



# Continuous Monitoring of Radon Contamination Levels in Lower Nam Phong River, Khon Kaen Province, Thailand

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**Abstract:** In this research, radon concentrations in surface water samples were measured at 8 stations and along 8 boat survey routes in the lower Nam Phong River, Khon Kaen Province, Thailand, using the RAD 7 Radon Detector and RAD AQUA accessories. The results of radon concentration at the 8 stations along the Nam Phong River ranged from 0.16 to 4.87 Bq/L, with an average of 1.17 Bq/L. For the boat survey routes along the Nam Phong River, radon concentrations ranged from 0.04247 to 0.12342 Bq/L, with an average of 0.07422 Bq/L. These results were lower than the maximum contaminant level of radon in water (MCL), 11.1 Bq/L, as the United States Environmental Protection Agency recommended. Finally, the results were used to assess various health risks to people in this research area, contributing to determining the public safety of radon exposure in the lower Nam Phong River.

**Keywords:** Radon; RAD 7; The lower Nam Phong River Basin

## 1. Introduction

Radon (<sup>222</sup>Rn) is a radioactive gas with a half-life of 3.82 days, colorless, odorless, and tasteless. It is a noble gas not combined with any element or another like a compound, which is one of the natural atomic radiation generated from the decay of Radium (<sup>226</sup>Ra) located in the decay chain of Uranium (<sup>238</sup>U) is the only metal source which is found in a gaseous state, there are almost in all places, at all times, it dissolves in water. It can readily diffuse with gases and water vapor. It is impossible to find pure surface water in the natural environment [1, 2]. One of the major pollutants that can constantly contaminate surface water is radon. Radon radiation pollutes surface water and affects human health through the use of surface water for drinking and daily use. For example, showering, washing dishes, and watering plants are other dangers of radon exposure, and radon inhalation spreads from surface water [3]. Although the amount of radon contamination in surface waters is relatively small compared to the areas where radon is dissolved. However, if radon-contaminated surface water is used regularly, it can accumulate sufficient amounts of radon that can harm the body [4, 5]. The health effects from radon-contaminated surface waters are essential factors that can cause cancer in the body: 1. Lung cancer from inhalation and 2. Stomach cancer from ingestion. One

of the significant factors that need to be determined regarding water usability is the radon concentration level and annual effective dose due to the ingestion of radon and the inhalation of radon released from surface water. [6, 7]. For this reason, radon concentrations in surface water should be measured, and health risks in different forms should be assessed to verify the safety of drinking and household water following the established standards of various agencies. The Nam Phong River is one of the most important rivers in the Northeast. It originates from Phu Kradueng and the Pa Sak River and Chi River flows through Phu Kradueng, Loei Province, Ubon Rat District, Nam Phong District, and Mueang District, Khon Kae Province before flowing into the Chi River at Kuichaug village, Kosum Phisai District, Maha Sarakham Province, then flows into the Mun River and the Mekong River respectively, all these are the lower Lam Nam Phong [8]. Geologic characteristics of the lower Nam Phong River in Khon Kaen Province is an area in the Khorat Plateau. It is in the Maha Sarakham Formation and is considered a rock salt category. From the radioactive measurement of salt, K–Ar is about 93 million years old and consists of terrace deposits and Alluvial deposits covering most areas. These two sediments consist of gravel, sand, silt, and laterite [9]. Most areas of the lower Nam Phong River together with large amounts of gravel, sand, and silt. These gravel, sand, and silt contain Uranium 238 and Radium 226, which can decay to radon. While decaying to produce radon, the lower Nam Phong River washes away radon from the gravel, sand, and silt. Although the amount of radon contamination in water bodies is small, a large amount of accumulation in the body from regular water use will result in a health hazard [4, 10]. Most of the tap water used by people in Khon Kaen in daily life is produced from the raw water pumping station of the lower Nam Phong River [10]. In the past ten years, Khon Kaen Province has experienced rapid economic expansion, expanding communities, houses, agricultural buildings, and various industrial factories, resulting in increased demand for water [11, 12]. At the same time, the Lower Nam Phong River has become the support area of waste all the time, which is causing it to exceed the ability to purify itself naturally, affecting water quality and utilization of water in the Lower Nam Phong River, which will affect damage the environment and quality of life [10, 13, 14]. In a study published in 2013 on cancer-causing factors due to radium-226 concentration in the Nam Phong River, Khon Kaen Province, it was found that the river was contaminated with radium-226 (the radium-226 is radon's parent nuclide), ranged from 0 to 77.27 Bq/L, averaging 47.61 Bq/L. This contamination resulted in an annual effective dose ranging from 7.04 to 15.45  $\mu\text{Sv/y}$ , averaging 10.988  $\mu\text{Sv/y}$ . Although the concentration of radium-226 in the Nam Phong River is below the USEPA standard of 111 mBq/L for radium-226 contamination, it is still considered high, necessitating continuous monitoring. Areas of concern include Ban Huai Bong in Thung Chomphu Subdistrict, Phu Wiang District; Ban Huai Sai in Ban Dong Subdistrict, Ubonrat District; and Ban Nong Tao in Khok Si Subdistrict, Mueang District [10]. There is a possibility that contamination levels could exceed the standard in the future. Additionally, radium-226 leads to increased radon decay, which poses direct health risks to those who consume water from the Nam Phong River. This research aimed to randomly measure radon concentrations and assess health risks in the lower Phong River, Khon Kaen Province, ensuring safety from exposure to radon-contaminated water.

## 2. Materials and Methods

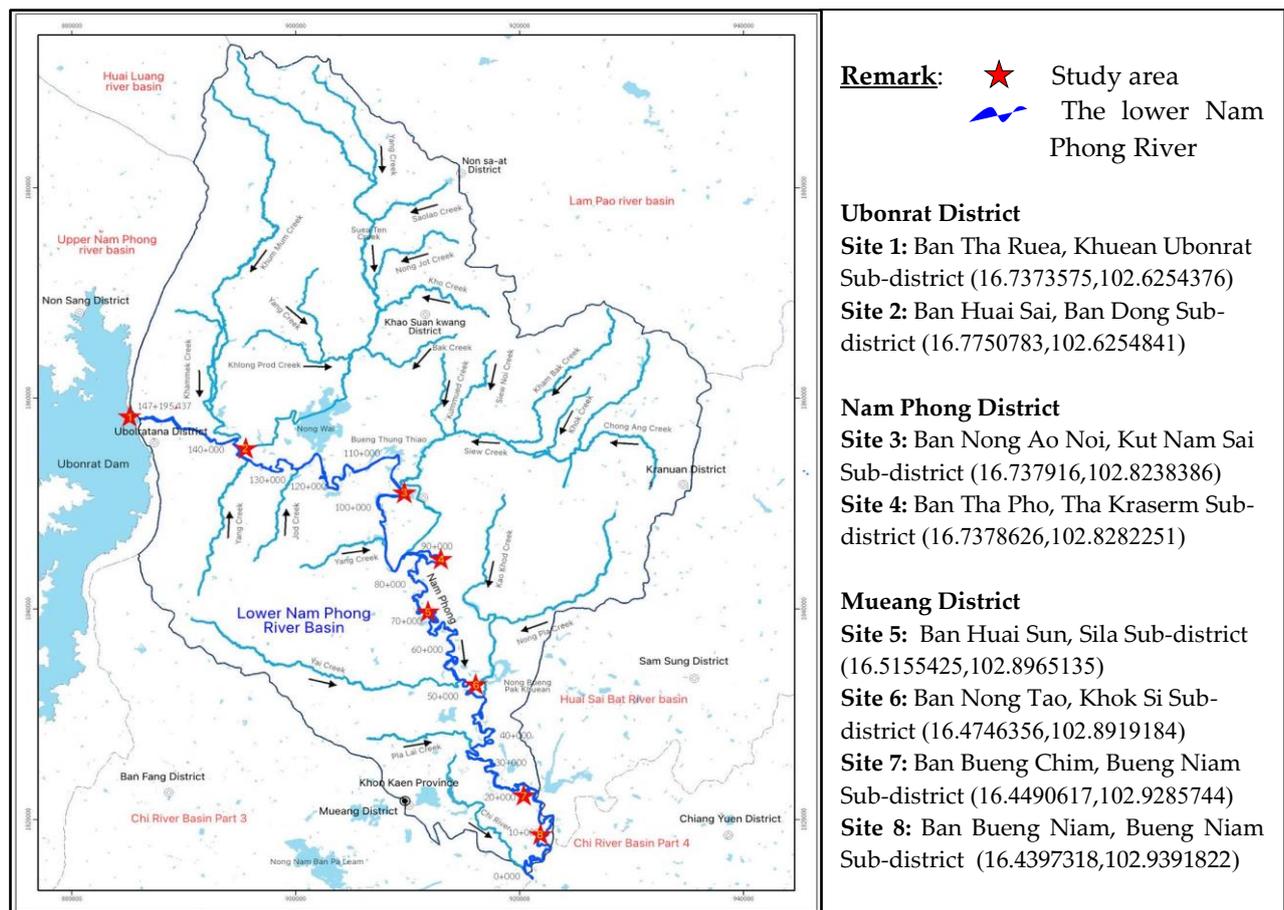
### 2.1 The survey and selection of study areas

The study focused on the lower Phong River in Khon Kaen Province, northeastern Thailand. The Nam Phong River spans approximately 2,386 square kilometers, with a length of around 136 kilometers and an average elevation of 150-500 meters above mean sea level [14]. The researcher randomly selected 8 study areas and 8 boat survey routes along the Phong River for the research. These selections were based on data measuring the radium content in the Phong River from V. Atyotha's 2013 research [10] and data from the raw water pumping station used for tap water production in Khon Kaen Province [15], as illustrated in Figure 1.

### 2.2 RAD 7 Radon Detector

The RAD 7 is a radon detector, and most of its semiconductor probes are made of silicon. One advantage of the RAD 7 is its durability and ability to detect alpha particles' energy levels accurately. It can differentiate between energy levels of isotopes such as  $^{218}\text{Po}$  and  $^{214}\text{Po}$ , which are radon decay products. Another important advantage of the RAD 7 is its ability to measure radon gas quickly and in real-time. The

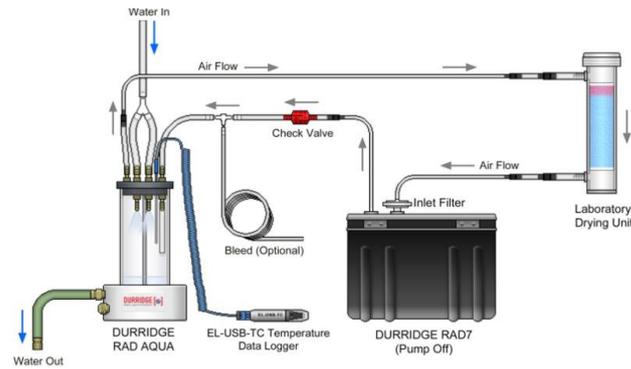
RAD 7 can measure radon concentration in various samples, including air, water, soil, rock, and building materials. However, to measure the radon concentration of each sample, a specific device must be used in conjunction with the RAD 7, tailored to the application for measuring radon concentration in that particular sample. For example, to measure radon concentration in a water sample, the RAD H<sub>2</sub>O must be used. Similarly, the RAD Aqua is necessary for radon concentration measurement in rivers, canals, seas, and oceans. Likewise, for measuring radon concentration in soil samples, the RAD in soils is required [16]. This study measures radon concentration in rivers. Therefore, we chose accessories for the experiment, such as RAD 7 and RAD Aqua.



**Figure 1.** The study areas in Lower Nam Phong River, Khon Kaen Province, Thailand

**2.3 RAD Aqua accessories**

This system measures radon concentrations in water samples taken from the Nam Phong River. The samples are collected using a pump connected to a hose approximately 1 meter from the water surface. Subsequently, the Nam Phong River water passes through an air-water exchanger equipped with a water spray nozzle. This nozzle diffuses the water into tiny droplets, facilitating the continuous release of radon gas from the incoming water. The radon gas is drawn into the RAD 7's internal pump, passing through a desiccant before entering a probe to measure radon concentration. This measurement is based on the energy of alpha particles emitted by <sup>218</sup>Po and <sup>214</sup>Po. Subsequently, the measured values are converted to radon concentration units, expressed in Bq/L. A calibrated electronic radon detector (RAD7 Serial No. 4167) by DURRIDGE Company, Inc., United States [16] was used to measure radon in air, soil gas, water, and river setup of this measurement system is illustrated in Figure 2.



**Figure 2.** The continuous measurement of radon concentration in Nam Phong River [15].

**2.4 The stations for continuous measurement of radon concentration**

A continuous radon measuring station was established, utilizing a RAD-Aqua device that received a continuous water flow from a submersible pump fixed at a depth of 1 meter from the river level for 24 hours. The installation process of the device is illustrated in Figure 3, with measurements scheduled every 20 minutes until the 24 hours have elapsed.



**Figure 3.** The stations continuously measurement of radon concentration in Site 1 Ban Tha Ruea, Khuean Ubonrat Sub-district along the lower Nam Phong River.

**2.5 The boat survey routes are used for continuous measurement of radon concentration.**

Continuous radon measurement during boat surveys was conducted using a RAD-Aqua device, which received a continuous flow of water from a submersible pump fixed at a depth of 1 meter from the river's surface for 4-6 hours. The installation process of the device is illustrated in Figure 4



**Figure 4.** The route boat survey will be conducted to measure radon concentration in Site 1 Ban Tha Ruea continuously, Khuean Ubonrat Sub-district along the lower Nam Phong River.

**2.6 Health Risk Calculation**

The annual effective dose from the ingestion of radon concentration in surface water ( $D_{ing}$ ) was calculated using Eq. 1 [17-18]:

$$D_{ing} = C_{RnW} \times F \times C_w \tag{1}$$

where  $C_{RnW}$  = the average radon concentration in surface water (Bq/L),  $F$  = dose conversion factor =  $3.5 \times 10^{-9}$  Sv/Bq, and  $C_w$  = water consumption throughout the year = 730 L/y [18].

The annual effective dose from the inhalation of radon concentration in surface water ( $D_{inh}$ ) was calculated using Eq. 2 [18-19]:

$$D_{inh} = C_{RnW} \times R_{AW} \times F \times E \times T \tag{2}$$

where  $C_{RnW}$  = the average radon concentration in surface water (Bq/m<sup>3</sup>),  $R_{AW}$  = the ratio of radon in air/water ( $10^{-4}$ ),  $F$  = the dose conversion factor of radon exposure ( $9 \times 10^{-9}$  Sv·h<sup>-1</sup>·Bq<sup>-1</sup>·m<sup>3</sup>),  $E$  = indoor balance factor between radon and its progeny (0.4), and  $T$  = the time indoors (7000 h·y<sup>-1</sup>) [17-18].

The excess lifetime cancer risk (ELCR) was calculated using Eq. 3 [20-21]:

$$ELCR = D_{total} \times A \times f \tag{3}$$

Where  $D_{total}$  = the sum of the annual effective dose from the ingestion and inhalation of radon concentration in surface water ( $D_{ing} + D_{inh}$ ),  $A$  is the average duration of life estimated to be 77.74 years for Thai people [22], and  $f$  = the fatal cancer risk per Sievert ( $5.5 \times 10^{-2}$  Sv<sup>-1</sup>) suggest by ICRP [23].

Lung cancer cases per year per million people (LCC) were calculated using Eq. 4 [20-21]:

$$LCC = D_{total} \times 18 \times 10^{-6} \tag{4}$$

the risk factor for lung cancer induction is  $18 \times 10^{-6}$  mSv<sup>-1</sup>·y [21].

### 3. Results and Discussion

#### 3.1 The results of radon concentrations in 8 stations

This research measured radon concentrations in surface water samples at 8 stations along the Nam Phong River using the RAD 7 Radon Detector and RAD Aqua accessories. The results of the radon concentrations,  $D_{ing}$ ,  $D_{inh}$ , ELCR, and LCC are shown in Table 1.

**Table1** . The results of 8 stations along Nam Phong River.

Site	Location	Radon		$D_{ing}$	$D_{inh}$	$D_{total}$	ELCR	LCC
		Bq/L	Bq/m <sup>3</sup>					
1	16.7373575,102.6254376	0.17	170	0.43	0.43	0.86	0.037	15.53
2	16.7750783,102.6254841	4.87	4870	12.44	12.27	24.72	1.057	444.88
3	16.737916,102.8238386	0.19	190	0.49	0.48	0.96	0.041	17.36
4	16.7378626,102.8282251	0.16	160	0.41	0.40	0.81	0.035	14.62
5	16.5155425,102.8965135	0.24	240	0.61	0.61	1.22	0.053	21.92
6	16.4746356,102.8919184	1.02	1020	2.61	2.57	5.18	0.221	93.18
7	16.4490617,102.9285744	0.18	180	0.46	0.45	0.91	0.039	16.44
8	16.4397318,102.9391822	2.50	2500	6.39	6.30	12.69	0.542	228.38
	<b>Min</b>	0.16	160	0.41	0.40	0.81	0.035	14.62
	<b>Max</b>	4.87	4,870	12.44	12.27	24.72	1.057	444.88
	<b>Mean</b>	1.17	1,166.25	2.98	2.94	5.92	0.253	106.54
	<b>S.D.</b>	1.70	1,703.22	4.35	4.29	8.64	0.370	155.59

Table 1 shows that radon concentrations ranged from 0.16 to 4.87 Bq/L, with an average concentration of 1.17 Bq/L. The highest radon concentration was observed at Site 2 in Ban Huai Sai, Ban Dong Sub-district,

Ubonrat District, reaching 4.87 Bq/L. In contrast, the lowest concentration was recorded at Site 4 in Ban Huai Sun, Sila Sub-district, Mueang Khon Kaen District, with a 0.16 Bq/L concentration. The results of radon concentration in the Nam Phong River were calculated based on the annual ingestion dose ( $D_{ing}$ ), the annual inhalation dose ( $D_{inh}$ ), the excess lifetime cancer risk (ELCR), and the evaluation of the number of lung cancer cases per year per million people (LCC). The findings revealed that the  $D_{ing}$  ranged from 0.41 to 12.44  $\mu\text{Sv/y}$  (mean = 2.98  $\mu\text{Sv/y}$ ), the  $D_{inh}$  ranged from 0.40 to 12.27  $\mu\text{Sv/y}$  (mean = 2.94  $\mu\text{Sv/y}$ ), the ELCR ranged from 0.035 to 1.057 % (mean = 0.253 %), and the  $LCC \times 10^{-6}$  ranged from 14.62 to 444.88 (mean = 106.54).

These results were compared with safety limit values, which WHO and USEPA recommend to the dangerous action level of radon concentration is 100 Bq/L for public or commercial drinking water supplies [1, 4-7] and the proposed regulation provides two options for the maximum level of radon that is allowable in community water supplies: 1. the proposed maximum Contaminant Level (MCL) is 11.1 Bq/L and 2. the proposed Alternative Maximum Contaminant Level (AMCL) is 148 Bq/L, respectively [1, 5] and the action level of the  $D_{ing}$  and the  $D_{inh}$  have a maximum permissible limit of 200  $\mu\text{Sv/y}$  if consumed by children and a maximum limit of 100  $\mu\text{Sv/y}$  if consumed by adults that are recommended by the WHO and the European Union Commission [1]. The comparison results show that the surface water radon concentration, the  $D_{ing}$ , and the  $D_{inh}$  were lower than the action level. The mean Excess Lifetime Cancer Risk (ELCR) for radon exposure in the study area was 0.25 %, which is relatively low compared to the action level set by the US EPA. The estimated risk of 1.3 % corresponds to radon exposure of 148 Bq/m<sup>3</sup> for the entire population [21]. The results of LCC ranged between 14.62 and 444.80 per million persons per year with a mean value of 106.54 per million persons per year, which is lower than the limit range of 170-230 per million persons recommended by ICRP [21].

### 3.2 The results of radon concentrations by 8 boat survey

This research measured radon concentrations in surface water samples during 8 boat survey routes along the Nam Phong River using the RAD 7 Radon Detector and RAD AQUA accessories. The results of the radon concentrations and the  $D_{ing}$ ,  $D_{inh}$ , ELCR, and LCC values are shown in Table 2.

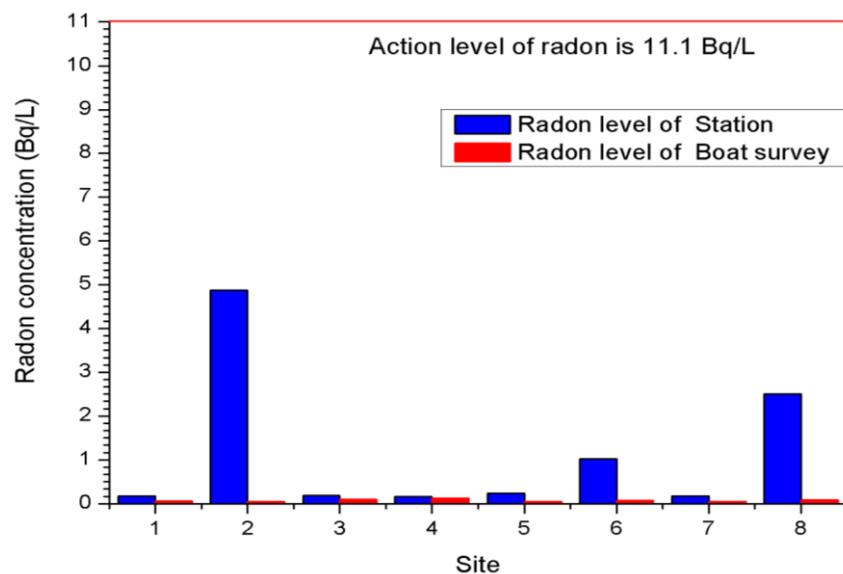
**Table 2.** The results of 8 boat surveys along Nam Phong River.

The boat survey	No. of routes	Distance of routes (m)	Radon		$D_{ing}$	$D_{inh}$	$D_{total}$	ELCR	LCC
			Bq/L	Bq/m <sup>3</sup>					
1	4	5,308.44	0.05749	57.49	0.434	0.428	0.862	0.0369	15.53
2	2	925.45	0.05023	50.23	0.128	0.127	0.255	0.0109	4.59
3	2	1,258.30	0.09460	94.60	0.242	0.238	0.480	0.0205	8.64
4	2	1,344.13	0.12342	123.42	0.315	0.311	0.626	0.0268	11.27
5	1	635.53	0.04247	42.47	0.109	0.107	0.216	0.0092	3.88
6	1	469.01	0.08008	80.08	0.205	0.202	0.407	0.0174	7.32
7	1	498.56	0.05404	54.04	0.138	0.136	0.274	0.0117	4.94
8	1	833.43	0.09144	91.44	0.234	0.230	0.464	0.0198	8.35
<b>Min</b>			0.04247	42.47	0.109	0.107	0.216	0.0092	3.88
<b>Max</b>			0.12342	123.42	0.434	0.428	0.862	0.0369	15.53
<b>Mean</b>			0.07422	74.22	0.226	0.222	0.448	0.0192	8.07
<b>S.D.</b>			0.02787	27.87	0.109	0.108	0.216	0.0093	3.90

According to Table 2, the radon concentrations in surface water samples were measured during 8 boat survey routes along the Nam Phong River, ranging from 0.04247 to 0.12342 Bq/L, with an average concentration of 0.07422 Bq/L. The highest radon concentration was observed at Site 4: Ban Tha Pho, Tha Kraserm Sub-district, reaching 0.12342 Bq/L, while the lowest concentration was recorded at Site 5: Ban Huai Sun, Sila Sub-district, with a concentration of 0.04247 Bq/L. The results of radon concentration in the Nam Phong River were calculated based on the annual ingestion dose ( $D_{ing}$ ), the annual inhalation dose ( $D_{inh}$ ), the

excess lifetime cancer risk (ELCR), and the evaluation of the number of lung cancer cases per year per million people (LCC). The findings revealed that the  $D_{ing}$  ranged from 0.109 to 0.434  $\mu\text{Sv/y}$  (mean = 0.226  $\mu\text{Sv/y}$ ), the  $D_{inh}$  ranged from 0.107 to 0.428  $\mu\text{Sv/y}$  (mean = 0.222  $\mu\text{Sv/y}$ ), the ELCR ranged from 0.0092 to 0.0369 (mean = 0.0192), and the LCC ranged from 3.88 to 15.53 (mean = 8.07).

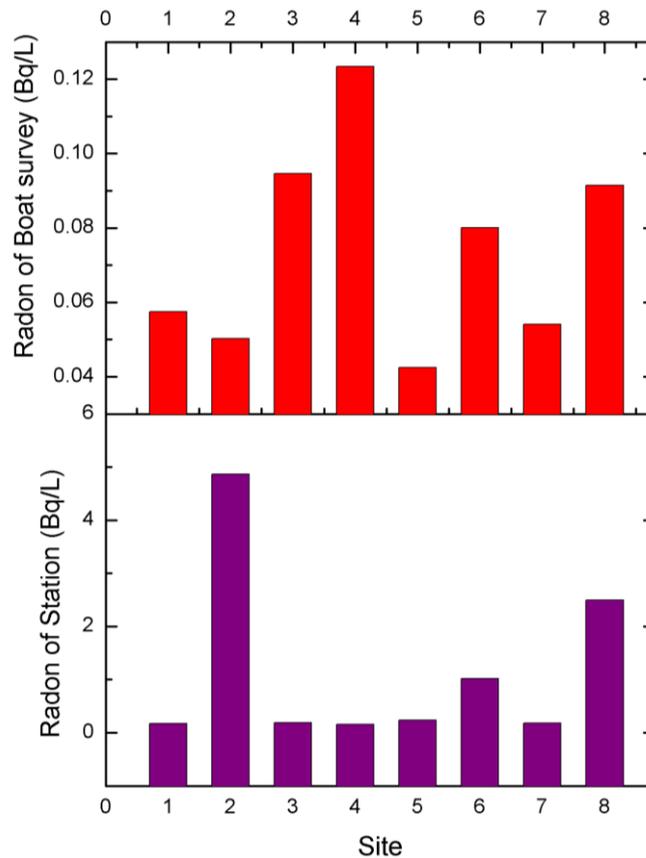
These results were compared with safety limit values, which WHO and USEPA recommend to find that the radon concentration, the  $D_{ing}$ , and the  $D_{inh}$  in surface water were lower than the action level. The mean Excess Lifetime Cancer Risk (ELCR) for radon exposure in the study area was 0.0192 %, which is relatively low compared to the action level set by the US EPA. The estimated risk of 1.3% corresponds to radon exposure of 148  $\text{Bq/m}^3$  for the entire population [21]. The results of LCC ranged between 3.88 and 15.53 per million persons per year with a mean value of 8.07 per million persons per year, which is lower than the limit range of 170 - 230 per million persons recommended by ICRP [21].



**Figure 5.** The relationship between radon concentration levels measured at the station and those measured during boat surveys and the action level of radon is 11.1 Bq/L, as advised by US EPA and WHO.

Figure 5 shows the levels of radon contamination in Nam Phong River obtained from measurements at stations installed along the river and measurements made on boats surveying the river. Both values were compared with the action level of the maximum contamination level of radon in the water, which is 11.1 Bq/L, recommended by the US EPA and WHO [1, 4-7]. All results from the measurements were lower than the action level. The data analysis in Figure 5 revealed that the radon concentration in the water measured at Stations 2, 6, and 8 had abnormally high values compared to the radon concentration in the water measured during the boat survey in the river. This difference is likely due to radon infiltration from shallow groundwater near the measuring station. Geological variations in different formations can influence radon content in groundwater, which is approximately 1,000 times greater than surface water. Stations in nearby areas with higher radon-producing rocks or soil may have higher concentrations, and areas with more standing water. Considering the dynamics within the river, water flow and mixing can significantly impact radon concentrations. Faster-moving water tends to have lower radon concentrations because the radon is more quickly diluted. In contrast, slower-moving or stagnant water can accumulate radon gas, leading to higher concentrations. The boat survey might have covered areas with more dilution from other water sources, resulting in lower readings [24-25].

Take data from Tables 1 and 2 and plot the graph to study the relationship between the radon concentration levels measured at stations and those measured during the boat survey, as shown in Figure 6.



**Figure 6.** The relationship between radon concentration levels measured at the station and those measured during boat surveys.

Analysis of the results in Figure 6 suggests that radon may have been transferred into the Nam Phong River, particularly at stations 6 and 8, as indicated by the high radon concentration levels measured at these locations. However, at Station 2, there may have been no radon transfer into the Nam Phong River, as the radon concentration measured during the boat survey was low. Furthermore, the higher radon values measured from boat tours in Areas 3 and 4, compared to other areas, may be attributed to rocks, soil, or sediment at the bottom of the river. The high concentration of radium-rich rivers decaying into radon could contribute to the elevated radon levels in these areas. It is important to note that this is solely an analysis of the results obtained from this research. Additional factors must be studied to gain a more comprehensive understanding of the transfer of radon in groundwater flowing into rivers. These include further measurements of radium and radon in groundwater, sediment, or rivers; assessment of water velocity; analysis of water quality parameters such as temperature, pH, conductivity, and nutrient levels; and consideration of seasonal and time (day-night). The complexity of these factors may necessitate additional research in the future.

#### 4. Conclusions

The radon contamination level in surface water from 8 stations and 8 boat surveys along the lower Nam Phong River Basin in all 3 Districts (Ubonrat District, Nam Phong District, and Mueang District), results measured radon contamination level in all samples were lower than action level by the US EPA and WHO. The total annual effective dose for inhalation and ingestion of radon in surface water samples was below 100  $\mu\text{Sv/y}$  suggested by the WHO. The mean excess lifetime cancer risk (ELCR) was below the permissible limit of 1.3 % indicated by the US EPA, and the mean of LCC is lower than the limit range of 170-230 per million persons recommended by ICRP. This project demonstrates that surface water in the study area is safe for public consumption. It also provides preliminary data to study the transfer of radon content from shallow groundwater flowing into rivers, which indicates locations where water pollution has occurred. If you want

to learn more about this work, the researcher suggests additional studies on several factors. These include additional measurements of radium and radon in groundwater, sediment, or rivers; water velocity; and various water quality parameters such as temperature, pH, conductivity, and nutrient levels. The study should also consider seasonal variations and the time of day (day and night). Given the complexity of the matter, further research is needed to explore these factors, which may lead to additional studies soon.

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