AVERAGE AIR TEMPERATURE AND TOTAL RAINFALL INFLUENCE BACTERIAL CONTAMINATION IN PROCESSED WATER IN SOUTHERN THAILAND

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Abstract. Testing for bacteria in water is done based on intended purposes, such as drinking, producing ice, utilizing it in the house, producing water taps, and processing water. Bacterial growth and survival in water are influenced by environmental factors, which may have consequences for human health. The purpose of this study was to identify factors influencing the failing standard of water quality for consumption. Water quality data from the annual report of Regional Medical Sciences Center and meteorological data from the National Statistical Office of Thailand were obtained for the fiscal years 2002-2021. A logistic regression model was used to identify factors associated with the failing standard of water quality for consumption. The findings revealed that 16.6% of the total sample did not meet the consumption standard, with Public Health Area (PHA) 11 and 12, failing at rates of 49.6% and 38.3%, respectively. Overall, water produced in PHA 11 was statistically (p-value < 0.05) substantially associated with bacterial contamination, which increased with production year, air temperature, and precipitation. In conclusion, environmental factors and other water quality were influential on biological water quality in Southern Thailand. Therefore, necessary measures must be taken to improve water quality standards in this area to safeguard the protection of consumers.
Keywords: *air temperature, rainfall, bacterial contamination, processed water, Southern Thailand*

Introduction

Water is essential for human survival in terms of consumption, employment, communication, and leisure (Bureau of Water Quality Management, 2014; Nimrat et al., 2021). Water shortage issues and water pollution, which have impacts on public health, are brought on by the current environmental changes and the growth of the community, economy, and society (Notification of National Water Resources office, 2019). Global water consumption demand for humanity has increased since 1900, and it is predicted that by 2050, water consumption will have increased by 20-30% (Singhanart, 2020). According to the United Nations (UN), 17 Sustainable Development Goals (SDGs) in 2015 were issued, and the sixth SDG is “Clean Water and Sanitation,” aiming to make clean, safe, and affordable water available to everyone on earth by 2030 (Alshomali and Gulseven, 2020). In parallel, the Thai government issued its national strategy in 2019 which covered the management of water resources (Notification of National Water Resources office, 2019). Between 2017 and 2019, water use in Southern Thailand’s

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coastline region increased. This became a factor in the raw water shortage problems over the summer because humans require more water in their daily lives while the amount of water in nature remains constant or decreases. This issue was especially brought up in urban regions and famous tourist destinations (Office of the National Economics and Social Development Council, 2022). However, Southern Thailand has better conditions than other areas in terms of water quality (Regional Environment Office 15, 2019).

Evaluation of the biological, chemical, and physical components of water can be referred to as water quality assessment (Bojarczuk et al., 2018; Jufri, 2020). Chemicals, viruses, protozoa, and parasites are all sources of contamination; however, in terms of prevalence, microbial pathogens pose the greatest threat to water safety (Badeenezhad et al., 2020). The examination of bacterial indicators in water, also known as Total Coliform Bacteria (TCB) and Fecal Coliform Bacteria (FCB), requires no special equipment and has low assay costs when compared to other bacteria (Hales, 2019; Seo et al., 2019). They can be found in the digestive systems of warm-blooded creatures, including humans. If they are found in water supplies, this implies that feces have contaminated the water (Nuangjui and Chanphiwat, 2012; Seo et al., 2019). A pathogenic bacterial indication is also present, which might result in serious conditions like gastroenteritis and diarrhea. The pathogens that cause diseases in humans, such as cholera, dysentery, and typhoid fever (*Vibrio cholerae*, *Shigella dysenteries*, *and Salmonella typhimurium* infection), can be identified using these pollutants (Kudsong et al., 2010; Nimrat et al., 2021; Takal and Quaye-Ballard, 2018). In fact, the quality standard in drinking water, ice, and processing water is set at TCB which must be less than 2.2; *Escherichia coli (E. coli)* should not be found (Notification of Public Health, 1981, 1984); *S. aureus* is less than 100 colony forming unit (CFU); and *Salmonella* spp. should not be found. Importantly, all product samples must be examined at least once a year (Notification of Public Health, 2020). Previous laboratory analysis of bacteria revealed that the water quality after passing a standard process and during delivery to consumers consistently failed to meet the specified standards. These could lead to epidemics and other public health problems. The main factors influencing bacterial growth are the environments in which they have previously existed. Water quality issues may be brought on by environmental factors such as temperature, rainfall, and poor water quality (Jufri, 2020). Moreover, water that has been improperly and unnaturally stored can have an unacceptable level of bacterial contamination (Gizaw et al., 2022), and because bacteria can constantly grow and change in number, this could lead to future health issues for consumers (Bureau of Environmental Health, 2009). To illustrate, changes in environmental factors are primarily the results of human actions, which influence climatic conditions, particularly increases in air temperature, precipitation, and degradation of water quality (Rajesh and Rehana, 2022). Therefore, some environmental experts predict that these factors have significant impacts on the environment and cause water management issues in the future (Marks, 2011; Minnesota Pollution Control Agency, 2008). Seasons, weather, temperature, distance from pollution sources, livestock management techniques, wildlife activity, excrement, sewage, and rainfall were the main environmental elements that affected bacterial contamination, growth, and survival (Islam et al., 2017; Joklik et al., 1980; Jufri, 2020; Jung et al., 2014; Minnesota Pollution Control Agency, 2008; You et al., 2019). However, when bacteria numbers fluctuate, it will be harder to detect bacterial loads, which is crucial for preventing waterborne outbreaks (Rodigues et al., 2019).

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Previous water quality monitoring data from government laboratories in Southern Thailand showed that biological standards were steadily deteriorating, which had the potential to cause epidemics and they were considered a public health issue. However, there was no study of factors that influenced the detection of bacteria that was greater than the standard value and was the source of water-borne diseases in PHA 11 and 12. As a result, it must be completed as soon as possible. Therefore, the purpose of this study was to investigate the associations between environmental factors (i.e., air temperature, rainfall) and bacterial contamination in drinking water, ice, water used in households, and processed water, which did not meet the requirements in PHA 11 and 12. This study's findings could explain changes in water quality. This study's findings could explain changes in water quality, sources of bacterial contamination and assist in reducing public health problems for long-term solutions. This also includes decision-making, creating operational plans for executives at relevant department levels to solve water quality problems in an effective and sustainable manner.

Materials and methods

Data sources

Data on bacteria-contaminated water quality samples from PHA 11 (Chumphon, Ranong, Surat Thani, Nakhon Sri Thammarat, Phang-nga, Krabi, and Phuket provinces) and PHA 12 (Trang, Phatthalung, Satun, Songkhla, Pattani, Yala, and Narathiwat provinces) between fiscal years 2002 and 2021 were obtained from two Regional Medical Science Centers (RMSC) in region 11 (RMSC 11 and RMSC 11/1) and two RMSC in region 12 (RMSC 12 and RMSC 12/1) (*Fig. 1*). Water quality data included the year of manufacture, public health area, types of water, and the number of samples with bacteria contamination. Meteorological data included the average air temperature and rainfall were obtained from the National Statistical Office's annual statistics.

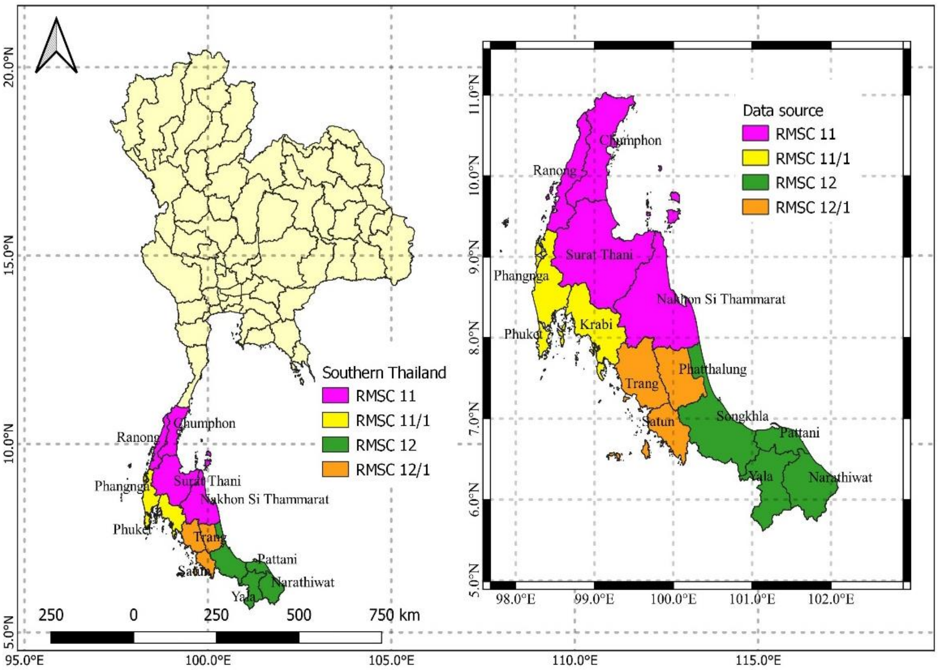

Figure 1. *Data sources in Southern Thailand; PHA 11 and PHA 12*

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The provinces include 2 PHAs in Southern Thailand: PHA 11 and PHA 12. The years ranged from 2002 to 2021. Water was classified into two groups: product water (water that can be produced in accordance with the given requirements or quality standards, for example, drinking water and ice) and processed water (water that has been chlorine-treated or basic filtered for use in washing raw materials, cooking food, and consuming), and four types: drinking, ice, consumption, and treated water (purified water undergoes a contaminant filtration process and chemical conditioning to be suitable for use, such as tap water). Water quality was divided into two groups: pass and fail from the standard of water quality for consumption. The quality was considered by looking at the contamination with bacteria such as TCB, *E. coli*, *Staphylococcus aureus* (*S. aureus*), and *Salmonella* spp. in accordance with the quality requirements set out in Ministry of Public Health Notification No. 61 (B.E. 2524), No. 78 (B.E. 2527) and No. 416. (B.E. 2563). The air temperature was divided into two groups: 26 to 28°C, and more than 28 to 29°C. Rainfall was also divided into two groups: 1000 to 2000 mm, and more than 2000 to 4000 mm.

Statistical data analyzed with the R software

All statistical analysis was done using the R program (R Core Team, 2020). Descriptive statistics were also performed. The factors associated with the failing standard of water quality for consumption were analyzed. The determinants were PHA, types of water, years of production, air temperature levels and rainfall levels. The outcomes of this study were water samples which passed or failed the standard of water quality for consumption. Chi-square test was then used to find the association between determinants and the outcomes. After that, multivariate analysis was performed using logistic regression. P-value < 0.05 was considered statistically significant, which were explained by Adjust Odds Ratio (Adj. OR) separate each factor and bacterial type. The ROC curve was used to evaluate the goodness of fit.

Results

Data regarding water quality

For the overall descriptive analysis, 16.6% of water in Southern Thailand did not meet the standard. The contamination varied according to PHA, water types, production years, air temperature, and rainfall levels. PHA 11 was the most common contaminant, accounted for 49.6% of the total, by TCB, *E. coli*, *S. aureus*, and *Salmonella* spp., which were each accounted for 63.6, 31.7, 2.5, and 2.2%, respectively. Drinking water contamination was the highest at 45.9%, with TCB, *E. coli*, *S. aureus*, and *Salmonella* spp. accounted for 51.4, 31.4, 24.1, and 22.2%, respectively. The highest level of contamination in the year of production in 2019 was 12.1%, with TCB, *E. coli*, *S. aureus*, and *Salmonella* spp. accounted for 10.3, 18.2, 14.1, and 9.1%, respectively. The air temperature of more than 28-29°C were the most common contaminant, accounted for 51.7%, by TCB, *E. coli*, *S. aureus*, and *Salmonella* spp., which accounted for 51.0, 54.8, 54.8, and 37.4%, respectively. More than 2,000 to 4,000 mm of the rainfall level fell short of the required standard by 52.93%. TCB, *E. coli*, *S. aureus* and *Salmonella* spp. contamination accounted for 54.9%, 46.9%, 48.2%, and 47.5%, respectively (*Table 1*).

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***Table 1**. Bacterial water quality classified by environmental factors*

Factors	Number (%)									
	Total		TCB		*E. coli*		*S. aureus*		*Salmonella* spp.	
	Pass	Failed	Pass	Failed	Pass	Failed	Pass	Failed	Pass	Failed
Public health areas										
PHA 11	21014 (46.84)	3696 (49.63)	21459 (47.83)	2351 (63.61)	23538 (52.46)	1172 (31.71)	24618 (54.87)	92 (2.49)	24629 (54.89)	81 (2.19)
PHA 12	17306 (38.57)	2851 (38.28)	17844 (39.77)	2313 (81.13)	19680 (43.86)	477 (16.73)	20114 (44.83)	43 (1.51)	20139 (44.89)	18 (0.63)
Types of water										
Drinking	17690 (47.27)	3419 (45.91)	18248 (46.42)	2861 (51.42)	20592 (47.65)	517 (31.35)	21090 (47.15)	19 (14.07)	21087 (47.10)	22 (22.22)
Making Ice	2536 (6.78)	1115 (14.97)	2984 (7.59)	667 (11.99)	3269 (7.56)	382 (23.16)	3597 (8.04)	54 (40.00)	3639 (8.13)	12 (12.12)
Consumption	8105 (21.66)	1234 (16.57)	8486 (21.59)	853 (15.33)	9009 (20.84)	330 (20.01)	9318 (20.83)	21 (15.55)	9309 (20.79)	30 (30.30)
Process water	9089 (24.29)	1679 (22.54)	9585 (24.39)	1183 (21.26)	10348 (23.94)	420 (25.47)	10727 (23.98)	41 (30.37)	10733 (23.97)	35 (35.35)
Years of production										
2002	608 (1.62)	176 (2.36)	643 (1.64)	141 (2.53)	749 (1.73)	35 (2.12)	784 (1.75)	0 (0.00)	784 (1.75)	0 (0.00)
2003	777 (2.08)	255 (3.42)	836 (2.13)	196 (3.52)	982 (2.27)	50 (3.03)	1028 (2.30)	4 (2.96)	1027 (2.29)	5 (5.05)
2004	752 (2.01)	198 (2.66)	801 (2.04)	149 (2.68)	912 (2.11)	38 (2.30)	942 (2.11)	8 (5.92)	947 (2.11)	3 (3.03)
2005	1113 (2.97)	203 (2.72)	1160 (2.95)	156 (2.80)	1284 (2.97)	32 (1.94)	1306 (2.92)	10 (7.41)	1311 (2.93)	5 (5.05)
2006	369 (0.99)	82 (1.10)	383 (0.97)	68 (1.22)	437 (1.01)	14 (0.85)	451 (1.01)	0 (0.00)	451 (1.01)	0 (0.00)
2007	932 (2.49)	171 (2.30)	985 (2.51)	118 (2.12)	1058 (2.45)	45 (2.73)	1098 (2.45)	5 (3.70)	1100 (2.46)	3 (3.03)
2008	409 (1.09)	65 (0.87)	426 (1.08)	48 (0.86)	459 (1.06)	15 (0.91)	474 (1.06)	0 (0.00)	472 (1.05)	2 (2.02)
2009	1248 (3.33)	374 (5.02)	1326 (3.37)	296 (5.32)	1564 (3.62)	58 (3.52)	1610 (3.60)	12 (8.89)	1614 (3.61)	8 (8.08)
2010	1051 (2.81)	121 (1.62)	1064 (2.71)	108 (1.94)	1159 (2.68)	13 (0.79)	1172 (2.62)	0 (0.00)	1172 (2.62)	0 (0.00)
2011	1089 (2.91)	175 (2.35)	1119 (2.85)	145 (2.61)	1236 (2.86)	28 (1.70)	1262 (2.82)	2 (1.48)	1264 (2.82)	0 (0.00)
2012	1464 (3.91)	245 (3.29)	1534 (3.90)	175 (3.14)	1651 (3.82)	58 (3.52)	1701 (3.80)	8 (5.93)	1705 (3.81)	4 (4.04)
2013	2735 (7.31)	361 (4.85)	2846 (7.24)	250 (4.49)	3002 (6.95)	94 (5.70)	3090 (6.91)	6 (4.44)	3085 (6.89)	11 (11.11)
2014	1542 (4.12)	158 (2.12)	1573 (4.00)	127 (2.28)	1671 (3.87)	29 (1.76)	1699 (3.80)	1 (0.74)	1699 (3.79)	1 (1.01)
2015	3188 (8.52)	365 (8.53)	3338 (8.49)	485 (8.72)	3691 (8.54)	132 (8.00)	3811 (8.52)	12 (8.89)	3817 (8.53)	6 (6.06)
2016	3903 (10.43)	860 (11.55)	4094 (10.42)	669 (12.02)	4588 (10.61)	175 (10.61)	4755 (10.63)	8 (5.93)	4755 (10.62)	8 (8.08)
2017	3313 (8.85)	772 (10.37)	3476 (8.84)	609 (10.94)	3935 (9.10)	150 (9.10)	4083 (9.13)	2 (1.48)	4074 (9.10)	11 (11.11)
2018	3741 (10.00)	894 (12.00)	3996 (10.17)	639 (11.48)	4413 (10.21)	222 (13.46)	4618 (10.32)	17 (12.59)	4619 (10.32)	16 (16.16)
2019	3490 (9.33)	899 (12.07)	3818 (9.71)	571 (10.26)	4089 (9.46)	300 (18.19)	4370 (9.77)	19 (14.07)	4380 (9.78)	9 (9.09)
2020	2370 (6.33)	466 (6.26)	2482 (6.32)	354 (6.36)	2737 (6.33)	99 (6.00)	2824 (6.31)	12 (8.89)	2835 (6.33)	1 (1.01)
2021	3326 (8.89)	337 (4.52)	3403 (8.66)	260 (4.67)	3601 (8.33)	62 (3.76)	3654 (8.17)	9 (6.67)	3657 (8.17)	6 (6.06)
Air temperature levels (°C)										
26-28	19208 (51.33)	3594 (48.26)	20076 (51.08)	2726 (48.99)	22057 (51.04)	745 (45.18)	22741 (50.84)	61 (45.18)	22740 (50.79)	62 (62.63)
More than 28-29	18212 (48.67)	3853 (51.74)	19227 (48.92)	2838 (51.01)	21161 (48.96)	904 (54.82)	21991 (49.16)	74 (54.81)	22028 (49.20)	37 (37.37)
Rainfall levels (mm)										
1000-2000	14820 (39.60)	3505 (47.07)	15817 (40.24)	2508 (45.07)	17450 (40.38)	875 (53.06)	18255 (40.81)	70 (51.85)	18273 (40.82)	52 (52.53)
More than 2000-4000	22600 (60.39)	3942 (52.93)	23486 (59.76)	3056 (54.93)	25768 (59.62)	774 (46.94)	26477 (59.19)	65 (48.15)	26495 (59.18)	47 (47.47)

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Climate information

The average air temperature in PHA 11 was 27.9°C, with a minimum of 27.6°C and a maximum of 28.4°C. The average rainfall was 1,972.7 mm, with a minimum of 1,461 mm and a maximum of 2,319 mm. The average air temperature in PHA 12 was 28°C, with minimum and maximum temperatures of 26.4°C and 29°C, respectively. Its rainfall levels ranged from a minimum of 1,518.4 mm to a maximum of 3,328.3 mm, with an average of 2,253.4 mm (*Table 2*).

Table 2*. The yearly average temperature and total rainfall are presented as classified by the public health areas*

Public health areas	Air temperature (°C)			
	Mean	**SD**	**Min**	**Max**
PHA 11	27.92	0.22	27.60	28.35
PHA 12	28.04	0.61	26.35	28.95
Rainfall (mm)				
PHA 11	1972.66	271.73	1460.95	2319.00
PHA 12	2253.36	434.17	1518.35	3328.25

Testing the association between bacteria contamination and environmental factors

The results from the chi-square test showed that PHA, types of water, years of production, air temperature levels, and rainfall levels were all associated with the detection of TCB and *E. coli*. While PHA, types of water, and years of production were all significantly associated with *S. aureus* and *Salmonella* spp. contamination (*Table 3*).

Table 3. *Associations between bacteria contamination and environmental factors*

Factors	P-value			
	TCB	***E. coli***	***S. aureus***	***Salmonella* spp.**
Public health area	<0.001	<0.001	<0.001	<0.001
Types of water	<0.001	<0.001	<0.001	<0.001
Years of production	<0.001	<0.001	<0.001	<0.001
Air temperature levels	<0.001	<0.001	0.900	0.990
Rainfall levels	<0.001	<0.001	0.090	0.800

Simple logistic regression analysis

Simple logistic regression was used to do an initial assessment of independent variables (bivariate analysis) and discovered that all factors had a likelihood of over the standard for TCB and *E. coli* contamination, whereas factors such as PHA, types of water, and rainfall levels were influenced *S. aureus* contamination. In addition, PHA, types of water, temperature levels, and rainfall levels were caused contaminated *Salmonella* spp.

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Multiple logistic regression analysis

S. aureus contamination exceeding the standard was associated with the types of water. Making ice, consumption water, and processed water which were 17.8, 2.9, and 5.3 times more likely than drinking water to exceed the standard for *S. aureus* contamination, respectively (*Table 4*).

Table 4. *Factors associated with S. aureus bacterial contamination in samples exceeding the standard*

Factors	Crude OR (95%CI)	Adj. OR (95%CI)	P (Wald's test)	P (LR-test)
Types of water				
Drinking	1	1		<0.001
Making ice	16.66 (9.87-28.14)	17.82 (10.48-30.29)	<0.001	
Consumption	4.24 (2.46-7.31)	2.85 (1.52-5.36)	0.001	
Process	2.50 (1.34-4.66)	5.28 (3.01-9.26)	<0.001	

Salmonella spp. contamination exceeding the standard was associated with the PHA, and types of water. The contamination in PHA 11 was 4.34 times more likely to be contaminated with *Salmonella* spp. than that in PHA 12. Making ice, consumption water, and processed water were 2.8, 2.9, and 4.3 times more likely than drinking water to exceed the standard for *Salmonella* spp. contamination, respectively (*Table 5*).

Table 5. *Factors associated with Salmonella spp. bacterial contamination in samples exceeding the standard*

Factors	Adj. OR	95%CI		P (Wald's test)	P (LR-test)
		Lower	Upper		
Public health areas					
PHA 12	1				<0.001
PHA 11	4.34	2.45	7.68	<0.001	
Types of water					
Drinking	1				<0.001
Making ice	2.76	1.35	5.67	0.006	
Consumption	2.87	1.50	5.14	<0.001	
Process	4.30	2.44	7.58	<0.001	

E. coli contamination exceeding the standard was associated with PHA, types of water, years of production, air temperature levels, and rainfall levels. The contamination in PHA 11 was 2.7 times more likely to be contaminated with *E. coli*. Then that in PHA 12. Making ice and processed water were 3.8 and 1.8 times more likely than drinking water to be contaminated with *E. coli*. From 2002 to 2009, the contamination was 11.4, 5.4, 7.6, 4.0, 12.9, 6.5, 5.0, 6.3 times, and from 2011 to 2020, it was 2.1, 2.4, 3.9, 3.4, 5.0, 4.8, 4.3, 8.4, 9.7 and 2.8 times more likely than 2010 to be contaminated with *E. coli*. The air temperature ranged between 28 and 29°C was 1.46 times more likely than

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26-28°C to be contaminated with *E. coli*. More than 2000-4000 mm of the rainfall level was 1.83 times more likely than 1000-2000 mm to exceed the standard for *E. coli* contamination (*Table 6*).

Table 6. *Factors associated with E. coli bacterial found in samples exceeding the standard*

Factors	**Adj. OR**	**95%CI**		**P (Wald's test)**	**P (LR-test)**
		Lower	**Upper**		
Public health areas					
PHA 12	1				<0.001
PHA 11	2.70	2.30	3.18	<0.001	
Types of water					
Drinking	1				<0.001
Making ice	3.75	3.25	4.33	<0.001	
Consumption	1.08	0.93	1.25	0.290	
Process	1.75	1.53	2.00	<0.001	
Years of production					
2010	1				<0.001
2002	11.42	5.55	23.48	<0.001	
2003	5.39	2.88	10.10	<0.001	
2004	7.55	3.76	15.14	<0.001	
2005	3.99	2.03	7.86	<0.001	
2006	12.86	5.44	30.43	<0.001	
2007	6.54	3.40	12.61	<0.001	
2008	4.99	2.32	10.74	<0.001	
2009	6.26	3.29	11.93	<0.001	
2011	2.14	1.07	4.27	0.031	
2012	2.43	1.32	4.48	0.004	
2013	3.93	2.17	7.12	<0.001	
2014	3.46	1.70	7.04	<0.001	
2015	4.99	2.66	9.35	<0.001	
2016	4.76	2.62	8.65	<0.001	
2017	4.29	2.34	7.86	<0.001	
2018	8.36	4.50	15.54	<0.001	
2019	9.65	5.21	17.85	<0.001	
2020	2.79	1.56	5.02	<0.001	
2021	1.39	0.74	2.61	0.311	
Air temperature levels (°C)					
26-28	1				<0.001
More than 28-29	1.46	1.16	1.85	0.002	
Rainfall levels (mm)					
1000-2000	1				<0.001
More than 2000-4000	1.83	1.44	2.33	<0.001	

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TCB contamination exceeding the standard was associated with PHA, types of water, years of production, air temperature levels, and rainfall levels. PHA 11 had a 1.4 times greater chance of contamination than PHA 12. Drinking, ice-making, and processing water were 1.8, 2.3, and 1.5 times more likely to be contaminated than water consumption, respectively. From 2002 to 2009, the contamination was higher than 4.5, 3.0, 3.2, 1.9, 4.1, 1.8, 1.5, 3.3 times, the contamination in 2011 was 1.5 times, and the contamination from 2014 to 2020 was 1.5, 1.4, 2.0, 2.2, 2.6 2.7, 2.3 and 1.7 times, which were all more likely than it was in 2021, respectively. The air temperature level at more than 28-29°C was 1.3 times more likely than 26-28°C. More than 2000-4000 mm of the rainfall levels were 1.4 times more likely than 1000-2000 mm to exceed the standard for TCB contamination, respectively (*Table 7*).

Table 7. *Factors associated with TCB found in samples exceeding the standard*

Factors	**Adj. OR**	**95%CI**		**P (Wald's test)**	**P (LR-test)**
		Lower	**Upper**		
Public health areas					
PHA 12	1				<0.001
PHA 11	1.45	1.34	1.57	<0.001	
Types of water					
Consumption	1				<0.001
Drinking	1.8	1.65	1.96	<0.001	
Making ice	2.34	2.1	2.62	<0.001	
Process	1.52	1.38	1.68	<0.001	
Years of production					
2021	1				<0.001
2002	4.54	3.46	5.95	<0.001	
2003	2.97	2.39	3.69	<0.001	
2004	3.17	2.4	4.19	<0.001	
2005	1.84	1.45	2.33	<0.001	
2006	4.07	2.9	5.71	<0.001	
2008	1.53	1.08	2.18	0.017	
2009	3.28	2.66	4.06	<0.001	
2010	1.12	0.87	1.44	0.37	
2011	1.54	1.24	1.91	<0.001	
2012	1.09	0.86	1.38	0.461	
2013	1.08	0.89	1.32	0.423	
2014	1.41	1.12	1.78	0.004	
2015	2.02	1.57	2.6	<0.001	
2016	2.15	1.73	2.67	<0.001	
2017	2.56	2.19	3	<0.001	
2018	2.71	2.27	3.24	<0.001	
2019	2.27	1.77	2.91	<0.001	
2020	1.68	1.39	2.03	<0.001	
Air temperature levels (°C)					
26-28	1				<0.001
More than 28-29	1.32	1.17	1.48	<0.001	
Rainfall levels (mm)					
1000-2000	1				<0.001
More than 2000-4000	1.35	1.19	1.54	<0.001	

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The area under the ROC curve (AUC) was used to evaluate the performance of multiple logistic regression models with the predictive capacity of the fitted model. This demonstrated that the types of water fit the occurrence data well, with 0.82 of AUC in *S. aureus*., and PHA, and types of water fit the occurrence data well with 0.78 of AUC in *Salmonella* spp. In *E. coli* and TCB, PHA, types of water, years of production, temperature levels, and rainfall levels had 0.68 and 0.62 of AUC, respectively.

Discussion

In this study all factors that could impact the water quality. Overall, the study areas, types of water, years of manufacture, air temperature levels, and rainfall levels were associated with statistically significant predictors of TCB and *E. coli* contamination, while the study areas, types of water, and years of production were statistically significant predictors of *S. aureus* and *Salmonella* spp. by chi-square test. Bivariate analysis of independent and dependent variables revealed that all parameters influencing TCB and *E. coli* contamination, while the study areas, water types, rainfall levels affected *S. aureus*, and the study areas, water types, air temperature levels, rainfall levels impacted *Salmonella* spp. Concerning multivariate analysis, the study locations, types of water, years of production, air temperature levels, and rainfall levels were environmental factors influencing the non-standardization of TCB and *E. coli*. In addition, the study locations and types of water influenced *Salmonella* spp. Only *S. aureus* was affected by the types of water.

Based on the findings of this study, the water produced in PHA 11 had higher bacterial contamination than the water produced in PHA 12. The indicator bacteria (TCB) failed the standard more frequently in PHA 12 than in PHA 11, while food poisoning bacteria (*E. coli*, *S. aureus*, *Salmonella* spp.) failed more frequently in PHA 11 than in PHA 12. Food poisoning cases were more common in PHA 11 than in PHA 12, which were corresponded to the previous 5-year morbidity rate data of Thai people's health statistics at the area level (Department of Diseases Control, 2022). Different areas could produce different types and amounts of bacterial contamination in their water. Similarly, Xu et al. reported in 2019 that the spatial location of the assays affected the climate and bacterial contamination loads (Xu et al., 2019). The study by You et al. in 2019 in China, stated that geographical variations in water resources, environment, topography, and climate affected water quality. The contamination of bacteria in the water was also influenced by weather such as temperature and rainfall, and population density (Poulin et al., 2020).

According to the study, making ice was the most likely to be contaminated with all four types of bacteria, followed by consumption, and drinking water, with statistical significance ($p < 0.05$), indicating that the quality of water that was strictly processed had the potential to detect contamination exceeding the standard. This may be caused by other related factors such as insufficiency of the transportation process, container storage locations, human hygiene during the manufacturing process, types of disinfectants, and filtration efficiency (Badeenezhad et al., 2020). This is similar to a study conducted by Gwimbi et al. (2019) who measured *E. coli* contamination in several bodies of water near the Lesotho Mohale Dam for drinking water production. Besides, there was a study by Onyango et al. (2018) investigating the contamination levels of four bacterial strains, TCB, *E. coli*, *S. aureus*, and *C. perfringens*, in three types of water in Isiolo County, the country: groundwater, surface water, and chlorinated water. Kenya

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also discovered that the number of bacteria in each type of water differed statistically. This study was additionally agreeable with Sriket et al. (2016) investigating TCB contamination in two water sources in Prachinburi Province, eastern Thailand: raw water and tap water. TCB level in raw water was found to be higher than in tap water. According to the Food and Drug Administration requirements, Ministry of Public Health, the presence of TCB, *E. coli*, *Salmonella* spp., and *S. aureus* in the making ice was not detected (Notification of Public Health, 1981, 1984, 2020), which is a more stringent standard than other types of water. This could be another reason why the ice failed to meet the highest standard.

TCB and *E. coli* contamination in water produced in the South Thailand between 2002 and 2021 were significantly different ($p < 0.05$). This contrasted with a study conducted by Onyango et al. (2018) between 2011 and 2016 in Isiolo County, Kenya that no statistically significant difference was found. This variation could be due to climate, seasons, or study periods, resulting in impacts on the levels of bacterial contamination in each water resource (Swistock and Sharps, 2022).

The contamination of TCB and *E. coli* increased as air temperature rose. This is consistent with a 2020 study on fecal coliform bacteria contamination in Uganda and Bangladesh by Poulin et al. (2020). Changes in air temperature were related to changes in water temperature, which affect climate changes and causes changes in water quality in natural water sources. Temperature was considered an important environmental factor because it controlled the maximum amount of dissolved oxygen in water and affects the survival of living organisms (Rajesh and Rehana, 2022). High temperatures contributed to global warming and had negative impacts on the environments (Jung et al., 2014). Similarly, every degree of warming temperature caused by climate changes could influence bacterial growth and survival (Jin, 2016). In fact, indicator bacteria could grow and survive at temperatures ranging from 10 to 45°C (Joklik et al., 1980). Pathogenic bacteria, on the other hand, might begin to die and their concentration might decrease as the temperature dropped (Islam et al., 2017).

Increasing rainfall caused a higher-than-normal detection of bacteria in the water. In this study, TCB and *E. coli* contamination increased as rainfall increased. It is consistent with the studies by Islam et al. (2017) and Poulin et al. (2020) which was found that heavy rains could cause water runoff into bodies of water, and then contaminate them with sediments, nutrients, pollutants, animal waste, and other materials from the community into the water sources, making it unsafe and causing water disease outbreaks (Jung et al., 2014; Poulin et al., 2020). This resulted in waterborne diseases such as diarrhea, cholera, and typhoid fever (Badeenezhad et al., 2020). These outbreaks were linked to pathogen concentrations in the water, and further climate change might increase the risk of waterborne illnesses (Islam et al., 2017).

It could be seen that the study’s findings were critical for government agencies and industry to plan and manage the reduction of bacterial contamination in water sources and reach the goal of providing everyone with equal access to clean water. This research also found environmental factors and other water quality had affected the contamination of some bacteria in water sources, such as indicator bacteria (TCB and *E. coli*), which are easily detected. While finding pathogenic bacteria (*S. aureus* and *Salmonella* spp.) in water is difficult due to their short life cycle and ease of destruction from the environmental change (Jin, 2016). Raised consumer safety awareness, and proposed solutions to health problems caused by contaminated water in Southern Thailand. As a result, relevant agencies should inspect every water source to ensure that clean water is available to the public. Such studies should be carried out on a regular basis to ensure water quality (Kanno et al., 2020).

The limitations of the present study were the use of the annual report and secondary data, which resulted in incomplete details and could not distinguish the time of manufacture of the samples. Further research is needed on factors such as land use and population density. The goal will be more comprehensive and useful.

Conclusions

Environmental factors, air temperature, precipitation, and other factors include production sites classified by health zones, years of production, and types of water sources were associated with non-standard bacterial contamination of TCB, *E. coli*, *S. aureus*, and *Salmonella* spp. in the South of Thailand. Preventive measures should be taken by the relevant organizations. Water quality must also be checked on a regular basis before it is delivered to consumers, and everyone should have access to clean, safe, easy, and sustainable water.

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