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Study of radon concentration and toxic elements in drinking and irrigated water and its implications in Sungai Petani, Kedah, Malaysia

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ABSTRACT

The radon activity concentration and toxic elements have been assessed in drinking and irrigated water samples collected from different locations of Sungai Petani, Kedah, Malaysia. The water samples were collected from wells, streams and taps. A calibrated alpha spectrometer RAD-7 (Model 2890) and Atomic Absorption Spectrometers (Perkin–Elmer, Model AAnalyst 200, Shimadzu, Model AA-700) were used to estimate radon activity concentration and toxic elements, respectively. Maximum average value of radon concentration among the various types of water sources was found 14.7 ± 1.44 Bq/l in well water used for drinking and irrigation and minimum was found 5.37 ± 0.58 Bq/l in tap water used for drinking. Contribution of radon in drinking water to indoor air and age dependent associated annual effective doses were calculated from the measured radon concentration and were found less than lower limit of recommended action level. The activity concentrations of Ni > Pb > Cd > As > Cr were found higher for streams water as compared to wells and tap water. Values of radon concentration in well water were found higher than EPA recommended level and lower than WHO action level while the annual effective doses and level of toxic elements in water reported in this study were found lower than recommended level.

1. Introduction

Concentration of radon from water is a potential health risk when the water is used for consumption in the household, mainly because of the increase of the concentration of radon in air that is inhaled. Radon is the first leading cause of lungs cancer among non smokers. It has been estimated that the relative health risk of lungs cancer enhances 16% per 100 Bq/m^3 (Darby et al., 2005). According to UNSCEAR, a 1.2 mSv world average annual effective dose is estimated due to inhalation of radon, thoron and their decay products (Ahmad et al., 2014; UNSCEAR., 2000a). Radon existing in rocks of the earth's terrestrial systems diffuses continuously through water in rocks, which leads the presence of radon in ground water. According to USNRC, radon is a noble gas which has highest

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solubility in water, with the mole fraction value (1.25×10^{-5} at 37 °C) of fifteen times higher than that of neon and helium (USNRC., 1999). In addition, it has been determined that radon inhalation dissolved in and released from water for human consumption accounts for 89% of the estimated cancer risk, whereas radon ingestion from drinking water accounts for 11% (USNRC., 1999). Dissolved radon exists in drinking water and sensitive cells in stomach and other organs of the body are exposed to the radon emitted radiation and its decay products once they are absorbed into the bloodstream (Oner, Yalim, Akkurt, & Orbay, 2009).

The contamination of toxic elements is a very serious problem in several communities and agriculture areas, mainly because of agrochemicals, which includes fertilizers and nutrients of plant, can lead to dramatic increases in toxic elements concentrations in the soil and water (Rattan, Datta, Chhonkar, Suribabu, & Singh, 2005). These toxic elements have to transfer to human health through ground and surface water (Chotpantarat, Ong, Sutthirat, & Osathaphan, 2012; Rashed, 2010). The level of groundwater contamination by toxic elements such as arsenic (As) and cadmium (Cd) is one of the most important environmental issues, because of their strong toxicity (Marcovecchio, Botté, & Freije, 2007).

In Malaysia, the sources of water depend on rainfall, which ranged from 2000 to 2500 mm on average annually. Most of the supply of water originates from streams and rivers in the country, while the contribution of ground water is 1% of the required water (Azrina, Khoo, Idris, Amin, & Razman, 2011). High concentration of radon and heavy metals in tap, river and well water used for drinking may pose adverse side effects. In this study, measurement of radon and toxic elements in water of Sungai Petani, Kedah, Malaysia was carried out to assess the non-carcinogenic and carcinogenic health risks for the population exposed to radon and toxic elements. Sungai Petani is a capital of district Kala Muda in the state of Kedah, situated in the north parts of Peninsular Malaysia and covers an area of 925 km^2 (Noresah & Ruslan, 2009). Fig. 1 shows the location of the study area.

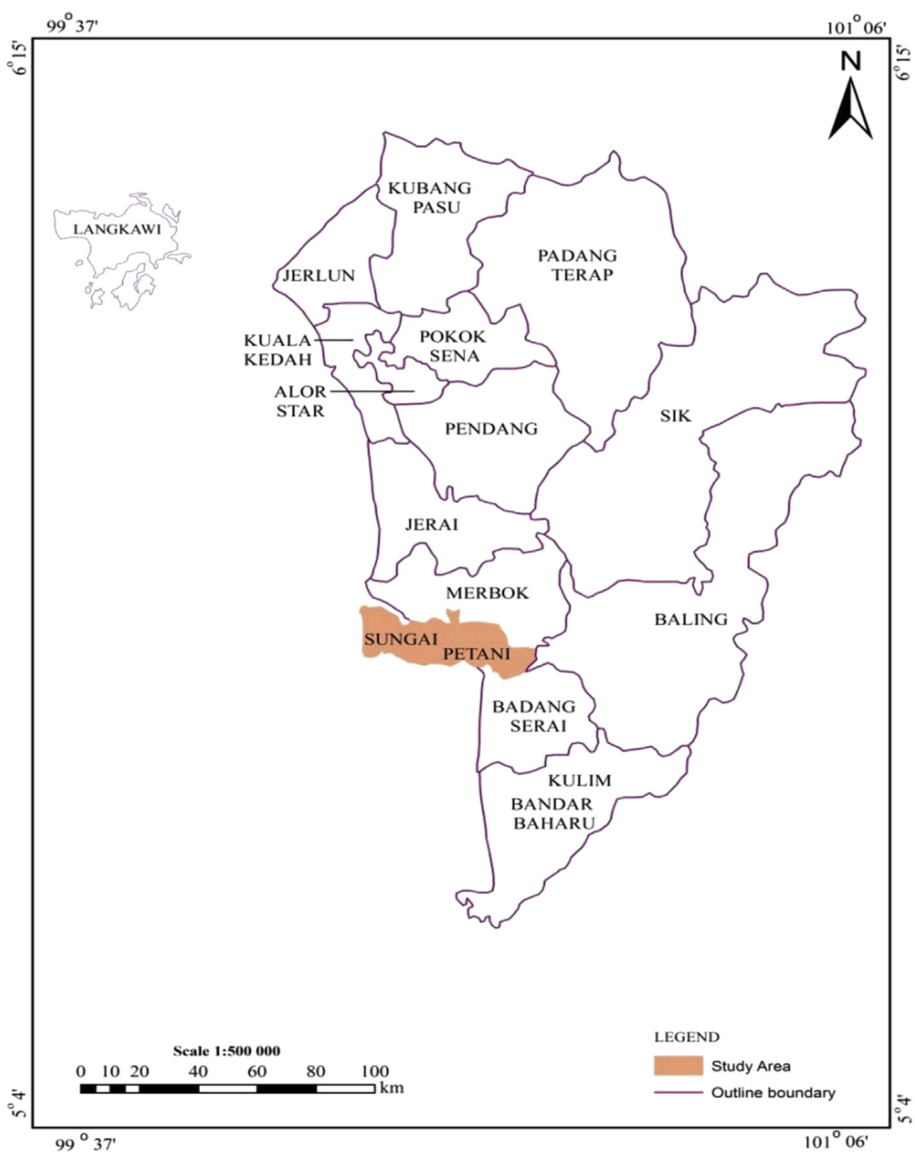

Fig. 1 – Location of the study area, Sungai Petani, Malaysia.

Table 1 – Radon concentration in drinking and irrigated water and its contribution to indoor radon.

S No	Site name	Site code	Source of water	Radon concentration Bq/l	Contribution of radon to indoor $C_{A\,Rn}^{222}$ (mBq/l)
1	Kampong Pulau Tiga Sungai Layar	SPW1	Well	17.0 ± 1.67	6.07 ± 0.59
2	Kampong Guar Station	SPW6	Well	12.4 ± 1.29	4.43 ± 0.46
3	Kampong Keda Che Bema	SP10-2	Well	14.7 ± 1.36	5.25 ± 0.48
4	Sungai Sembiling	SPR1	Stream	9.4 ± 0.88	3.36 ± 0.31
5	Sungai Muda	SPW8	Stream	8.4 ± 0.80	3.00 ± 0.28
6	Kampong Bukit Lembu, Suangil Lalang	SPW3	Stream	6.7 ± 0.86	2.39 ± 0.30
7	Kampong Jelatang	SPW5	Stream	7.1 ± 0.91	2.53 ± 0.32
8	Kampong Kilang Maku	SPW9	Tap	3.9 ± 0.51	1.39 ± 0.18
9	Kampong Keda Che Bema	SPW10	Tap	4.9 ± 0.58	1.75 ± 0.20
10	Kampong Bakar Kapor	SPW11	Tap	2.7 ± 0.31	0.96 ± 0.11
11	Kampong Patai Cicak	SPW12	Tap	6.0 ± 0.63	2.14 ± 0.22
12	Kampong Sinar Permata	SPW13	Tap	6.7 ± 0.68	2.39 ± 0.24
13	Kampong Teroi Sung	SPW14	Tap	6.4 ± 0.63	2.28 ± 0.22
14	Kampung Raja	SPW15	Tap	7.0 ± 0.71	2.50 ± 0.25
15	Kampong Pengkalan Lebai Man	SPW16	Tap	6.7 ± 0.83	2.39 ± 0.29
16	Kampong Serukam	SPW17	Tap	4.1 ± 0.42	1.46 ± 0.15

2. Materials and methods

The sources of drinking water in the area under study are tap and well and water used for irrigation is streams, lakes and well water. Samples of water were collected from tap, wells, and streams. Before the collection of water samples, bottles were rinsed with 15% HNO_3 and with double de-ionized water in triplet. In order to insure sample quality, samples from well were collected directly from well after purging for 10 min. Tap water was collected directly from tap and water from streams was taken within 5 cm of the water surface. All samples were labeled with date, time and sample code.

Radon concentration in these samples was measured using calibrated alpha spectrometer RAD-7 (Model 2890) according to EPA protocol test. Measurement time of 30 min at Wat-250 protocol and Grab mode was taken for all water samples. Water sample of 250 ml each was sealed off for 3–4 h before measurement.

The contribution of radon from water to indoor radon was calculated using equation (1) (Zalewski, Karpiñska, Mnich, Kapała, & Zalewski, 2001).

$$C_{aRn}{}^{222} = C_{wRn}{}^{222} \times W \times \frac{e}{(V \times \lambda_c)} \quad (1)$$

where $C_{aRn}{}^{222}$ shows the contribution of radon from water to indoor radon, $C_{wRn}{}^{222}$ shows concentration of radon in water, W shows consumption of water (0.01 m^3/h per person), e, V and λ_c show coefficient of radon from water to indoor air (0.5), bulk of indoor (20 m^3 per person) and air exhange rate (0.7 h^{-1}), respectively (UNSCEAR, 1993; Xinwei, 2006) .

Annual effective dose for ingestion was calculated using equation (2) (Ajayi & Achuka, 2009).

$$E_d = A_c A_i C_f \quad (2)$$

Where E_d represents annual effective dose for ingestion, A_c is radon concentration (Bq/l), A_i is the intake of water (730, 330 and 230 l/y for adult, childern and babies respectively) (WHO., 1988) and C_f represents dose conversion factors for radon (3.5, 5.9 and 23 nSv Bq^{-1} for audlts, childerns and babies, respectively) (UNSCEAR., 2000b).

For the measurement of toxic elements in water samples, all samples were concentrated from 1 L to 50 ml with 5 ml of HNO_3. Each sample was filtered through double rings filter paper before concentration. Atomic Absorption Spectrometers (Perkin–Elmer, Model A Analyst 200, Shimadzu, Model AA-700) were used for analysis of Cd, Ni, Cr, Pb and As. The instrument was calibrated continuously with the certified standard solution (Merck Darmstadt, Germany and Fisher Scientific, UK limited).

3. Result and discussion

The results obtained for radon concentration and contribution of radon from water to indoor radon from various types of water sources collected from different areas of Sungai Petani are reported in Table 1. The activity concentration of radon in well water ranged from 12.4 ± 1.29 to 17.0 ± 1.67 Bq/l with an average of 14.7 ± 1.44 Bq/l, whereas that in stream and tap water ranged from 6.7 ± 0.86 to 9.4 ± 0.88 Bq/l with an average of 7.9 ± 0.86 Bq/l and 2.7 ± 0.31 to 7.0 ± 0.71 Bq/l with

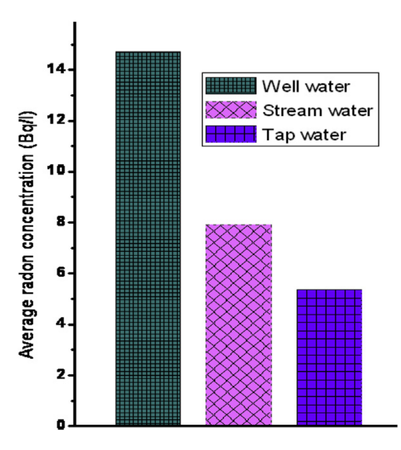

Fig. 2 – Average radon concentration in different sources of water.

Table 2 – ^{222}Ra activity concentration (Bq/l) in different sources of water with different parts of the world.

Region	Sources of water	^{222}Ra activity concentration	Reference
Italy	Well	12.7	(Kozłowska et al., 2009)
Brazil	Well	0.02–112.5 (15.4)	(Bonotto, 2014)
China	Ground water	0.71–3735 (229.4)	(Zhuo, Iida, & Yang, 2001)
Cyprus	Ground water	0.1–5 (1.4)	(Sarrou & Pashalidis, 2003)
Pakistan (Balakot)	Bore/well	17.31–24.52 (20.43)	(Khan, Ali, Khan, Khattak, & Khan, 2010)
Pakistan	Well	0.670–1.45 (1.21)	(Nasir & Shah, 2012)
(D. I. Khan)	Tap	0.333–0.903 (0.602)	
Venezuela	Tap	0–2	(Horvath et al., 2000)
India	Tap	6.44–8.36 (7.35)	(Shivakumara et al., 2014)
China	Tap	8–18 (12)	(Xinwei, 2006)
Turkay	Tap	0.91–12.58	(Tarim et al., 2012)
Jordon	Tap	2.5–4.7	(Al-Bataina, Ismail, Kullab, Abumurad, & Mustafa, 1997)
Sungai Petani	Well	12.4–17 (14.7)	Present study
	Tap	2.7–7.0 (5.37)	

Table 3 – Annual effective doses from drinking water.

S No	Sample Code	Source of water	< 2 years	2–16 years	> 17 years
			$(mSv\ y^{-1})\ 10^{-2}$	$(mSv\ y^{-1})10^{-2}$	$(mSv\ y^{-1})\ 10^{-2}$
1	SPW1	Well	8.99 ± 0.88	3.30 ± 0.32	4.34 ± 0.42
2	SPW6	Well	6.56 ± 0.68	2.41 ± 0.25	3.16 ± 0.33
3	SP10-2	Well	7.78 ± 0.71	2.85 ± 0.26	3.75 ± 0.34
4	SPW9	Tap	2.06 ± 0.26	0.75 ± 0.09	0.99 ± 0.13
5	SPW10	Tap	2.59 ± 0.30	0.95 ± 0.11	1.25 ± 0.14
6	SPW11	Tap	1.43 ± 0.16	0.52 ± 0.06	0.68 ± 0.07
7	SPW12	Tap	3.17 ± 0.33	1.16 ± 0.12	1.53 ± 0.16
8	SPW13	Tap	3.54 ± 0.35	1.30 ± 0.13	1.71 ± 0.17
9	SPW14	Tap	3.39 ± 0.33	1.24 ± 0.12	1.63 ± 0.16
10	SPW15	Tap	3.70 ± 0.37	1.36 ± 0.13	1.78 ± 0.18
11	SPW16	Tap	3.54 ± 0.43	1.30 ± 0.16	1.71 ± 0.21
12	SPW17	Tap	2.17 ± 0.22	0.79 ± 0.08	1.04 ± 0.10

Table 4 – Toxic elements in drinking and irrigated water (μg/l) and international standard limits.

S No	Site code	Source of water	As	Cr	Ni	Cd	Pb
1	SPW1	Well	1.92 ± 0.2	2.62 ± 0.36	7.96 ± 0.88	1.7 ± 0.22	3.52 ± 0.44
2	SPW6	Well	2.2 ± 0.32	2.16 ± 0.3	8.7 ± 1.06	2.54 ± 0.44	8.8 ± 1.04
3	SP10-2	Well	1.22 ± 0.16	1.62 ± 0.12	5.28 ± 0.82	3.66 ± 0.52	5.46 ± 0.74
4	SPR1	Stream	7.2 ± 0.8	3.32 ± 0.46	9.56 ± 0.9	4.42 ± 0.76	9.74 ± 1.14
5	SPW8	Stream	4.7 ± 0.6	3.82 ± 0.52	8.44 ± 1.04	4 ± 0.62	7.5 ± 0.96
6	SPW3	Stream	5.83 ± 1.80	4.84 ± 0.66	10.2 ± 1.16	3.88 ± 0.6	8.48 ± 1.02
7	SPW5	Stream	3.56 ± 0.56	5.4 ± 1.16	12.2 ± 1.2	4.82 ± 0.72	4.4 ± 0.6
8	SPW9	Tap	0.76 ± 0.12	1.26 ± 0.18	4.8 ± 0.72	1.9 ± 0.18	4.8 ± 0.62
9	SPW10	Tap	2.18 ± 0.22	1.38 ± 0.2	3.92 ± 0.54	2.58 ± 0.58	5.42 ± 0.74
10	SPW11	Tap	1.56 ± 0.14	1.72 ± 0.16	2.96 ± 0.46	3.68 ± 0.48	3.74 ± 0.5
11	SPW12	Tap	0.96 ± 0.18	0.76 ± 0.12	1.32 ± 0.14	2.08 ± 0.52	2.78 ± 0.44
12	SPW13	Tap	2.74 ± 0.32	0.6 ± 0.18	4.44 ± 0.64	2.92 ± 0.54	7.4 ± 0.8
13	SPW14	Tap	1.06 ± 0.12	1.96 ± 0.2	3.26 ± 0.5	2.42 ± 0.4	3.86 ± 0.54
14	SPW15	Tap	0.9 ± 0.16	2.12 ± 0.22	2.5 ± 0.4	1.54 ± 0.18	2.4 ± 0.44
15	SPW16	Tap	2.5 ± 0.34	0.52 ± 0.18	1.76 ± 0.24	1.92 ± 0.2	1.72 ± 0.16
16	SPW17	Tap	0.94 ± 0.16	0.98 ± 0.2	2.86 ± 0.48	0.9 ± 0.14	2.98 ± 0.4
Mean			2.51	2.19	5.63	2.81	5.18
WHO[a]			10	50	70	3	10
USEPA[b]PCD[c]			10[b]	100[b]	20[c]	5[b]	15[b]

[a] (WHO., 2011).
[b] (USEPA., 2012).
[c] (PCD, 2004); (Wongsasuluk, Chotpantarat, Siriwong, & Robson, 2014).

an average of 5.37 ± 0.58 Bq/l, respectively. Fig. 2 shows average radon concentration in different sources of water. The results show that activity concentrations of radon in well water were higher than EPA action level of 11 Bq/l (Shivakumara, Chandrashekara, Kavitha, & Paramesh, 2014; USEPA., 2000) and less than WHO action level of 100 Bq/l (Al-Nafiey, Jaafar, & Bauk, 2014; WHO., 2008). High values of radon in well water is attributed to depth of well, as the activity of radon concentration in ground water is usually higher than surface water (Mustapha, Patel, & Rathore, 2002; Nasir & Shah, 2012). The values of radon concentrations in tap and stream water were lower than action level of EPA and WHO, which may be the reflection of long aeration process undergone by the water in the process of treatment and due to aeration of radon gas to the atmosphere and also due to the lack of major contact with radon emanating mineral material (Chandrashekara, Veda, & Paramesh, 2012; Shivakumara et al., 2014).

The results of the ^{222}Ra activity concentrations in wells and tap water of the study area were compared with those reported for other countries of the world (Table 2). The average value of radon concentration in well water was lower compared to the values reported in Brazil, China and Pakistan (Balakot), and was higher compared to the values reported in Italy, Cyprus and Pakistan (D. I. Khan). In case of tap water the average value of radon concentration was lower than China, Turkey and India, and was higher than Pakistan (D. I. Khan), Venezuela and Jordon. The contribution of radon from water to indoor radon varied from 0.96 ± 0.11 mBq/l to 6.07 ± 0.59 mBq/l.

Results obtained for age dependent effective doses due to ingestion of radon in drinking water are reported in Table 3. The results reveal that the committed effective doses due to the ingestion of radon in drinking water varied from 0.014 ± 0.0016 to 0.0899 ± 0.0088 mSv y^{-1}, 0.0052 ± 0.0006 to 0.033 ± 0.0032 mSv y^{-1} and 0.0068 ± 0.0007 to 0.0434 ± 0.0042 mSv y^{-1}, for age groups <2, 2–16 and >16 years, respectively and were below the action levels recommended by different radiological protection agencies (ICRP., 1991; WHO., 2008).

The results obtained for toxic elements in water are summarized in Table 4 along with the standards recommended by different agencies. Fig. 3 shows variation in the toxic elements in water of the study area. The maximum concentration of toxic elements were 12.2 ± 1.2 μg/l for Ni, 9.74 ± 1.14 μg/l for Pb, 4.82 ± 0.72 μg/l for Cd, 5.4 ± 1.16 μg/l for Cr and 7.2 ± 0.8 μg/l for As in streams water and minimum were 1.32 ± 0.14 μg/l for Ni, 1.72 ± 0.16 μg/l for Pb, 0.9 ± 0.14 μg/l for Cd, 0.52 ± 0.18 μg/l for Cr, 0.76 ± 0.12 μg/l for As in tap water. The activity of toxic elements was higher in steams water than tap and wells water which may be due to human activities and industrialization in the study area. However all values obtained for toxic elements were lower than the permissible standards for drinking water.

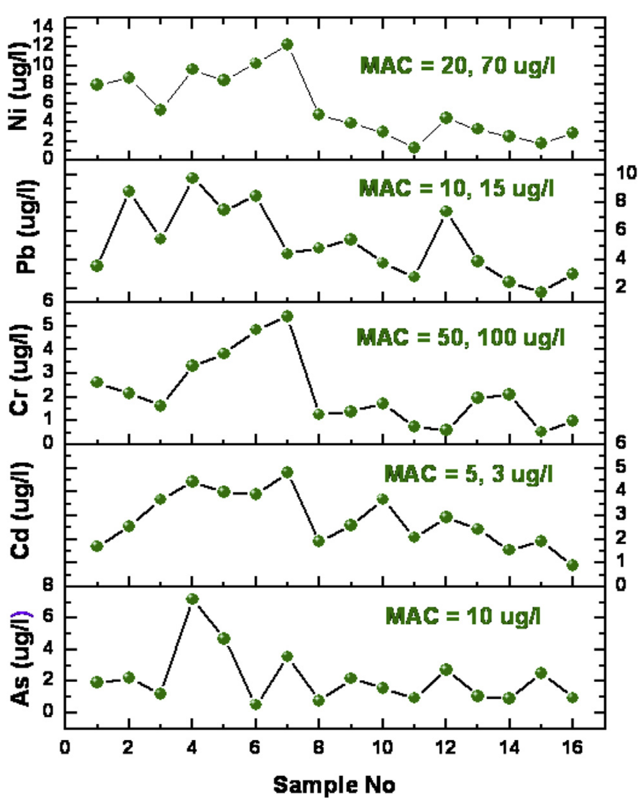

Fig. 3 – Variation in toxic elements in water collected from Sungai Petani (MAC stands for Maximum Allowable Concentration).

4. Conclusion

This study investigated the human health risk from radon concentration and toxic elements in drinking and irrigated water collected from different locations of Sungai Petani, Malayisa. High radon concentrations were observed in well water sources with the highest observed value of (17.0 ± 1.67) Bq/l and low radon concentrations were observed in tap water sources with the hightest value of (7.0 ± 0.71) Bq/l. Average radon concentration in water collected from rivers was found higher then tap water. Values of radon concentration in well water exceed the EPA recommended level of 11 Bq/l but are below the action level of 100 Bq/l recommended by WHO, while in case of tap and stream water all samples were found below the action level of both US EPA and WHO. However it is recommended to boil the well water befor use for drinking in oder to decrease the level of radon concentration. The results reveal the fact that values of annual effective doses are below the permissable limit of ICRP and WHO. The order of distribution of toxic elements was Ni > Pb > Cd > As > Cr (5.63 > 5.18 > 2.81 > 2.51 > 2.19 μg/l, respectively) and found with in recommended levels.

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