Journal of Geoscience and Environment Protection, 2019, 7, 69-80
http://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

# Factors Influencing Radon ($^{222}$Ra) Levels of Water: An International Comparison

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**How to cite this paper:** Nagaraja, M., Sukumar, A., Dhanalakshmi, V., & Rajashekara, S. (2019). Factors Influencing Radon ($^{222}$Ra) Levels of Water: An International Comparison. *Journal of Geoscience and Environment Protection, 7,* 69-80.
https://doi.org/10.4236/gep.2019.75008

**Received:** April 12, 2019
**Accepted:** May 20, 2019
**Published:** May 23, 2019



## Abstract

Radon levels were measured in 59 water samples of rural and urban places of Bangalore city following procedures of standardized techniques. Though water level of radon above 100 Bqll$^{-1}$ of WHO is ascribed to causes of lung cancer and leukaemia, very low levels were found in different urban and rural places, but urban-rural gradient observed significantly higher urban levels than rural levels. Correlation between depth of water sampled and radon levels estimated indicates that in urban places, lower water depth is related to higher radon levels, while it is vice versa in rural. It is due to more water use for rural agriculture and more urban water pollution and granite quarries. In comparison to other countries, it is observed that water radon levels are at wide ranges from the lowest to the highest estimated with different techniques and differ due to types of water, soil, rocks and sampling season.

## Keywords

Water Radon, Status Comparison, Influencing Factors, Urban and Rural Exposure

## 1. Introduction

Radon, a radioactive alpha-particle-emitting gas, originates from the decay series of uranium and thorium, exists ubiquitously in soil, air and water and finally reaches lungs (Khan et al., 2010). It is known that the inhaled short-lived radon progeny, but not the radon gas, is one of the causal factors of lung cancer and leukaemia (International Commission on Radiation Units and Measurements, 2012). Among these two, radon gas status of lung doses could be determined, whereas its short-lived progeny could not be estimated directly (Gilfedder et al., 2012). Radon gas found in ground water is from natural source, mostly from geological origin and some extent from man-made source, like pollution. Measurement of radon ($^{222}$Rn) from ground water samples of specific region indicates probable source for the lung status whether it is within the admissible condition. The concentration of radon estimated in water samples of one region is compared with reported levels of other regions and also with recommended admissible levels of WHO for effective interpretation and suggestion for safety management.

Several factors, namely ground water temperature, depth, places, seasons, soil and rock types, etc. are found affecting radon gas concentration of water, and these factors are to be considered for monitoring of human exposure to radon gas and its health hazard prediction. The indoor radon ($^{222}$Rn) level that was found low ($33.4 \pm 6.1$ Bq·m$^{-3}$), indicated no significant exposure risk for the inhabitants of Bangalore city (Satish et al., 2010). In the present study, radon levels measured in the water samples from rural and urban places of Bangalore city, India were compared with other reported values for the importance of protection from radiation hazards and knowing various factors influencing the radon levels.

## 2. Materials and Methods

Radon, though existing in different forms, is mostly measured its level in water, particularly the $^{222}$Rn and RAD-$H_2O$ is the method used in the present study to measure the water levels of $^{222}$Rn sampled in and around Bangalore cities. Study area: Basaveshwar Nagar (12˚59'12"N 77˚32'19"E), Yeshwanthpura (13.0285˚N 77.546˚E), Electronic city (12.85˚N 77.67˚E) and Sulibele (13˚10'N 77˚48'E) were four places selected for water sampling and Sulibele is a village about 48 kms away from Bangalore city, while other three places considered as urban areas within the city limit.

### 2.1. Groundwater Sampling

Deep bore well water used for drinking, agriculture and industrial purposes were collected from randomly selected drilled tube wells of three urban areas of Bangalore city and one adjoining village about 48 kms away from the city. A total of 59 samples were collected from 3 urban areas (Basaveshwara nagar N = 18, Yeshwanthpura N = 13 and Electronic city N = 9) and one rural area (Sulibele N = 19). The correct locations of the tube wells from where sampled, were identified and recorded; further other parameters, such as depth of groundwater tube wells, time, date, etc. were also noted. The sampling of water was carried out from May to December 2014. The water samples (N 59) were collected personally by gently filling in 250 ml leak-proof and properly levelled plastic bottles specifically designed for study of radon activity in water, ensuring least radon loss during sampling, transport and storage period, following the guidelines reported by Stringer and Burnett (2004) and Dimova et al. (2009). The good quality sampling was assured by collecting after the tube well water was pumped for 10 minutes. Care was taken to avoid any air bubble inside the bottles by filling the water directly by overflowing and subsequently capping them under the water (Vitz, 1991).

## 2.2. Method of Analysis

The concentrations of Radon ($^{222}Rn$) in the tube well water were measured with use of a radon-in-air monitor, RAD-7 (Durridge Co. Ltd.) and RAD $H_2O$ technique of closed loop aeration concept (Lee & Kim, 2006; Lee & Burnett, 2013). In comparison to other methods of Gamma Spectroscopy, Lucas Cell and Liquid Scintillation (LS), the RAD $H_2O$ technique has several advantages, such as faster, more accurate, portable, less labour intensive, less expensive and less problem of need of elimination of noxious chemicals. The $\alpha$-particles released from $^{210}Po$ causes unnecessary background and interferes with measurement in most radon instruments, whereas the present instrument has been designed to measure these particles without its adverse side effect of interference. Desiccant is to be used regularly to get correct and reliable radon concentration and for longer durability of the instrument. Care should be taken to maintain relative humidity less than 6%, to avoid radon escape from water into atmosphere and to avoid water to enter into the instrument, RAD-7. While one Becquerel is equal to one radioactive disintegration per second, Becquerel per cubic metre ($Bql/m^3$) is the unit of Rn level of measurement, particularly as its level in the air. Water level of Rn may be very high, in the hundreds of thousands of Becquerel per cubic meter. Hence the Rn level is expressed in Becquerel per litre ($Bqll^{-1}$).

## 2.3. Radon Measurement with RAD-7

The 250 mL sample bottle was connected to the RAD-7 detector (Monitor) through aerator and the internal air pump of the radon-monitor was used to re-circulate a closed air-loop through the water sample, purging radon from water into air loop. The air was continuously re-circulated through the water to extract the radon until RAD-$H_2O$ system reaches a state of equilibrium within about 5 minutes, after which no more radon can be extracted from the water. After reaching equilibrium between water, air and radon progeny attached to the PIPS detector (Passivated implanted Planar Silicon detector), the radon activity concentration measured in the air loop was used for calculating the initial radon-in-water concentration of the respective sample. The RAD-7 allows determination of radon-in-air activity concentration by detecting the $\alpha$-decaying radon progreny $^{218}Po$ and $^{214}Po$ using PIPS detector. The radon monitor of RAD-7 uses high electric field above a silicon semi-conductor detected at ground potential to attract the positively changed polonium daughters, $^{218}Po$ and $^{214}Po$, which are counted as a measure of $^{222}Rn$ concentration in air. The pump will run for 5 minutes, aerating the sample and delivering the radon to the RAD-7 and then the system will count the radon and the concentration is recorded. Radon concentration is that of water determined by collecting radon gas through the energy specific windows, which eliminate interference and maintain very low backgrounds. Further, the parameters for water have been worked out following the guidelines suggested by others (Gruber et al., 2009; Jobbágy et al., 2017) and thus the radon measurement was standardized.

The concentrations of groundwater radon were given in mean values with Standard Error (SE) and student "t" was found for significance between the mean concentrations of urban and rural areas. The binominal distribution was plotted and Pearson correlation ("r" value) was used for the relationship between ground water depth and radon level.

## 3. Results and Discussion

### 3.1. Comparison of Radon Levels in Bangalore Cities

In **Tables 1-4**, are shown the groundwater radon levels and water depth of different sites selected respectively in Basaveshwara nagar (18 sites), Yeshwanthpura (13 sites), Electronic city (9 sites) and Sulibele (19 sites). **Table 5** and **Figure 1** show ranges and mean concentrations of groundwater radon for the 3 urban areas and 1 rural area, the significance between the mean concentrations of the urban and the rural areas and the mean water depth (feet) of these areas. The urban and rural areas' radon concentrations are lower than WHO's maximum admissible

**Table 1.** Radon levels and water sampling depth of different places of Basaveshwara Nagar (BSN, urban Bangalore).

| SN | Places of | Depth (Feet) | Radon ($Bqll^{-1}$) |
|---|---|---|---|
| 1 | Shivanalli | 300 | 46.20 |
| 2 | Shivanagar | 150 | 55.20 |
| 3 | Basaveshwanagar | 300 | 11.50 |
| 4 | Basaveshwarnagar | 300 | 47.20 |
| 5 | Basaveshwarnagar | 500 | 18.10 |
| 6 | Agraharadasarahalli | 700 | 38.20 |
| 7 | Vijayanagara | 450 | 11.80 |
| 8 | Vijayanagara | 450 | 70.30 |
| 9 | Vijayanagara | 400 | 83.10 |
| 10 | Vijayanagara | 500 | 22.60 |
| 11 | Marenahalli | 500 | 14.20 |
| 12 | Pushpanjalinagara | 400 | 28.10 |
| 13 | Moodalapalya | 500 | 11.00 |
| 14 | Ngarabhavi | 400 | 42.70 |
| 15 | Nagarabhavi II stage | 400 | 16.90 |
| 16 | Nagarabhavi II stage | 450 | 13.40 |
| 17 | Ambedkar college | 450 | 33.60 |
| 18 | Malathhalli | 100 | 44.80 |
| | Mean ± SE | 402.78 ± 32.5 | 33.83 ± 5.0 |

**Table 2.** Radon levels and water sampling depth of different places of Yeshwanthpura (YPR, urban Bangalore).

| SN | Place | Depth (Feet) | Radon ($Bql l^{-1}$) |
|---|---|---|---|
| 1 | Mathikere | 650 | 55.00 |
| 2 | Mathikere | 600 | 88.40 |
| 3 | MSR Nagar | 750 | 59.70 |
| 4 | MSR Nagar | 850 | 35.00 |
| 5 | Dollars Colony | 550 | 87.00 |
| 6 | Dollars Colony | 350 | 20.30 |
| 7 | Dollars Colony | 400 | 50.10 |
| 8 | RMC Yard | 550 | 16.80 |
| 9 | Krishnananda Nagar | 500 | 14.30 |
| 10 | Lakshmidevi Nagara | 400 | 5.28 |
| 11 | Sunkadda Katte (1) | 500 | 7.53 |
| 12 | Sunkadda katte (2) | 200 | 25.60 |
| 13 | Sunkadda Katte (3) | 120 | 43.50 |
| | Mean ± SE | 493.85 ± 56.6 | 39.12 ± 7.7 |

**Table 3.** Radon levels and water sampling depth of different places of Electronic City (EC, urban Bangalore).

| SN | Place | Depth (Feet) | Radon ($Bql l^{-1}$) |
|---|---|---|---|
| 1 | Yarandalli | 350 | 33.20 |
| 2 | Bommasandra | 300 | 30.50 |
| 3 | Bommasandra | 300 | 30.50 |
| 4 | Bommasandra | 650 | 21.50 |
| 5 | Thirupalya | 1000 | 25.10 |
| 6 | Thirupalya | 1200 | 69.60 |
| 7 | Bommasandra | 1280 | 72.40 |
| 8 | Adugodi | 300 | 11.70 |
| 9 | Jigani | 350 | 57.30 |
| | Mean ± SE | 636.67 ± 137.8 | 39.09 ± 7.3 |

**Table 4.** Radon levels and water sampling depth of different places of Sulibele (Bangalore rural).

| SN | Place | Depth (Feet) | Radon ($Bql l^{-1}$) |
|---|---|---|---|
| 1 | Rajapura | 1000 | 32.40 |
| 2 | Yarandalli | 300 | 48.00 |
| 3 | Yarandalli | 730 | 32.90 |
| 4 | Yarandalli | 350 | 52.10 |
| 5 | Arasanahalli | 1050 | 46.60 |
| 6 | Siddanahalli | 190 | 28.10 |

**Continued**

| | | | |
|---|---|---|---|
| 7 | Siddanahalli | 550 | 29.50 |
| 8 | Sulibele | 480 | 32.10 |
| 9 | Sulibele | 620 | 15.40 |
| 10 | Rampura | 330 | 34.80 |
| 11 | Sulibele | 300 | 34.10 |
| 12 | Rampura | 1300 | 3.05 |
| 13 | Rampura | 900 | 25.20 |
| 14 | Rampura | 800 | 14.40 |
| 15 | Rampura | 950 | 5.49 |
| 16 | Arasanahalli | 350 | 23.40 |
| 17 | Arasanahalli | 300 | 15.70 |
| 18 | Arasanahalli | 1200 | 4.88 |
| 19 | Arasanahalli | 200 | 28.90 |
| | Mean ± SE | 626.32 ± 81.7 | 26.69 ± 3.3 |

**Table 5.** Comparison of radon levels of groundwater between urban and rural places of Bangalore city.

| SN | Place | N | Ranges ($Bqll^{-1}$) | Depth (Feet) | Mean ± SE $Bqll^{-1}$ | "r" Values | Effective dose Sv $Bqll^{-1}$ |
|---|---|---|---|---|---|---|---|
| 1 | Basaveshw-ara Nagar (urban) | 18 | 11.5 to 83.0 | 402.78 ± 32.5 | 33.83 ±5.0* | −0.3 | 169.15 |
| 2 | Yeshwan-pura (urban) | 13 | 5.28 to 88.40 | 493.85 ± 56.6 | 39.12 ± 7.7* | 0.29 | 195.6 |
| 3 | Electronic city (urban) | 09 | 11.70 to 72.40 | 636.67 ± 137.8 | 39.09 ± 7.3** | 0.42 | 202.0 |
| 4 | Sulibele (rural) | 19 | 3.05 to 52.10 | 626.32 ± 81.7 | 26.69 ± 3.3 | 0.48 | 116.9 |

Note: significance between Rural vs. urban; * = $P < 0.05$, ** = $p < 0.01$.

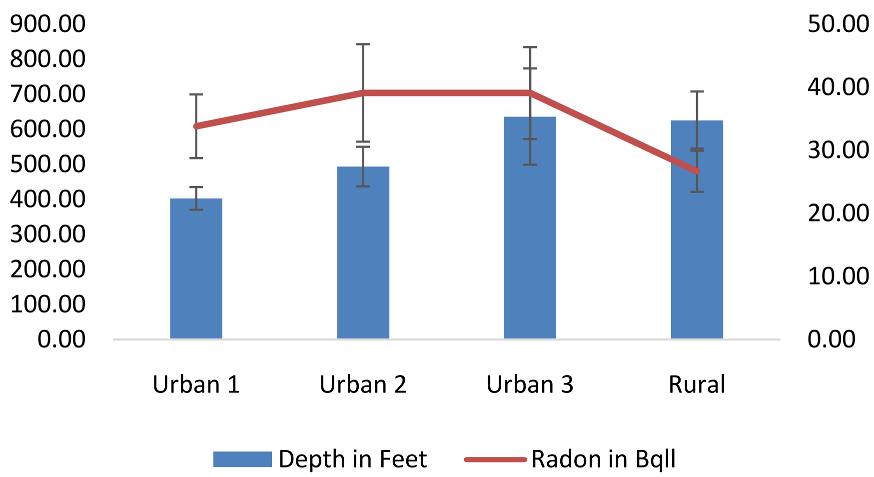


**Figure 1.** Bar diagram showing mean levels of radon and depth of water sampled in 59 places (rural and urban areas) of Bangalore city.

levels of 100 Bql$l^{-1}$, particularly 1/3 is lower. When compared between them, urban areas show significantly higher (Basaveshwara nagar and Yeshwanthpura at $P < 0.05$ level, Electronic city at $p < 0.01$) concentrations than rural area (**Figure 1**). Such variation is ascribed to differences in granite industries, quarries and urban pollution which are further related to most of the open wells/bore-wells being polluted due to sewage discharged into the river.

### 3.2. Comparison with International Status

The radon concentrations found in different water samples of places from different countries show wide ranges (**Table 6**). Kam and Bozkurt (2007) reported

**Table 6.** comparison of water levels of Radon ($^{222}Rn$) from the places of different countries.

| SN | Place | Water type | Ranges | Mean Level | Remarks | References |
|---|---|---|---|---|---|---|
| 1 | Mining area of băiţa-Ştei, Bihor, Romania | Well water, | - | 35.5 kbq·M(−3) | Within the WHO'S values | Moldovan et al. (2014) |
| | | Spring water | | 18.5 kbq·m(−3) | | |
| | | Tap water | | 6.9 kbq·m(−3) | | |
| 2 | City of Sakarya, Turkey | Well water | 1.98 to 20.80 Bq·L(−1) | 9.05 Bq·l(−1) | Within the WHO'S values | Yakut et al. (2013) |
| | | Spring water | 0.75 to 59.65 Bq·l(−1) | 13.78 Bq l(−1) | | |
| | | Bottled water | 0.75 to 22.8 Bq·l(−1) | 5.41 Bq·l(−1) | | |
| 3 | City Of Riyadh, Saudi Arabia | Deep wells | 0.34 ± 0.05 to 3.52 ± 0.30 Bq·l(−1) | 1.01±0.10 Bq·l(−1) | The levels were within the city Of Riyadh in Saudi Arabia | Aleissa et al. (2013) |
| | | Shallow wells | 0.72 ± 0.08 to 7.21 ± 0.58 Bq·l(−1) | 2.74 ± 0.24 Bq·L(−1) | | |
| 4 | Fault zone of Balakot & Mansehra, Pakistan | All types of water | 4.99 to 24.52 kbq/m(3) | 15.52 kbq/m(3) | | Khan et al. (2010) |
| 5 | Eastern São Paulo State, Brazil | One well | - | 374 Bq/dm(3) | Different between two wells | Lucas Fde et al. (2009) |
| | | Another well | | 1275 Bq/dm(3) | | |
| 6 | Tbilisi, Georgia | Tap water | 3 - 5 Bq·L(−1) | - | | Pagava et al. (2008) |
| | | Thermal water boreholes | 5 - 19 Bq·L(−1) | - | | |
| 7 | Zgierz, Ozorków, Stryków and Głowno (cities of Poland) | Deep well water | 1 kbq/m$^3$ to 13 kbq/m$^3$ | - | | Kluszczyński et al. (2006) |
| 8 | Ramsar, Iran | Drinking water | - | Greater than 10 kbq/m(3) | Within normal values | Mowlavi et al. (2009) |
| 9 | Kastamonu, Turkey | Water | - | 0.0089 Bq/l | Within the natural limits | Kam & Bozkurt (2007) |
| 10 | Busan, South Korea | Ground water | 0 to about 300 Bq·l(−1). | - | Highest and lowest in different places | Cho et al. (2004) |
| 11 | Migdonia basin, Greece | Drining water | Upto 170 Bq × L(−1) | - | The level of 50 Bq × L(−1) is exceeded in 23% of water supplies | Savidou et al. (2001) |
| 12 | Kenya | Ground water | 0.8 +/− 0.5 to 371.7 +/− 33.5 Bq·L(−1) | - | | Otwoma & Mustapha (1998) |

Note: World Health Organization recommended level of 100 Bq·l$l^{-1}$ for radon.

very lowest level (0.0089 $Bqll^{-1}$) of radon in the water samples of Kastamonu, Turkey, whereas minimum levels below WHO level were reported in majority of places namely, Mining area of băiţa-Ştei, Bihor (Romania), Sakarya city (Turkey), Riyadh City (Saudi Arabia), Fault zone of Balakot & Mansehra (Pakistan) and Tbilisi (Georgia). Moreover, a wide range of radon concentrations were also reported in other places namely, Busan (South Korea), Migdonia basin (Greece) and Kenya. The radon levels found in 3 urban and 1 rural places of Bangalore city were in the category of minimum status. When our results reveal that there is no significant public health risk from radon ingested and inhalation with drinking water in the study region, similar status was reported in the subjects from Southern Part of West Bank - Palestine, by Thabayneh (2015).

### 3.3. Influencing Factors

In our study, radon levels were higher in urban ground water than rural ground water, and such difference may be due to variation not only in lithology, structural attributes, presence of radium/uranium in rocks (Somashekar & Ravikumar, 2010), but also in source, type and exposure gradient of pollution existing between urban and rural places. Similarly, Erdogan et al. (2017) revealed that radon concentration measured in the spring water of the town of Seydişehir, Turkey showed variation due to local geological conditions (i.e. faults) and human activities. Kávási et al. (2011) estimated from the consumption of water containing radon effective doses that were 0.05 mSv·y(−1) and 0.14 mSv·y(−1) respectively for tap and spring waters. Cho et al. (2004) observed that the radon concentrations of deep bore well water of Busan, Sout Korea are highly dependent on the type of geological rock aquifers and also regional difference in the water levels of radon i.e. highest in Sasang ward and lowest in Jung ward. Elevated water level of Rn found at the western part of the Lake Volvi (Migdonia basin in Northern Greece), due probably to the local intense tectonism (Savidou et al., 2001). Lucas Fde et al. (2009) found seasonal variation in groundwater drawn from two wells drilled on metamorphic rocks exposed at Eastern São Paulo State, Brazil and also high differences between two well water concentrations, 374 Bq/dm(3) in one well and about 1275 Bq/dm(3) in the other one.

In the present study, water depth was associated with the radon levels; significantly in the urban places the lower the depth, higher the water radon was observed, while higher the depth, lower the radon level was observed. **Figure 2** of binominal distribution of radon and water depth shows that irrespective of places, the radon accumulation 10 - 40 $Bqll^{-1}$ at the depth of 200 to 600 feet. Aleissa et al. (2013) found that $^{222}Rn$ concentrations were higher in shallow (300 m depth) well water (average: 2.74 ± 0.24 $Bqll^{-1}$) than that of deep (1000 m depth) well water (average: 1.01 ± 0.10 $Bqll^{-1}$).

Khan et al. (2010) indicated that the nature of water does not matter with regard to the presence of radon, however, the level of radon concentration varies in different types of water. In the tap waters of Klodzka valley in the Sudety

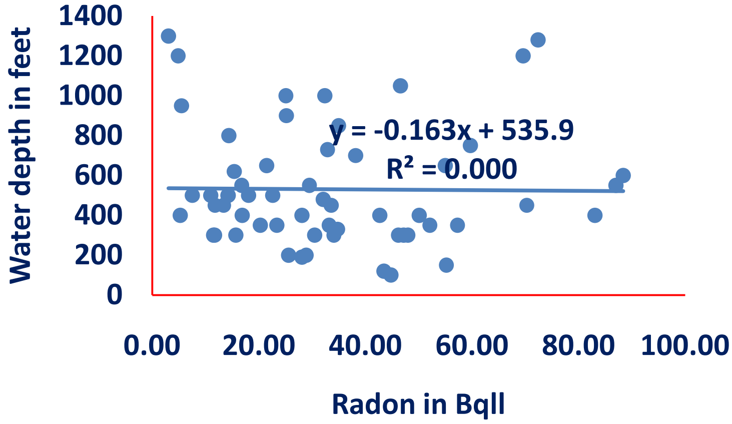


**Figure 2.** A scattered diagram showing the binominal distribution of the radon levels and depth of water sampled in 59 places of Bangalore city.

mountains in Poland, the radon concentration is very low or below the lower limit of detection, whereas concentration higher than 74 Bq/l was found in the spring water (Kozlowska et al., 1999).

Further, measurement techniques are important because of radon concentrations being used for international comparison, effective management of control measures and health prediction. Though standardized methods are made available (Jobbágy et al., 2017), the values detected may vary from one place to another one. Hence, Kelleher et al. (2017) pointed out that such inter-laboratory variation in sampling and analytical techniques could be minimized and controlled through participation in the inter-laboratory quality control programmes for water radon analysis. Eikenberg et al. (2014) suggested that consistency of measurement could be achieved by checking interference caused by radon progeny like $^{228}$Ra.

Epidemiological studies have shown a clear link between breathing high concentrations of indoor radon and water levels of radon. According to the United States Environmental Protection Agency, radon is the second most frequent cause of lung cancer, after cigarette smoking, but it is the number one cause among non-smokers. In a study, radon level was 21% higher in indoor air of building when well water used (Casey et al., 2015). Uzun and Demiröz (2016) opined that since the source of the radon gas is the radium content of the earth crust, water coming from ground may contain dissolved radon and the radon can diffuse from water to air. By finding radon transfer velocity coefficient from water-air interface, Ongori et al. (2015) indicated that there is possibility of escape from water to air that justifies the use of radon in water measurements. Calmet et al. (2011) found out that people may be exposed to radon from water as it degasses from water during handling. Lawrence et al. (1992) revealed that in many of the houses, the water supply was shown to contribute significantly to levels of indoor $^{222}$Rn. Hence, further studies are required to understand other routes of entry of radon from water to air, to biomonitor exposure status and to find out ways and means avoid public exposure to water source of radon.

## 4. Conclusion

It has been revealed from epidemiological findings that radon exposure to the level above 100 Bqll$^{-1}$ is associated with incidence of lung cancer and leukaemia and water level of radon is one of the sources of exposure being assessed throughout the world. There are several causal factors for the high levels of radon in groundwater that may be natural as well as man-made pollution. When higher levels of radon were found in groundwater of urban places than rural place adjoining Bangalore city, both natural condition and pollution are ascribed to such hike. Further studies are required about radon status in bioindicators that will substantiate the relationship between radon and cancer.

## Acknowledgements

The authors thank sincerely the Principal, RIE, Mysore and the Director, NCERT, New Delhi for their moral support.

## Conflicts of Interest

The authors declare that they have no conflict of interest.

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