Analysis of radon in shallow-well water: a case study at Phichit subdistrict in Songkhla province, Thailand

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Abstract. Radon levels were measured in shallow-well water samples collected from Phichit subdistrict in Songkhla province, Thailand. A total of 35 water samples from shallow-wells were collected and measured for the radon concentration. The measurements were performed using a RAD7 portable radon detector. The radon concentrations varied from 0.18 ± 0.07 to 98.1 ± 5.92 Bq/L with a mean value of 16.76 ± 2.33 Bq/L. These recorded values were compared with the safe limit values recommended for drinking water by various health and environmental protection agencies. Thirty-four percent of the recorded values were within the safe limit of 11 Bq/L recommended by the US Environmental Protection Agency. The annual effective dose from ingestion and inhalation of radon was also evaluated. The estimated total effective dose varied from 0.48 to 262.91 µSv/year. The total effective dose in most of the samples (~90%) in this study was within the safe limit (0.1 mSv/year) recommended by the World Health Organization (WHO) and the European Council.

1. Introduction
Radon gas and its radioactive isotopes receive special attention among all other naturally occurring radioactive materials because they contribute the largest amount of total annual effective dose to humans [1]. The most important aspect of high radon concentrations is its hazard on human health as it is a cause of lung cancer [2-4]. Moreover, a very high radon concentration in drinking water can also lead to a significant risk of the stomach and gastrointestinal cancer [5, 6]. Knowledge of the levels of radon in each source including household water, particularly water from ground sources is necessary to protect the public from consequences of excessive exposure to radiations. Radon in water has been measured in many parts of the world due to the risk of radiation exposure from drinking water [7-11].

Most of radon in buildings comes directly from soil that is in contact with or beneath the basement or foundation. Radon is also found in groundwater and will enter a home whenever this water is used. In many situations such as showering, washing clothes and flushing toilets, radon can be released from the water and then mixed with the indoor air. Thus, radon from water contributes to the total inhalation risk associated with radon in indoor air. In addition to this, drinking water contains dissolved radon, and the radiation emitted by radon and its radioactive decay products can expose sensitive cells in the stomach as well as other organs to radiation-induced damage once they are absorbed into the bloodstream.

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Even though, radon is often being discussed as a threat to human health, it shall also be mentioned here that it can be used as an ideal tracer for a considerable variety of applications in the fields of environmental geology and hydrogeology. For instance, radon, which is a noble gas, has a strong affinity to non-aqueous phase liquids (NAPLs). This property makes it applicable as naturally occurring partitioning tracer for assessing residual NAPL contamination of aquifers [12]. Due to the distinct water/air partitioning behavior of radon and its straightforward on-site detectability, the radon distribution pattern in the groundwater can be used as an appropriate measurement for assessing the progression of an in situ air sparging (IAS) measurement as a function of space and time [13].

From the result of a survey at Moo 3, Phichit subdistrict, Na Mom district, Songkhla province, people in this area still used the shallow-well water for consumption. Hence, it was reasonable to investigate the radon levels in the shallow-well water being used for drinking. The purpose of this study was to investigate the radon levels in shallow-well water from the chosen villages and towns in Phichit subdistrict, which was used for drinking purpose and to determine its health hazards.

2. Materials and methods

2.1. Description of the area

Shallow wells in Moo 3, Phichit subdistrict, Na Mom district, Songkhla province, were chosen for this research. This study area was located on the eastern side of the southern part of Thailand (latitude 6.992476 north and longitude 100°01′-101°06′ east). The altitude was approximately 4 meters above sea level. Its area was approximately 40.5 square kilometers or 25 - 312.5 Rai. The study area is surrounded by steep and tall mountains with the center flat plain used for planting rice, rubber and fruit trees. The geology of the study area consisted of granite with its conversion as shown in figure 1 [14]. The influence of gas and hot solution was determined by detecting feldspar's conversion to mineral kaolin granite; the metal elements in rocks would be eroded and dissolved in the soil and groundwater easily [14].

![Figure 3. Map of the study area in Phichit subdistrict, Songkhla province [14].](image_url)

2.2. Sample collection and measurements of radon activity concentration

A total of 35 water samples from Moo 3, Phichit subdistrict, were collected and measured for radon concentration. Shallow-well water was used by the residents in this area for consumption without prior treatment. The RAD7 portable radon detector (Durridge Company Inc.) was used in this study for the radon concentration measurement. The schematic diagram of RAD7 H2O assembly is shown in figure 2. [15] The water samples were taken in 250-ml vials designed for the RAD7 device and provided by the manufacturer. During the sampling period the weather condition should be fairly stable. The water was hand pumped for 5-10 min prior to sample collection. The water sampling was quite complicated because the radon gas is easily escaped from water. The sampling has to be done without any aeration which might lead to outgassing. Hence, the water samples should be collected in such a way that no bubbling. In this research, water sample was measured simultaneously at the sampling site after collection. The time difference between taking the sample and measuring was only few minutes; hence
no decay of radon occurred in the water samples. For accurate readings, the RAD7 has been dried out thoroughly to reduce the relative humidity to below 10% before making each measurement.

![Schematic diagram of RAD7-H$_2$O assembly](image)

**Figure 2.** The schematic diagram of RAD7-H$_2$O assembly [15].

RAD7-H$_2$O is an addition to RAD7 that enables measurements of radon in water over a concentration range from less than 0.37 Bq/L up to $0.15 \times 10^5$ Bq/L. The operation of this instrument is based on the following principles: (1) radon is expelled from water sample by using a bubbling kit, (2) expelled radon enters a hemisphere chamber by air circulation, (3) polonium decayed from radon is collected onto a silicon solid state detector by an electric field, and (4) radon concentration is estimated from the count rate of polonium. RAD7-H$_2$O gives results within 30 min after measuring with a sensitivity that matches or exceeds that of the liquid scintillation method. The RAD7-H$_2$O method employs a closed loop aeration scheme whereby the air volume and water volume are constant and independent of the flow rate. The air that recirculates through the water continuously extracts the dissolved radon until a state of equilibrium develops. The RAD7-H$_2$O system reaches this state of equilibrium within about 5 min, after which no more radon can be extracted from the water.

The extraction efficiency or percentage of radon removed from the water to the air loop is very high about 94% for a 250 mL sample. The exact value of the extraction efficiency depends somewhat on ambient temperature, but it is almost always well above 90%. The RAD7 detector converts alpha radiation directly to an electric signal. RAD7 has the ability to tell the difference between the new radon daughters and the old radon daughters left from previous tests [15].

### 2.3 Evaluation of mean annual effective dose

Radon enters human body through ingestion and through inhalation as radon is released from water to indoor air. Therefore, radon in water is a source of radiation dose to both stomach and lungs. The annual effective dose for ingestion and inhalation were calculated according to parameters introduced by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) report [16].

For ingestion, the following parameters were used:
- The effective dose coefficient from ingestion of radon is 3.5 nSv/Bq [16];
- Annual intakes by infants, children and adults are 100, 75 and 50 L, respectively;
- The annual effective doses from ingestion corresponding to 1 Bq/L are 0.35 μSv/year for infants, 0.26 μSv/year for children, and 0.18 μSv/year for adults.

For inhalation, the following parameters were used:
- Ratio of radon in air to radon in tap water supply is $10^{-4}$ Bq/m$^3$;
- Average indoor occupancy time per person is 7000 h/year;
- Equilibrium factor between radon and its progeny is 0.4;
- Dose conversion factor for radon exposure is 9 nSv/Bq/h/m$^3$, and
The annual effective dose from inhalation corresponding to the concentration of 1 Bq/L in tap water is 2.5 μSv/year. 

The World Health Organization (WHO) [17] and European (EU) Council [18] recommended 0.1 mSv/year annual effective dose from drinking water as the safe limit of the three radioisotopes: $^{222}$Rn, $^3$H and $^{40}$K.

3. Results and discussion

The results of radon measurements in shallow-well water from Phichit subdistrict are shown in table 1. The radon concentration in the samples ranged from 0.18± 0.07 to 98.1± 5.92 Bq/L with a mean value of 16.7 ± 2.33 Bq/L. Many health and environmental protection agencies recommended a safe limit of radon in drinking water for human beings. The US Environment Protection Agency proposed the allowed maximum contamination level for radon concentration in water to be 11 Bq/L [19]. UNSCEAR suggested a value of radon concentration in water for human consumption between 4 and 40 Bq/L [1]. These levels represented the concentrations that would not pose any significant risk to human health from drinking water over a lifetime. The recorded values of radon concentration in the shallow-well water were within the safe limit recommended by US Environmental Protection Agency [19] and UNSCEAR [1]. All measured radon activity concentrations in samples were well below the European Commission recommended reference level for radon in drinking water of 100 Bq/L [20].

From Table 1, the annual effective doses from ingestion and inhalation of radon were calculated according to the parameters introduced by UNSCEAR (2000) report [16]. The range of annual effective doses from ingestion and inhalation of radon were 0.03 - 17.66 and 0.45 - 245.25 μSv/year, respectively. The estimated total annual effective dose due to ingestion and inhalation ranged from 0.48 to 262.91 μSv/year. The World Health Organization [17] and EU Council [17] recommended 0.1 mSv/year annual effective dose from drinking water as the safe limit for three radioisotopes: $^{222}$Rn, $^3$H and $^{40}$K. Hence, the total annual effective dose in most water samples (~90%) of this study was within the safe limit.

4. Conclusions

In this paper, the results of the radon measurements in 35 shallow-well water samples collected from Phichit district in Songkhla province were presented. The measurements were performed by using a RAD7 electronic radon detector. The majority of the shallow-well water samples were within the internationally recommended safe limit and therefore it was safe for drinking purposes. The total effective dose in most samples in this study were also within the safe limit (0.1 mSv/year) recommended by WHO and EU Council. There was no significant radiological risk due to radon ingestion for the residents in this area.
Table 1. Results of radon measurements in Shallow-well water

| Sample No. | Radon Concentration in shallow-well water (Bq/L) | Temperature (°C) | Annual effective dose (μSv/year) |
|------------|-------------------------------------------------|-----------------|----------------------------------|
|            | Minimum                                         | Maximum         | Mean    | SD      | Ingestion | Inhalation | Total    |
| 1          | 3.93                                            | 6.73            | 5.52    | 1.17    | 25.5      | 0.99       | 13.80    | 14.79    |
| 2          | 6.47                                            | 8.13            | 7.35    | 0.70    | 25.5      | 1.32       | 18.37    | 19.69    |
| 3          | 8.82                                            | 9.70            | 9.19    | 0.39    | 25.2      | 1.65       | 22.97    | 24.62    |
| 4          | 23.30                                           | 26.90           | 24.70   | 1.73    | 24.3      | 4.45       | 61.75    | 66.20    |
| 5          | 0.29                                            | 0.73            | 0.51    | 0.19    | 23.4      | 0.09       | 1.27     | 1.36     |
| 6          | 77.80                                           | 96.30           | 89.00   | 8.11    | 24.0      | 16.02      | 222.5    | 238.52   |
| 7          | 90.10                                           | 104.00          | 98.10   | 5.92    | 24.3      | 17.66      | 245.25   | 262.91   |
| 8          | 23.60                                           | 32.30           | 29.00   | 3.78    | 24.5      | 5.22       | 72.50    | 77.72    |
| 9          | 5.91                                            | 8.28            | 7.02    | 1.08    | 24.6      | 1.26       | 17.55    | 18.81    |
| 10         | 9.41                                            | 11.50           | 10.40   | 0.88    | 24.3      | 1.87       | 26.00    | 27.87    |
| 11         | 11.50                                           | 16.60           | 13.60   | 2.13    | 24.3      | 2.44       | 34.00    | 36.44    |
| 12         | 6.43                                            | 8.09            | 7.27    | 0.68    | 24.3      | 1.30       | 18.17    | 19.47    |
| 13         | 5.59                                            | 7.94            | 6.65    | 1.18    | 24.6      | 1.20       | 16.62    | 18.82    |
| 14         | 55.90                                           | 68.20           | 59.90   | 5.61    | 25.6      | 10.78      | 149.75   | 160.53   |
| 15         | 3.86                                            | 5.65            | 4.56    | 0.78    | 24.0      | 0.82       | 11.40    | 12.22    |
| 16         | 10.60                                           | 15.20           | 12.60   | 1.95    | 24.0      | 2.27       | 31.50    | 33.77    |
| 17         | 86.20                                           | 93.00           | 90.70   | 3.03    | 24.2      | 16.32      | 226.75   | 243.07   |
| 18         | 27.20                                           | 30.10           | 28.70   | 1.25    | 24.8      | 5.17       | 71.75    | 76.92    |
| 19         | 13.80                                           | 18.80           | 16.70   | 2.33    | 27.4      | 3.00       | 41.75    | 44.75    |
| 20         | 2.42                                            | 2.86            | 2.61    | 0.18    | 33.8      | 0.47       | 6.52     | 6.99     |
| 21         | 14.70                                           | 16.70           | 15.60   | 0.83    | 33.5      | 2.80       | 39.00    | 41.80    |
| 22         | 1.14                                            | 1.57            | 1.39    | 0.18    | 32.8      | 0.25       | 3.47     | 3.72     |
| 23         | 2.00                                            | 3.37            | 2.75    | 0.82    | 36.2      | 0.50       | 6.87     | 7.37     |
| 24         | 1.29                                            | 1.86            | 1.61    | 0.24    | 34.1      | 0.29       | 4.02     | 4.31     |
| 25         | 7.87                                            | 11.30           | 9.82    | 1.43    | 35.9      | 1.77       | 24.55    | 26.32    |
| 26         | 1.86                                            | 3.13            | 2.64    | 0.55    | 33.2      | 0.47       | 6.60     | 7.07     |
| 27         | 1.14                                            | 2.29            | 1.57    | 0.55    | 37.4      | 0.28       | 3.92     | 4.20     |
| 28         | 0.86                                            | 2.43            | 1.50    | 0.68    | 32.8      | 0.27       | 3.75     | 4.02     |
| 29         | 3.15                                            | 5.43            | 4.32    | 0.98    | 34.1      | 0.78       | 10.80    | 11.58    |
| 30         | 0.43                                            | 1.29            | 0.79    | 0.38    | 33.5      | 0.14       | 1.97     | 2.11     |
| 31         | 0.14                                            | 0.29            | 0.18    | 0.07    | 34.7      | 0.03       | 0.45     | 0.48     |
| 32         | 0.57                                            | 2.00            | 1.11    | 0.62    | 36.2      | 0.20       | 2.77     | 2.97     |
| 33         | 1.00                                            | 3.29            | 1.93    | 1.07    | 34.4      | 0.34       | 4.82     | 5.16     |
| 34         | 4.43                                            | 5.58            | 5.21    | 0.53    | 33.2      | 0.93       | 13.02    | 13.95    |
| 35         | 11.20                                           | 12.8            | 12.10   | 0.74    | 37.1      | 2.18       | 30.25    | 32.43    |

SD—Standard deviation

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