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Risk Factors Affecting the Bacterial Contamination in Water of Thailand's Upper South 2020 - 2022

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Abstract

Bacterial contamination in water is an important cause of human health problems. Water-borne infections are among the top 10 reasons for illness in Thailand and accounted for 40 % of all infections necessitating surveillance. The purpose of this study was to identify environmental factors influencing bacterial contamination in water in the upper southern region of Thailand. Secondary data on water quality were obtained from 2 Regional Medical Sciences Centers, and environmental data were collected from the National Statistical Office's annual reports for 2020 - 2022. A multiple logistic regression model was used to investigate the factors influencing bacterial contamination to exceed the standard. There were 674 water samples contaminated with bacteria, which implied 10.97 % of the total number of samples. The factors that were significantly associated with greater bacterial contamination than standard were provinces and years of production, water types, bacterial types and rainfall levels. Bacteria were more likely to contaminate the water generated in Chumphon province. The quantity contamination for consumption water varied by years of production, with Total Coliform Bacteria (TCB) being the most contaminated bacterial strain as rainfall increases. High precipitation deteriorated biological water quality, which was the origin of water-borne diseases. Entrepreneurs and other connected organizations must constantly watch for bacterial contamination when there is a change in a manufacturing site or when the season changes from hot to rainy.

Keywords: Risk factors, Bacteria, Contamination, Water, Public health area, Thailand

Introduction

Bacterial contamination in water is a leading cause of human illness. A high bacteria concentration indicates a lack of cleanliness and hygiene [1]. Indicators organisms for biological water quality surveillance can be used to assess cleanliness, and pathogenic bacteria can be used for the detection of water-borne diseases [2,3]. The presence of an indicator organism indicates the presence of pathogenic organisms [4,5]. Coliform bacteria (e.g., fecal coliform and *E. coli*) are used as water hygiene indicators since they are not generally detected in clean water [1,6]. Pathogenic bacteria cause illness when exposed to water, such as *E. coli*, *Salmonella* spp., *Vibrio cholerae* and *Campylobacter* [7]. Most food and water-borne disease outbreaks are caused by *Shigella* spp., *Vibrio cholerae* [6], *Salmonella* spp. and *E. coli* [8]. Consuming bacterially contaminated water exposes one's health to communicable diseases such as diarrhea, typhoid, dysentery, cholera and hepatitis A [9]. In addition, waterborne infection epidemics continue to be a major global public health issue. Waterborne diseases can be contracted by eating or drinking contaminated local economy products [7]. Every year, an estimated 2 billion people drink contaminated water, resulting in an epidemic of 502,000 diarrhea deaths [10], and approximately 3.4 million people die from water-related diseases [11]. Water-borne diarrhea was documented in the 2018 Handbook of Common Diseases in Thailand, which revealed the country's 3rd-highest morbidity rate, with 40 % of that infected death [12]. Hepatitis A is also one of the most contagious diseases, followed by hepatitis E and typhoid fever [13]. Disease symptoms might include gastrointestinal illnesses such as severe diarrhea, nausea, jaundice, headaches and fatigue [4].

Nutrients and environments are the 2 most principal factors influencing bacterial growth and population [14]. Several studies discovered environmental factors, temperatures, rainfall and humidity influenced bacterial contamination in water [15-19], while others found no relevance but found the types of microorganisms. Geographical locations, seasons, types of water, water treatment process, salinity, organic matters, pH [20], sediment [21] and disease carriers such as flies [5] can be considered all factors that influence water bacterial contamination.

The Upper South of Thailand lies between the Gulf of Thailand to the east and the Andaman Sea to the west. This region is affected by monsoons from the northeast and the southwest, resulting in 2 seasons: Hot and rainy. The average air temperature for the entire year is 20.0 - 28.1 °C, the annual accumulated precipitation is 1,418.1 - 4,183.7 mm, and 70 - 83 % relative humidity on average are found [22]. The water quality is acceptable and better than in other regions of Thailand [23]. Bacterial contamination in water can occur at any time during manufacturing, transportation and storage processes before it reaches consumers [24]. Water quality tests undertaken by government laboratories in the Upper South have repeatedly found that bacterial contamination exceeds the standard level in both raw and processed water [25]. Referring to the standards of Ministry of Public Health Notifications No. 61 and 416, which demand a water quality inspection at least once a year, TCB is less than 2.2, *S. aureus* is fewer than 100 CFU, and *E. coli* and *Salmonella* spp. are not discovered per 100 mL [26,27]. Additionally, numerous patients during 2020 - 2022 in the Upper South of Thailand were found to have infections caused by water, with 71,343, 40,200 and 30,877 cases, respectively [28]. It is necessary to look more closely at the environmental factors influencing the prevalence of bacteria in the upper southern region, especially air temperatures and rainfall. Therefore, this study was aimed to identify factors associated with bacterial contamination in water based on the literature review.

Materials and methods

Data source

Water quality data in 2020 - 2022 were obtained from the annual reports of Public Health Area 11 (PHA 11) which consisted of the Regional Medical Sciences Center 11 (RMSC 11) and RMSC 11/1, the Department of Medical Sciences, the Ministry of Public Health. RMSC 11 is in charge of inspecting water quality in 4 provinces: Chumphon, Ranong, Surat Thani and Nakhon Sri Thammarat whereas RMSC 11/1 is responsible for inspecting water quality in 3 provinces: Phang Nga, Phuket and Krabi. Meteorological data, air temperatures and rainfall in 2020 - 2022 were also taken from the National Statistical Office of Thailand's Statistical Yearbook (**Figure 1**).

Data management

The raw data were acquired from the frequency of water samples tested for bacteriological quality by total sample counts as well as the number of non-standard water samples. That data was classified according to provinces, years of production, water types and bacterial kinds. The water types were classified into 4 categories: Drinking (clean water for people to drink), ice (water generated by solidification), processed (water used in manufacturing, particularly in the food industry) and consumed (household water such as tap water). The bacterial types were classified into 4 types: TCB, *Escherichia coli* (*E. coli*), *Staphylococcus aureus* (*S. au*) and *Salmonella* spp. (Sal) by counting the total frequency of each type of bacteria for non-standard water quality (or which failed the standard according to the announcement of the Ministry of Public Health No. 61 and 416). The years of production consisted of 3 years: 2020, 2021 and 2022. The provinces consisted of Chumphon, Ranong, Surat Thani, Nakhon Sri Thammarat, Phang Nga, Phuket and Krabi. Air temperatures and rainfall levels were divided into 2 levels using the average as a criterion. Air temperatures were divided into 2 levels: Less than or equal to 27.5 °C, and more than 27.5 °C. Rainfall was divided into 2 levels: Less than or equal to 2,500 mm, and more than 2,500 mm. The number of water samples that passed and failed inside the standard thresholds was grouped by the provinces, the years of production, the bacterial kinds, the temperature levels and the rainfall levels.

Statistics analysis

The determinants of this study were environmental elements that were risk factors, specifically the provinces, the years of production, the bacterium types, the water types, the temperature levels and the rainfall levels as aforementioned. The outcomes of this study were samples that failed to meet the standard criteria, and all were categorical data. The descriptive analysis was performed by statistics of the frequency and the percentage of categorical variables, as well as bacterial prevalence to see the frequency of bacterial contamination in each province, which was calculated having the non-standard samples divided by the total number of the samples and then multiplying by a constant value. Besides, the chi-square test was employed to examine the association between the determinants and the outcomes. The independent variables were then incorporated one by one in a simple model to evaluate their univariate relationships with the results. The independent variables were statistically significant, which were included in the initial multiple logistic regression model. The area under the ROC curve (AUC) was used to evaluate the predictive performance of the model. The results from a model were shown as confidence interval (CI) plots. All statistics and models were analyzed at 95 % of the confidence level using the R and RStudio program version 4.1.1 [29].

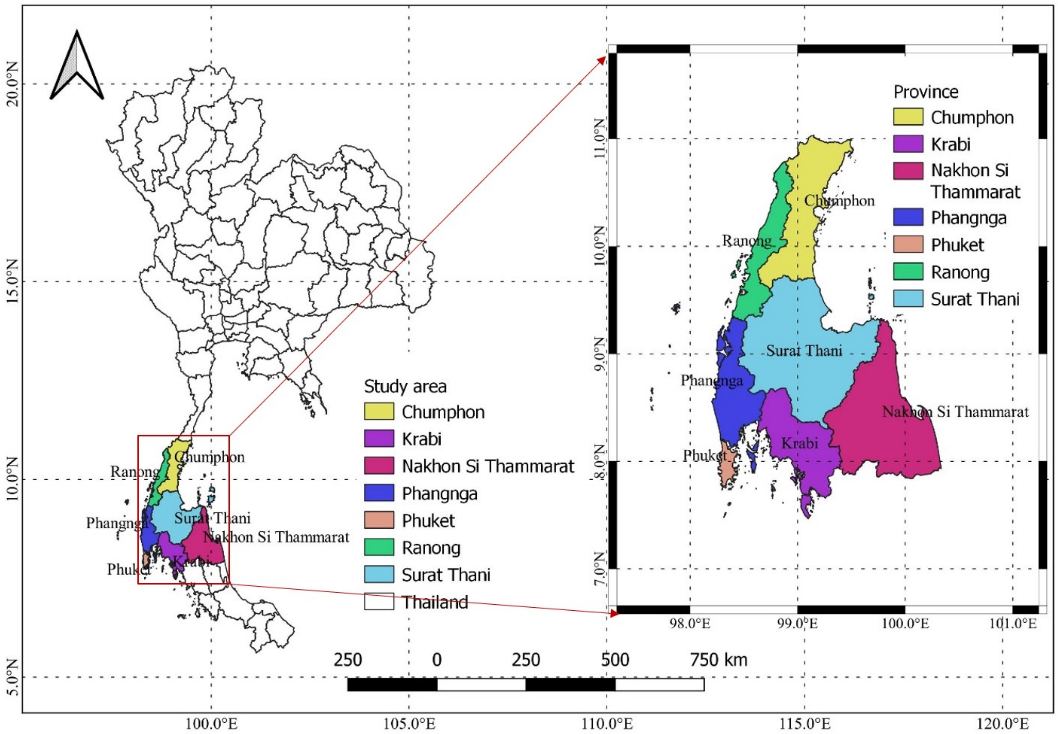

Figure 1 Data sources of 7 provinces in the Upper South of Thailand.

Results and discussion

Descriptive analysis of water quality data

In Ranong, the highest prevalence of non-standard water quality was found in 2020, at 21.43 %, whereas the lowest was revealed in Phuket, at 8.37 %. In 2021, the greatest non-standard water was in Ranong at 20 %, while the lowest was in Krabi, at 8.07 %. In 2022, the highest prevalence was shown in Chumphon, at 21.77 %, while the lowest appeared in Phuket, at 7.14 %. In terms of bacteria, the greatest bacterial prevalence was in Ranong (20.9 %), and the lowest was in Phuket (8.6 %) as shown in **Figures 2**(**a**) - **2**(**d**)). Moreover, an increasing trend of the prevalence of bacteria exceeding the standard was found in Chumphon and Surat Thani, while a decreasing trend of the prevalence of bacteria exceeding the standard was found in Ranong. In Phang Nga, Krabi, Phuket and Nakhon Sri Thammarat, there were fluctuations in the detection of bacterial contamination. It could be seen that bacterial contamination is common in upper southern Thailand as an effect of the humid tropical, temperatures and topography conducive to bacterial growth and sustenance [23]. From 2017 until the present, all sectors have become conscious of the importance of using water safely. Quality checks are performed on a regular basis. Drinking water, in accordance with Food and Drug Administration regulations [26,27] and household tap water [30] must meet the required standards. Besides, in accordance with the national strategic plan, the goal is to provide everyone with access to safe drinking water, according to United Nations (UN) agreements to achieve Sustainable Development Goal 6 (SDG 6) [31].

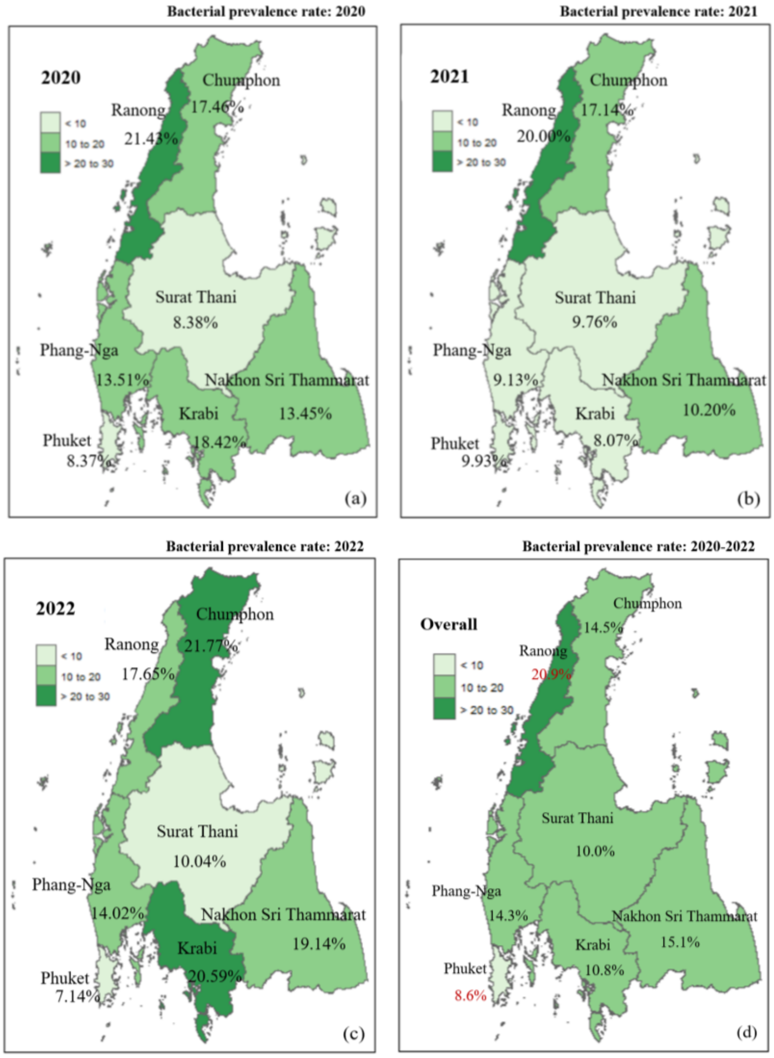

Figure 2 Thematic maps of bacterial prevalence separated into each province and each year of production, in 2020 (a), 2021 (b), 2022 (c), and overall, 2020 - 2022 (d).

Out of the total of 6,142 samples, 674 (10.97 %) exceeded the criteria for bacterial contamination. As shown in **Table 1**, the highest bacterial contamination was found in Ranong (20.87 %), while the lowest was found in Phuket (8.65 %). The prevalence of bacterial contamination exceeding the standard level was the maximum in 2022 (12.25 %) and the lowest prevalence was in 2021 (9.92 %). The consumption water showed the highest level of bacterial contamination (15.44 %) whereas the drinking water was at the lowest level (6.34 %). Importantly, the highest bacterial contamination (12.30 %) was found at air temperatures less than or equal to 27.5 °C, whereas the lowest (0.97 %) was observed at above 27.5 °C. Regarding the rainfall, there was the highest bacterial contamination at greater than 2,500 mm of the rainfall levels (12.64 %). The lowest bacterial contamination was observed at less than or equal to 2,500 mm of rainfall (9.95 %). Furthermore, the highest bacteria contaminated in the water were the TCB strains (24.27 %), while the lowest bacteria were *Salmonella* spp. (0.86 %). In Thailand, agencies under the Ministry of Public Health have measures to monitor water quality to ensure that it is safe for consumption. A handbook on environmental health standards has been produced to guide all sectors in the same direction to manage, prevent, and monitor regularly [32], including a Thailand Drinking Water Standard Guide to ensure that drinking water quality meets quality standards, and strictly enforce laws that contain penalties and prohibit sales [33].

Table 1 Bacterial prevalence rate divided by each risk factors.

Risk factors	Total samples	Non-standard samples	Prevalence rate/100
Provinces of production			
Chumphon	365	53	14.52
Ranong	158	33	20.87
Surat Thani	1,484	149	10.04
Nakhon Sri Thammarat	742	122	16.44
Phuket	2,450	212	8.65
Phang Nga	490	56	11.43
Krabi	453	49	10.82
Years of production			
2020	1,530	157	10.26
2021	2,066	205	9.92
2022	2,546	312	12.25
Water types			
Drinking	2,635	167	6.34
Ice	915	109	11.91
Processed	169	24	14.20
Consumption	2,423	374	15.44
Bacterial types			
TCB	1,949	473	24.27
E. coli	1,625	161	9.91
S. aureus	1,274	29	2.28
Salmonella spp.	1,294	11	0.86
Rainfall levels (mm)			
≤ 2,500	3,808	379	9.95
> 2,500	2,334	295	12.64
Air temperature levels (°C)			
≤ 27.5	2,960	364	54.01
> 27.5	3,182	310	45.99

Descriptions of meteorological data

The average air temperature in Thailand's Upper South in 2020 - 2022 was 27.70 ± 0.19 °C. The highest average temperature was at 29.03 ± 0.25 °C in Phuket, while the lowest was at 27.27 ± 0.23 °C in Surat Thani. The average annual rainfall was 2,573.33 ± 526.99 mm. The highest rainfall amount was measured in Ranong, with 4,133.47 ± 1,271.74 mm, while the lowest rainfall was recorded in Surat Thani, with 1,562.63 ± 438.41 mm, as stated in **Table 2**. This information is congruent with statistics from the Regional Environment Office 15, which shows that the highest total rainfall appears in Ranong and Phang Nga, known as the 8-month rainy city with only 4-month sunshine. In addition, in Thailand's upper southern area, the highest average air temperature is in Phuket because its most locations are mountainous plains, and it receives monsoon winds all year [23].

Table 2 The average and standard deviation of meteorological data divided by provinces between 2020 and 2022.

Provinces	**Average ± SD**	
	Air temperatures (°C)	**Rainfall (mm)**
Surat Thani	27.27 ± 0.23	1562.63 ± 438.41
Chumphon	27.50 ± 0.17	1864.87 ± 170.65
Nakhon Sri Thammarat	27.63 ± 0.15	2663.77 ± 507.86
Ranong	27.60 ± 0.26	4133.47 ± 1271.74
Phuket	29.03 ± 0.25	2068.87 ± 449.48
Krabi	27.30 ± 0.17	1850.70 ± 398.28
Phang Nga	27.53 ± 0.12	3868.27 ± 452.51
Average	27.70 ± 0.19	2573.33 ± 526.99

The results of the chi-square test and the univariate analysis revealed that bacterial contamination above the standard were substantially associated with the provinces of production, the water types, the production years, the bacterial types, the temperature levels and the rainfall levels (explained in supplementary file S1). **Table 3**, showing the results of the multiple logistic regression model, revealed that the provinces of production, the water types, the production years, the bacterial types and the precipitation levels increased the risk of detecting bacterial contamination above the standard. The performance of the model, which was evaluated by the ROC curve, showed high accuracy (AUC = 0.82) and good convergence with the actual data.

The model was able to predict the likelihood of finding bacterial contamination in Surat Thani, Chumphon, Nakhon Sri Thammarat, Ranong and Krabi, where there was greater bacterial contamination than the standard, with 1.93, 3.35, 2.56, 2.28 and 3.91 times, respectively, when compared to Phuket. This study found that bacterial contamination varied according to the producing provinces. Most of the southern province areas are plateaus with large mountain ranges and coastal plains. When a monsoon breeze blows through, there is a lot of rain, and the weather varies throughout the year. Due to the various geographic and climatic variables like temperatures, precipitations, sediments, turbidity and retention periods, the types and degrees of bacterial contamination were influenced [34]. Similarly, You *et al.* [35] study discovered that variations in geography, environments, terrains, and climates caused changes in water quality. In 2006, Tharnpoophasiam *et al.* [36] evaluated the difference in water quality between the tsunami-affected area and the nearby untouched areas. The 2 regions were discovered to have varied water quality. Similarly, Bastaraud *et al.* [37] stressed that the main factor of bacterial contamination was the location of the production facility. This also aligns with the research conducted by Archer *et al.* [30], which indicated that climate change and geography contributed to the increased spread of bacteria.

According to the water types, when compared to the drinking water, the bacteria contamination in the ice, the process water and the consumption water were found to be 2.4, 2.79 and 3.41 times higher, respectively. The consumption water or the tap water was more prone to bacterial contamination than the regular drinking, the ice and the process water. Tap water was mostly derived from well water, underground water and rain. Chlorine and sand filters were used to eliminate microorganisms and stored in big containers before being piped to households [38]. Cross-contamination can occur during transmission to homes over damaged pipes. Unclean containers and prolonged storage can increase the number of bacteria growths as well [39]. The current study was additionally consistent with the study of Thongkhow *et al.* [40] conducted in Nakhon Sri Thammarat, Thailand, which discovered non-standard water quality due to a lack of regular quality control, resulting in a major cause of bacterial contamination. In fact, water which is processed, such as drinking water, ice and food processing water, is required to store in non-recyclable materials and should contain low bacterial contamination; therefore, water producers must be fined, banned, and halted for sales, and production until the water quality meet this criterion standard [41].

The bacterial contamination was 1.45 times higher in 2022 than in 2021. The number and types of bacteria could be identified depending on their life cycles, living habitats and the periods of the study time [6]. This study indicated that the quantity of bacterial contamination in water fluctuated and exceeded the highest standard in 2022. This could be due to environmental changes that caused the overall rainfall in 2022 to be higher than in 2020 - 2021 [22]. This was considered one of the reasons for the increased bacterial contamination. These results were congruent with the findings of Poulin *et al.* [42], who discovered that strong rains could carry sewage from the neighborhood or agricultural runoff into water sources; bacterial contamination, therefore, rises.

Types of bacteria were associated with water quality that did not meet the specified standards. For each bacteria type, *S. aureus*, *E. coli* and TCB were 2.79, 13.46 and 40.47 times more contaminated than the norm, respectively, when compared to *Salmonella* spp. This study discovered that the indicator bacteria (TCB and *E. coli*) were more likely found than the pathogenic bacteria (*S. aureus* and *Salmonella* spp.) to surpass the standard criteria. The presence of these bacteria indicated that there was a reasonable chance of detecting pathogenic bacteria in the water [43]. This finding was consistent with Yates' [21] study, which discovered that the indicator bacteria were always identified before the pathogenic bacteria were detected, and they were typically more difficult to find in nature and grow in the environment than TCB and *E. coli*.

In addition, rainfall also influenced bacteria counts and water quality. When the rainfall amounts exceeded 2,500 mm, bacterial contamination was 1.78 times higher than it was with less than or equal to 2,500 mm of the rainfall amounts. This analysis revealed that when the rainfall amounts increased, there was an increase in bacterial contaminants in the water. Similarly, a 2019 study on factors impacting on water bacterial pollution by Seo *et al.* [44] in South Korea discovered that higher rainfall increased the rate of bacterial contamination. Likewise, Powers *et al.* [45] discovered in a 2012 - 2014 study that higher rainfall in Kenya caused changes in water quality and increased bacterial contamination, as sewage from houses and farmland infiltrated the water supply. In addition, an investigation conducted by Love and Laub in Texas found substantial evidence linking increased rainfall to a higher concentration of bacteria. Their study, conducted in both urban and rural areas, emphasized that this correlation was particularly pronounced within city environments [46].

Table 3 Factors association with the bacterial contamination in the Upper South of Thailand.

Risk factors	Crude OR (95 % CI)	Adj OR (95 % CI)	*p*-value
Provinces of production			< 0.001
Surat Thani	1.18 (0.95, 1.47)	1.93 (1.46, 2.56)	
Chumphon	1.79 (1.30, 2.48)	3.35 (2.27, 4.93)	
Nakhon Sri Thammarat	2.08 (1.63, 2.64)	2.56 (1.85, 3.54)	
Ranong	2.79 (1.85, 4.19)	2.28 (1.36, 3.80)	
Phuket	1.00	1.00	
Krabi	1.28 (0.92, 1.78)	2.91 (1.91, 4.43)	
Phang Nga	1.36 (1.00, 1.86)	1.46 (0.98, 2.16)	
Water types			< 0.001
Drinking	1.00	1.00	
Ice	2.00 (1.55, 2.58)	2.40 (1.81, 3.20)	
Process	2.45 (1.54, 3.87)	2.79 (1.68, 4.63)	
Consumption	2.70 (2.23, 3.27)	3.41 (2.75, 4.23)	
Years of production			< 0.001
2020	1.04 (0.83, 1.29)	1.19 (0.83, 1.71)	
2021	1.00	1.00	
2022	1.27 (1.05, 1.53)	1.45 (1.09, 1.94)	
Bacterial types			< 0.001
Salmonella spp.	1.00	1.00	
Staphylococcus aureus	2.72 (1.35, 5.46)	2.79 (1.38, 5.61)	
Escherichia coli	12.83 (6.93, 23.73)	13.46 (7.26, 24.98)	
Total Coliforms Bacteria	37.38 (20.46, 68.27)	40.47 (22.09, 74.13)	

Risk factors	Crude OR (95 % CI)	Adj OR (95 % CI)	*p*-value
Rainfall levels (mm)			< 0.001
≤ 2,500	1.00	1.00	
> 2,500	1.31 (1.11, 1.54)	1.78 (1.27, 2.50)	
Temperature levels (°C)			< 0.001
≤ 27.5	1.00	1.00	
> 27.5	0.77 (0.66, 0.90)	0.91 (0.58, 1.42)	

Note: Crude OR (crude odds ratio) = cOR, Adj OR (adjust odds ratio) = aOR.

This study discovered that the provinces, the years of production, the types of water, the bacterial species, and the rainfall levels were the major risk factors for above-standard bacterial contamination in the water in Thailand's Upper South. The likelihood of bacterial contamination was the greatest in Chumphon, particularly in 2022. TCB was the most prevalent in the consumption water and rose with the increasing rainfall. Furthermore, this information can act as a database for all relevant organizations to conduct holistic water management, fostering collaboration to provide clean, safe and sufficient water quality for everybody. Sustainable access is consistent with the United Nations National Strategic Plan and SDG 6 [31]. A 95 % confidence intervals plot of bacterial prevalence rate was split by the overall mean at 10.97 % (red line) as shown in **Figure 3**. In RMSC 11, there was more bacterial prevalence than in RMSC 11/1. That is, the highest prevalence of the bacteria was found in Chumphon, followed by Nakhon Sri Thammarat and Ranong, respectively. The prevalence of these 3 provinces was also higher than the overall average, indicating a high risk of the bacterial contamination exceeding the standard. The results also showed the prevalence of the bacteria exceeding the highest standard in 2022 in the consumption water, with TCB bacteria being the most prevalent when the rainfall amount was greater than 2,500 mm. According to the study's findings, the issues to be researched are environmental risk factors that influence water pollution when it changes. This is because the volume and kinds of bacteria vary depending on their habitats and environments [47]. As a result, reducing the risk of bacterial contamination requires regulating environmental changes and being cautious at every stage of the process, from production, transportation to customers [48].

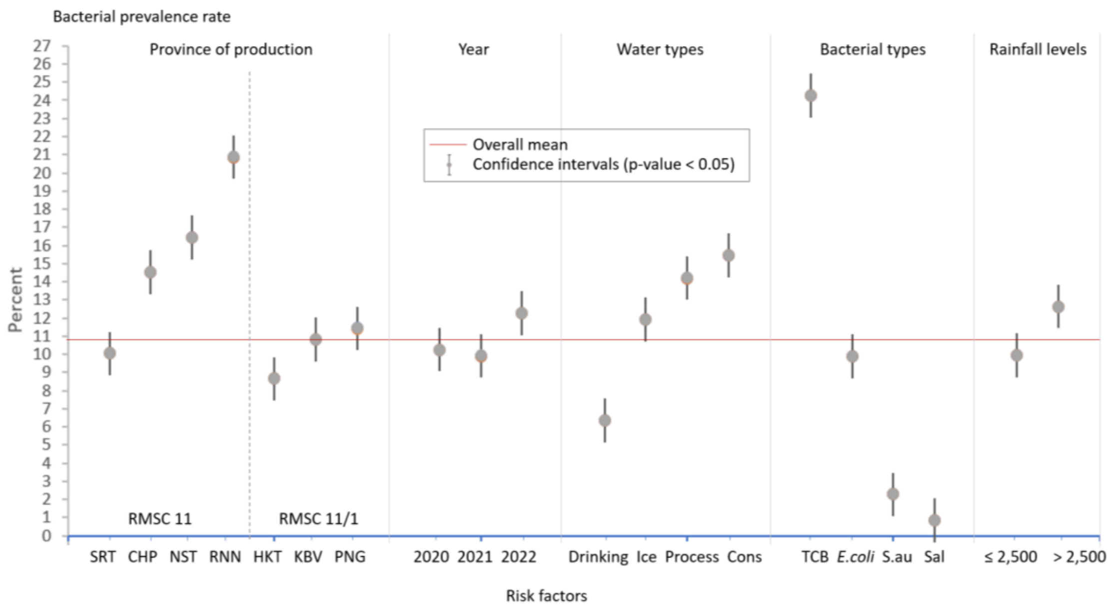

Figure 3 The 95 % CI of the factors influencing the bacterial prevalence in the water from the multiple logistic regression model. Note: SRT is Surat Thani, CHP is Chumphon, NST is Nakhon Sri Thammarat, RNN is Ranong, HKT is Phuket, KBV is Karabi, PNG is Phang Nga and Cons is Consumption.

Study limitations

This investigation of the secondary data was employed in this study. As a result, there were some limitations on the details that can be accessed. There was also the possibility of bias or misunderstanding in the data analysis. In addition, this was the initial study of the environmental factors affecting bacterial contamination in water. Therefore, the information and the duration were restricted. Further research should be conducted by expanding the research duration, adding spatial data, and physical and chemical water quality, all of which could influence bacterial contamination.

Conclusions

This study demonstrated that the most significant environmental factors affecting bacterial contamination in water exceeding the required levels in Thailand's upper southern region were the locations and the years of production, the types of water, the types of bacteria, and the rainfall amounts. These were also the main contributors underlying rising water-bacterial contamination, which caused infections transmitted through the water. Bacteria contamination in water could become a public health issue in Thailand. Monitoring changes in risk variables such as greater precipitation during the rainy season or modifications in the locations of water production are critical that operators and relevant authorities should rigorously supervise.

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References

[1] S Srikullabutr, P Sattasathuchana, A Kerdsin and N Thengchaisri. Prevalence of coliform bacterial contamination in cat drinking water in households in Thailand. *Vet. World* 2021; **14**, 721-6.

[2] C Somnuk and L Jareanviset. Coliform bacteria examination in ready to eat food at Rambhai Barni Rajabhat University. *Rajabhat Rambhai Barni Res. J.* 2016; **10**, 89-94.

[3] World Health Organization. Guidelines for drinking-water quality, Available at: http://www. who.int, accessed January 2023.

[4] Minnesota Department of Health. Coliform bacteria, Available at: https://www.health.state.mn.us/ communities/environment/water/docs/contaminants/coliform.pdf, accessed January 2023.

[5] M Metz, J Sheehan and PCH Feng. Use of indicator bacteria for monitoring sanitary quality of raw milk cheeses - a literature review. *Food Microbiol.* 2020; **85**, 103283.

[6] PK Pandey, PH Kass, ML Soupir, S Biswas and VP Singh. Contamination of water resources by pathogenic bacteria. *AMB Express* 2014; **4**, 51.

[7] E Taviani, HVD Berg, F Nhassengo, E Nguluve, J Paulo, O Pedro and G Ferrero. Occurrence of waterborne pathogens and antibiotic resistance in water supply systems in a small town in Mozambique. *BMC Microbiol.* 2022; **22**, 243.

[8] ER Atwill and S Jeamsripong. Bacterial diversity and potential risk factors associated with *Salmonella* contamination of seafood products sold in retail markets in Bangkok, Thailand. *PeerJ* 2021; **9**, e12694.

[9] J Ahmed, LP Wong, YP Chua, N Channa, RB Mahar, A Yasmin, JA VanDerslice and JV Garn. Quantitative microbial risk assessment of drinking water quality to predict the risk of waterborne diseases in primary-school children. *Int. J. Environ. Res. Publ. Health* 2020; **17**, 2774.

[10] HH Patel and M Pharm. Water-borne diseases, Available at: https://www.news-medical.net/health/ Water-Borne-Diseases.aspx, accessed January 2023.

[11] The United States Agency for International Development (USAID), Available at: https://pdf.usaid.gov/pdf_ docs/PA00XVHF.pdf, accessed January 2023.

[12] Luma Health Insurance. Guide to common diseases in Thailand, Available at: https://www. lumahealth.com/guides/thailand/common-diseases-in-thailand, accessed January 2023.

[13] The Borgen Project. Water quality in Thailand, Available at: https://borgenproject.org/water-quality-in-thailand-2/, accessed January 2023.
[14] F Briški and MV Domanovac. Environmental microbiology. *Phys. Sci. Rev.* 2017; **2**, 20160118.
[15] S Jeamsripong, R Chuanchuen and ER Atwill. Assessment of bacterial accumulation and environmental factors in sentinel oysters and estuarine water quality from the Phang Nga estuary area in Thailand. *Int. J. Environ. Res. Publ. Health* 2018; **15**, 1970.
[16] S Hales. Climate change, extreme rainfall events, drinking water and enteric disease. *Rev. Environ. Health* 2019; **34**, 1-3.
[17] EJ Gomez, JA Delgado and JM Gonzalez. Environmental factors affect the response of microbial extracellular enzyme activity in soils when determined as a function of water availability and temperature. *Ecol. Evol.* 2020; **10**, 10105-15.
[18] N Onmek, J Kongcharoen, A Singtong, A Penjumrus and S Junnoo. Environmental factors and ventilation affect concentrations of microorganisms in hospital wards of southern Thailand. *J. Environ. Publ. Health* 2020; **2020**, 7292198.
[19] S Jeamsripong, V Thaotumpitak, S Anuntawirun, N Roongrojmongkhon and ER Atwill. Meteorological and water quality factors associated with microbial diversity in coastal water from intensified oyster production areas of Thailand. *Water* 2022; **14**, 3838.
[20] D Hou, Z Huang, S Zeng, J Liu, D Wei, X Deng, S Weng, Z He and J He. Environmental factors shape water microbial community structure and function in shrimp cultural enclosure ecosystems. *Front. Microbiol.* 2017; **8**, 2359.
[21] MV Yates. Drinking water microbiology. *Encyclopedia Microbiol.* 2019; **4**, 83-9.
[22] National Statistical Office. Statistical yearbook Thailand 2022, Available at: http://service.nso.go.th/nso/nsopublish/pubs/e-book/SYB-2022/index.html, accessed December 2022.
[23] Regional Environment Office 15, Available at: http://www.oic.go.th/FILEWEB/CABINFOCENTER66/DRAWER040/GENERAL/DATA0000/00000545.PDF, accessed December 2021.
[24] K Klaharn, D Pichpol, T Meeyam, T Harintharanon, P Lohaanukul and V Punyapornwithaya. Bacterial contamination of chicken meat in slaughterhouses and the associated risk factors: A nationwide study in Thailand. *PLos One* 2022; **17**, e0269416.
[25] Regional Medical Sciences Center 11, Surat Thani, Available at: https://rmsc11. dmsc.moph.go.th/e-book/Annual2565/, accessed December 2022.
[26] The Ministry of Public Health. *Drinking water in sealed containers*. The Government Gazette, Bangkok, Thailand, 1981.
[27] The Ministry of Public Health. *Prescribing quality standard terms conditions and method for the analysis of food on pathogenic microorganisms*. The Government Gazette, Bangkok, Thailand, 2020.
[28] Department of Diseases Control. Health statistics of Thai people at the area level, Available at: https://www.hiso.or.th/thaihealthstat/area/index.php?ma=4&pf=01818101&tp=203, accessed December 2022.
[29] RC Team. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria, 2020.
[30] EJ Archer, C Baker-Austin, TJ Osborn, NR Jones, J Martínez-Urtaza, J Trinanes, JD Oliver, FJC González and IR Lake. Climate warming and increasing *Vibrio vulnificus* infections in North America. *Sci. Rep.* 2023; **13**, 3893.
[31] IS Alshomali and O Gulseven. A note on SDG 6 - clean water and sanitation for all. *Res. Gate* 2020, https://doi.org/10.13140/RG.2.2.16461.38881.
[32] Bureau of Environmental Health, Available at: https://env.anamai.moph.go.th/web-upload/migrated/files/env/n553_ 7e737d1ff6decd08e3616a1da3c8d07f_h004.pdf, accessed July 2021.
[33] Department of Medical Sciences, Ministry of Public Health, Available at: https://www.kanpho.go.th/new/downloads/A2.pdf, accessed April 2020.
[34] K Xu, C Valeo, J He and Z Xu. Climate and land use influences on bacteria levels in stormwater. *Water* 2019; **11**, 2451.
[35] Q You, N Fang, L Liu, W Yang, L Zhang and Y Wang. Effects of land use, topography, climate, and socio-economic factors on geographical variation pattern of inland surface water quality in China. *PLoS One* 2019; **14**, e0217840.
[36] P Tharnpoophasiam, U Suthisarnsuntorn, S Worakhunpiset, P Charoenjai, W Tunyong, S Phrom-in and S Chattanadee. Preliminary post-tsunami water quality survey in Phang-Nga province, southern Thailand. *Southeast Asian J. Trop. Med. Publ. Health* 2006; **37**, 216-20.

[37] A Bastaraud, JM Rakotondramanga, J Mahazosaotra, N Ravaonindrina and R Jambou. Environmental factors and the microbial quality of urban drinking water in a low-income country: The case of Madagascar. *Water* 2018; **10**, 1450.

[38] Department of water resources. Guidelines for providing clean water in the community, Available at: https://www.dwr.go.th/en/index.php/1_14nalltang.pdf, accessed January 2023.

[39] A Shahryari, CD Smith and A Amini. Degradation of bacterial water quality in drinking water after bottling. *Open Microbiol. J.* 2020; **14**, 78-83.

[40] P Thongkhow, A Kummuda, S Sawee and P Makkaew. Bacteriological quality of ice and associated sanitary conditions in food and beverage premises in Thasala, Nakhon Si Thammarat, Thailand. *Malays. J. Publ. Health Med.* 2021; **21**, 252-6.

[41] Department of Health. Handbook for improving the quality of drinking water in hospitals, Available at: https://apps.hpc.go.th/dl/web/upFile/2019/12-5027-20191227122624/4bb5cf02960604709e10b3f51c0c3860.pdf, accessed March 2023.

[42] C Poulin, R Peletz, A Ercumen, AJ Pickering, K Marshall, AB Boehm, R Khush and C Delaire. What environmental factors influence the concentration of fecal indicator bacteria in groundwater? Insights from explanatory modeling in Uganda and Bangladesh. *Environ. Sci. Tech.* 2020; **54**, 13566-78.

[43] P Feng. Impact of molecular biology on the detection of foodborne pathogens. *Mol. Biotechnol.* 1997; **7**, 267-78.

[44] M Seo, H Lee and Y Kim. Relationship between coliform bacteria and water quality factors at weir stations in the Nakdong River, South Korea. *Water* 2019; **11**, 1171.

[45] JE Powers, M Mureithi, J Mboya, J Campolo, JM Swarthouh, J Pajka, C Null and AJ Pikering. Effects of high temperature and heavy precipitation on drinking water quality and child hand contamination levels in rural Kenya. *Environ. Sci. Tech.* 2023; **57**, 6975-88.

[46] Announcement of the Department of Health, Available at: https://foodsan.anamai.moph.go.th/th/water-quality/download/ ?did=204437&id=72141&reload=, accessed July 2021.

[47] MN Babic, C Gostincar and N Gunde-Cimerman. Microorganisms populating the water-related indoor biome. *Appl. Microbiol. Biotechnol.* 2020; **104**, 6443-62.

[48] FDA US Food and Drug Administration. HACCP principles & application guidelines, Available at: https://www.fda.gov/food/hazard-analysis-critical-control-point-haccp/haccp-principles-application-guidelines#:~:text=HACCP%20is%20a%20management%20system, consumption%20of%20the%20finished%20product, accessed July 2022.

Supplementary file

Table S1 Analysis of Deviance Chi-square.

	Df	Deviance Resid.	Df Resid.	Dev	Pr (> Chi)
NULL			305	1175.59	
Province	6	53.25	299	1122.34	1.044e-09 ***
Type.water	3	143.90	296	978.44	< 2.2e-16 ***
yeargr	2	9.58	294	968.86	0.008303 **
Bact.type	3	637.62	291	331.24	< 2.2e-16 ***
Tempgr	1	4.05	290	327.18	0.044052 *
Raingr	1	7.25	289	319.94	0.007100 **

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '

R commands

```
setwd("D:\\Shared drives\\Kritsanee's thesis\\7.Data paper 2\\STR 3 years ago")
library(epiDisplay)
# Read data file
d <- read.csv("data1.csv")
str(d)
#Change type variables to factors
d$Province <-factor(d$Province)
d$Type.water <-factor(d$Type.water)
d$Bact.type <-factor(d$Bact.type)
#Multiple logistic regression
m<-glm(data=d,cbind(Sample_F,Sample_P)~Province+Type.water+yeargr+Bact.type+tempgr
    +raingr,family=binomial)
summary(m)
anova(m,test="Chisq")
```