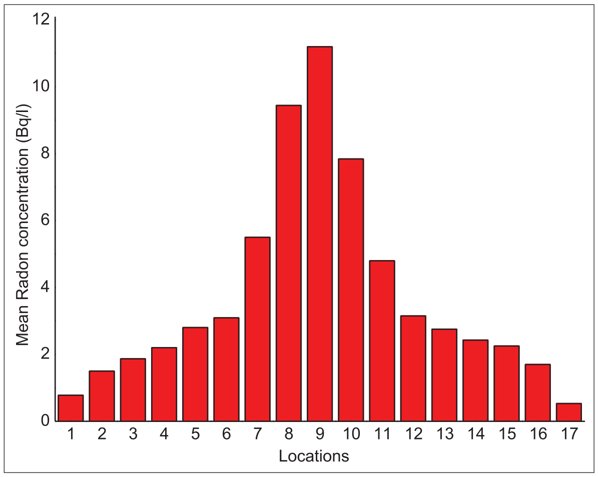

Figure 4: Mean radon concentration in water samples

Table 2: Comparison of radon concentration in groundwater with those reported by other researchers

Other regions of Punjab	Radon concentration in water (Bq/l)		References
	Range	Mean value	
Fazilka	01.40-04.90	03.68	[9]
Bathinda	00.90-05.10	02.63	[19]
Kapurthala	00.23-02.10	00.88	[20]
National Institute of Technology, Jalandhar	20.56-07.75	05.14	[21]
Ropar	00.45-04.83	02.48	[22]
Hoshiarpur	00.32-04.56	01.68	[22]
Gurdaspur	00.20-08.80	05.08	[23]
Pathankot	11.50-49.21	24.59	[16]
Amritsar	00.53-11.20	03.75	Present study

will be lognormal distribution. The measured values of annual effective dose per person were found to be well below the recommended limit of 100 μSvy^{-1} suggested by the WHO[33] and European council.[34] The results of the present investigation will be helpful in future for mapping the radon concentration in different regions of Punjab, India.

CONCLUSIONS

- The results of the radon concentration in drinking water samples in Amritsar area were below the safe limits recommended by the USEPA and UNSCEAR. The water of these locations is safe for the members of public
- The variation of radon concentration may be due to the depth of the water source, geological structure of the studied area, and may be correlated to varying uranium content in drinking water
- The value of average annual effective dose from ingestion of water and inhalation of water-borne radon was 0.79 μSvy^{-1} and 9.45 μSvy^{-1}, which is negligibly low - as normally expected for any radionuclide associated with internal hazard, the dose due to inhalation of radon is higher as compared to ingestion
- The estimated total annual effective dose also lies well within the safe limits as recommended by the WHO and European council.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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