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Monitoring of Radon-222 Concentration in Surface Waters of the Ban Phai Subwatershed Northeast Thailand Using a Method to Concentrate Radon by Air-circulation

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Abstract

Radon-222 (^{222}Rn) concentration in surface water is a useful indicator for groundwater seepage. However, the natural concentration of ^{222}Rn in surface water is too low to measure. It is therefore necessary to concentrate ^{222}Rn content in water samples before analysis. This is a difficult operation requiring specialized equipment. We developed a method of measurement of ^{222}Rn concentration in surface water (a method to concentrate radon by air-circulation) and applied it to detect groundwater seepage in the Ban Phai subwatershed, northeast Thailand. We also measured electric conductivity to determine whether dissolved ions in water were brought by groundwater. In areas of high-elevation (>180 m above sea level), ^{222}Rn concentration in surface water was low, indicating that the velocity of subsurface water flow was slow even in the rainy season. This result supported a flow velocity previously calculated from the permeability of surface soil and the hydraulic gradient. Our measurements of ^{222}Rn concentrations revealed that groundwater can be obtained by digging to a depth of about 1 m in the river bed in some areas. In areas of low-elevation (<160 m above sea level), electric conductivity increased markedly in the dry season. This was attributed to evaporation, rather than the effect of groundwater seepage, because the ^{222}Rn concentration was low, suggesting little influence of groundwater.

Discipline: Agricultural engineering
Additional key words: electric conductivity, evaporation, groundwater seepage

Introduction

Radon-222 (^{222}Rn) is a water-soluble radioactive gas generated underground by the decay of Radium-226 (^{226}Ra). ^{222}Rn concentration in groundwater, therefore, is much higher than that in surface water. When the component of groundwater in surface water is large, the ^{222}Rn concentration in the surface water increases. The measurement of ^{222}Rn concentration in water can therefore be used to identify groundwater seepage into surface water[2,3,5,6,13,15]. However, because the ^{222}Rn concentration in surface water is too low to measure, it is necessary to concentrate ^{222}Rn content in water samples. This is a difficult operation requiring specialized apparatus[1,12]. In this study, we applied a method for the measurement of ^{222}Rn concentration in surface water that we had previously developed[7] (a method to concentrate radon by air-circulation) to the Ban Phai subwatershed of northeast Thailand. The aim of our study was to monitor ^{222}Rn concentrations in surface water and to use these data to identify groundwater seepage into that surface water. We also measured electric conductivity to evaluate the degree of salinization and, thus, determined whether the dissolved ions were brought by groundwater.

Materials and methods

1. Study area

We selected the Ban Phai subwatershed, which is about 40 km south of Khon Kaen, as our study area. The elevation of this area decreases toward the west. The annual rainfall is about 1,000 mm, and the rainy season is from May to October. Loamy Sand (LS) is present from the surface to a depth of about 1 m, and Sandy Clay (SC) from about 1 to 4 m depth. Below the SC layer there is

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weathered sandstone to a depth of about 30 m, which contains groundwater that is confined by the overlying SC layer[9]. Groundwater is recharged in high-elevation areas (>180 m above sea level) and discharged in low-elevation areas (<180 m)[16]. There are salt-rich layers at depths of several tens of meters to several hundreds of meters[11]. When groundwater has passed through these layers and reaches the surface in a discharge area, the surface water becomes more saline in that area[10].

2. Field investigation

Field investigations were conducted monthly, from August 2005 to July 2006 to identify the annual variation of ^{222}Rn concentration in surface water. The total rainfall during the period of our investigation was about 700 mm (Fig. 1), which was lower than usual (about 1,000 mm annually), implying that the amount of surface water would be lower than usual in the dry season. The locations of the water sampling sites are shown in Fig. 2. Locations 1 and 2 are ponds (>180 m above sea level), locations 3–5 are streams (160–180 m), location 7 is a stream (<160 m), locations 6 and 9 are lakes (<160 m), and location 8 is a pond (<160 m). We collected water samples from close to the shores at all locations. In the field, we measured water temperature and electric conductivity using a portable EC meter (Yokogawa SC 82).

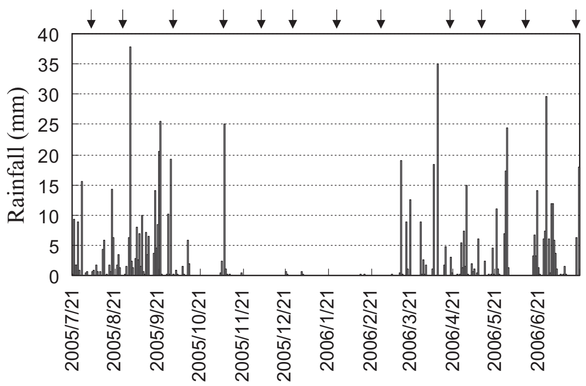

Fig. 1. Daily rainfall near location 3 (shown in Fig. 2) during the period of our investigation

Total rainfall was about 700 mm. Arrows show the dates when samples were collected.

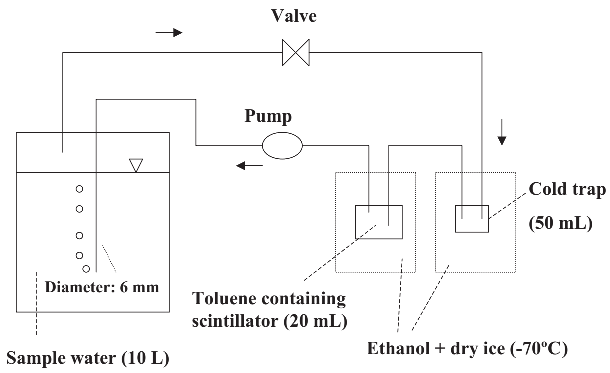

Fig. 3. Apparatus for concentrating ^{222}Rn in water sample[7]

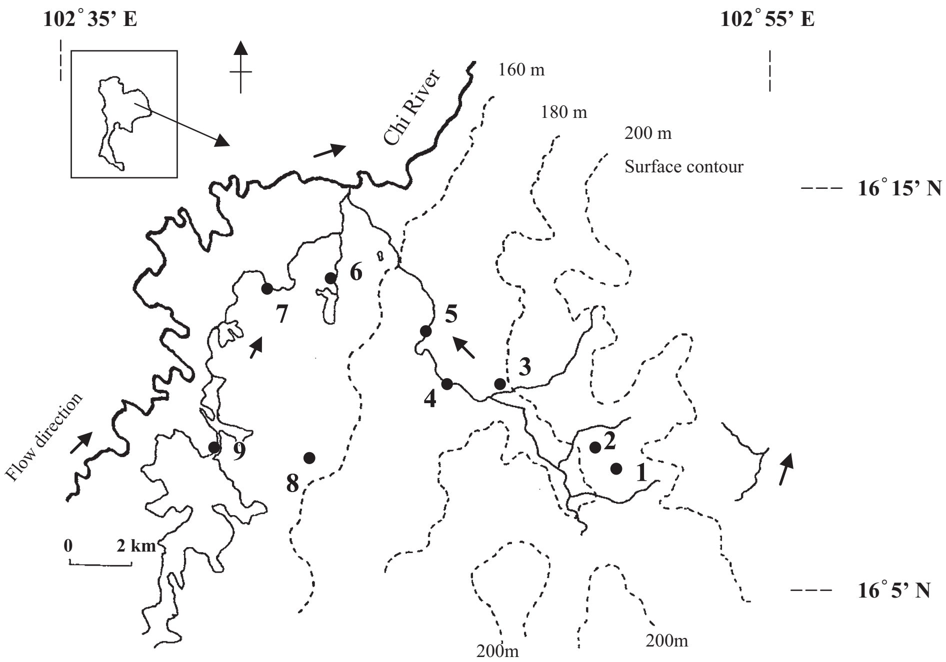

Fig. 2. Location of water sampling sites

3. Measurement of ^{222}Rn concentration

We concentrated the ^{222}Rn content of water samples in toluene with scintillators (4.0 g/L of PPO and 0.1 g/L of POPOP) cooled in an ethanol-dry ice bath by forced-air circulation (Fig. 3)[7]. The duration of air circulation was 60 min and was decided on by taking into consideration the collection rate and the efficiency of the operation. The collection rate of ^{222}Rn (C_R) is given by the following equations[8,14]

$$C_R = A \times \frac{D_t V_t}{D_t V_t + D_w V_w + D_a V_a} \tag{1}$$

$$D_w = \frac{9.12}{17 + T} \tag{2}$$

where

A = correction coefficient (0.34 in the case of the apparatus shown in Fig. 3);

D_t = solubility coefficient of ^{222}Rn for cooled toluene (200 at about –70ºC);

V_t = volume of toluene (20 mL);

D_w = solubility coefficient of ^{222}Rn for water;

V_w = volume of water (10 L);

D_a = solubility of air (=1);

V_a = volume of air (1,200 mL);

T = water temperature (ºC).

After the ^{222}Rn was concentrated, we measured alpha rays from ^{222}Rn and its progeny with a liquid scintillation counter (Hidex Triathler). The counting time was 70 min. The background of alpha rays is much less than that of alpha and beta rays, indicating that the detection limit can be lowered. The detection limit of this method is about 1 mBq/L.

Results and discussion

1. Range of ^{222}Rn concentration in Ban Phai subwatershed

The range of ^{222}Rn concentrations observed in surface water was very large, from 6 to 587 mBq/L (Table 1). Hamada et al. (2005) reported ^{222}Rn concentrations in surface water were 8–278 mBq/L in February, 2004 and July, 2005 in the same region[8]. The result of our monitoring for one year was nearly the same as the previous research.

2. ^{222}Rn concentration in high-elevation area

For locations 1 and 2, the ponds in high-elevation areas, ^{222}Rn concentrations were low, from 15 to 68 mBq/L, indicating that the amount of subsurface flow into the ponds was very little even in the rainy season. The permeability of the surface soil above 1 m depth (LS) is on the order of 10^{-4} cm/s and the gradient of the surface of the clay layer below 1 m depth (SC, permeability is on the order of 10^{-6} cm/s) is about 1/100. The velocity of subsurface water flow in the LS layer was previously calculated to be on the order of 10^{-6} cm/s[9]. This calculated velocity of subsurface water flow was supported by the measurement of ^{222}Rn concentration (low values).

3. Influence of human activity on ^{222}Rn concentration in surface water

It has previously been reported that the ^{222}Rn concentration at location 3, which is a small stream, was higher in the rainy season than in the dry season because of greater subsurface flow in the rainy season[8]. However, the ^{222}Rn concentration (Table 1) and the electric conductivity (Table 2) at the end of August (August 29–31) were very low, at 11 mBq/L and 51 µS/cm respectively. This was caused by farmers discharging rainwater directly to the stream at this time (Photo 1). ^{222}Rn concentrations in surface water are thus affected by human activities, such

Table 1. Result of measurement of ^{222}Rn concentrations in surface water (2005–2006)

Unit: mBq/L.

Location	Aug. 1–3	Aug. 29–31	Oct. 3–5	Nov. 8–10	Dec. 6–8	Jan. 4–6	Feb. 6–8	Mar. 6–8	Apr. 24–26	May 15–17	Jun. 19–21	Jul. 17–19
1	27	29	43	31	22	21	15	31	37	68	29	19
2	41	42	48	57	30	26	42	17	22	34	28	32
3	150	11	58	136	35	37	59	76	30	37	12	57
4	18	41	34	58	79	382	122	136	127	95	19	38
5	317	382	225	587	212	418	463	466	146	155	113	184
6	412	68	118	203	126	106	124	239	122	169	57	176
7	151	186	103	175	63	121	104	172	76	55	53	153
8	46	38	82	96	86	81	67	73	55	62	6	22
9	56	140	43	73	51	103	114	74	56	85	65	37

Counting error: 2–7%.

Table 2. Measured electric conductivity of surface water (2005–2006)

Unit: µS/cm at 25 ºC.

Location	Aug. 1–3	Aug. 29–31	Oct. 3–5	Nov. 8–10	Dec. 6–8	Jan. 4–6	Feb. 6–8	Mar. 6–8	Apr. 24–26	May 15–17	Jun. 19–21	Jul. 17–19
1	258	210	163	198	232	274	382	462	477	655	571	340
2	321	290	160	190	217	228	258	287	287	352	376	332
3	735	51	261	434	478	496	533	639	537	469	479	321
4	258	284	189	316	384	404	438	463	315	329	239	315
5	264	262	197	315	332	361	346	344	321	313	266	254
6	2,287	1,484	1,510	1,560	1,952	2,330	3,156	3,444	5,010	4,185	4,865	5,160
7	1,109	1,019	833	1,054	1,165	1,205	1,279	1,348	3,123	1,774	590	1,101
8	2,617	2,677	2,021	2,561	3,013	3,652	4,619	6,074	9,183	10,563	14,179	14,713
9	1,420	1,514	1,072	1,010	1,196	1,172	1,277	1,457	1,580	1,795	1,755	2,057

as discharge of rain water.

4. Detection of groundwater by measurement of ^{222}Rn concentration in surface water

In the large stream at location 4 (Photo 2), ^{222}Rn concentrations in surface water were low during most of the study period. However, because the stream was not flowing in January, we collected sample water from a pool in the river bed (Photo 3). The ^{222}Rn concentration in this sample was very high, 382 mBq/L, suggesting that the surface of the pool was at the groundwater table. This value was very low compared with ^{222}Rn concentrations in groundwater in this area which we measured (7–21 Bq/L). The reason was inferred that the groundwater velocity was very slow and many ^{222}Rn atoms in water decayed in the pool and dispersed into the atmosphere. After one month (February), farmers dug deeply into the river bed to access water for irrigation (Photo 4).

^{222}Rn concentrations in the small stream at location 5 were high, from 113 to 587 mBq/L, suggesting that groundwater seeped into the stream at this location (Photo 5). These results show that groundwater can be obtained by digging to a depth of about 1 m in the river bed at locations 4 and 5. The electric conductivity was lower than 1,000 µS/cm throughout the year at these locations indicating that the groundwater can be used for agriculture.

5. ^{222}Rn concentration in low-elevation areas

In the low-elevation areas (locations 6 to 9), ^{222}Rn concentrations varied from 6 to 412 m Bq/L. Within this range, ^{222}Rn concentrations at locations 6 and 7 were high, whereas those at locations 8 and 9 were low. The electric conductivity in the pond at location 8 increased markedly from November 2005 to July 2006, and was higher than 10,000 µS/cm during the period from May to July 2006, indicating a high salt content at this time. However, ^{222}Rn concentrations at location 8 were low (6–62 mBq/L) during this period (May to July 2006), indicating that the source of the salt in the surface water was not groundwater. Because the rainfall during the period of our investigation was lower than usual, we suggested that evaporation from the pond raised the concentration of salt in the surface water at this location. Photos 6 and 7 show location 8 on 29 August 2005 and 11 August 2006, respectively. The reservoir level in 2006 was lower than in 2005.

The variation of electric conductivity at location 6 during the study period showed a similar trend to that at location 8. It has been reported that salinity is likely to be a problem when electric conductivity is higher than 2,000 µS/cm[4]. To avoid salinization, it is therefore necessary to take measures such as adding fresh water. Our investigation revealed that the electric conductivity of surface water increased markedly during the dry season in some areas. We will continue to measure electric conductivity in surface water in order to determine if the increase of electric conductivity in surface water is an annual event.

Photo 1. Location 3 (August 31, 2005)
Discharge of rainwater into the stream.

Photo 2. Location 4 (July 18, 2006)
^{222}Rn concentration was 38 mBq/L.

Photo 3. Location 4 (January 20, 2006)
We sampled water from a pool in the river bed.

Photo 4. Location 4 (February 7, 2006)
Farmers had dug into the river bed to access water. The water table was 55 cm deep below the river bed.

Photo 5. Location 5 (August 30, 2005)
^{222}Rn concentration was high, 382 mBq/L.

Photo 6. Location 8 (August 29, 2005)
Electric conductivity was 2,677 μS/cm.

Photo 7. Location 8 (August 11, 2006)
Electric conductivity was 8,022 μS/cm.

Conclusions

We monitored ^{222}Rn concentration and electric conductivity over a period of one year in surface waters of the Ban Phai watershed, northeast Thailand. The conclusions we reached are:

(1) The range of ^{222}Rn concentrations was very large, from 6 to 587 mBq/L.

(2) ^{222}Rn concentrations in ponds in high-elevation area (>180 m above sea level) were low, and supported a calculated velocity of subsurface water flow (on the order of 10^{-6} cm/s).

(3) ^{222}Rn concentration in surface water was affected by human activities, such as the draining of excess rainwater into streams.

(4) The measurement of ^{222}Rn concentration revealed that groundwater can be obtained by digging to a depth of about 1 m in the river bed at the locations 4 and 5.

(5) The electric conductivity of surface water at location 8 (a low elevation area, <160 m above sea level) increased markedly in the dry season. We inferred this to be the result of evaporation, rather than groundwater seepage, because the ^{222}Rn concentration of the surface water was low. We need to determine whether the marked increase in electric conductivity of surface water is an annual event.

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