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Influence of Climatic Factors on the Occurrence of *Vibrio parahaemolyticus* Food Poisoning in the Republic of Korea

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Abstract: This study aimed to investigate the outbreaks and characteristics of *Vibrio parahaemolyticus* food poisoning in the Republic of Korea and the impact of climatic factors on the food poisoning occurrence. All data were obtained from the official statistics of the Republic of Korea (2002 to 2017). A trend analysis, Pearson's correlation analysis, and regression analysis were used to determine the relationship between the outbreaks of *V. parahaemolyticus* food poisoning and climatic factors. During the study period, the number of outbreaks of *V. parahaemolyticus* food poisoning ranked third among bacterial food poisoning. The food poisoning incidences of *V. parahaemolyticus* occurred mostly from July to September. The average temperature, maximum and minimum temperatures, precipitation, number of days with rainfall, and humidity showed a significant positive correlation with the number of outbreaks of *V. parahaemolyticus* food poisoning ($p < 0.001$), but daytime hours showed a negative correlation ($p < 0.01$). The data further indicated that minimum temperature was the most influential variable on the outbreaks of food poisoning ($p < 0.01$). These results indicate that the outbreaks of *V. parahaemolyticus* food poisoning in the Republic of Korea are associated with climatic factors, suggesting that these incidences may have been impacted by climate change, especially due to warming around the Korean peninsula.

Keywords: climatic factors; *V. parahaemolyticus* food poisoning; climate change; Republic of Korea

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1. Introduction

Vibrio species are naturally occurring bacteria throughout the world. *Vibrio cholera*, *Vibrio parahaemolyticus*, and *Vibrio vulnificus* are currently recognized as the major species. They are known to be foodborne pathogens that cause disease through the consumption of contaminated marine products. Each species causes different diseases [1,2].

V. parahaemolyticus is a Gram-negative bacillus and halophilic bacterium found in marine and estuarine environments in tropical and temperate regions. It may cause gastrointestinal illness in humans when ingested. It is characterized as non-spore-forming and facultative anaerobes. It can be isolated not only from seawater samples, but also from samples of humans, fish, and shellfish. *V. parahaemolyticus* is known to proliferate rapidly when the seawater temperature rises above 15 °C. On the other hand, it is weakened by low and high temperatures, so it hardly grows below 10 °C or above 45 °C and is killed by heating at 60 °C for 10 min. It perishes easily in water without salt [3,4].

Vibrio enteritis food poisoning is one of the major food poisonings that occurs worldwide. *V. parahaemolyticus* is the leading causal agent of human gastroenteritis worldwide. It has been pointed out that *V. parahaemolyticus* food poisoning is very often caused by consuming contaminated fish and shellfish raw, or undercooked or mishandled shellfish [3,5]. *V. parahaemolyticus* is regarded as a major biological hazard coming from marine products and an environmental hazard threatening food safety, so it has been studied for decades. Nevertheless, it still poses a significant burden as a foodborne disease even in developed countries [6–8]. According to the food poisoning statistics of the Republic of Korea (hereafter referred to as Korea), although there are variations depending on the

year, *V. parahaemolyticus* has contributed to outbreaks of major bacterial food poisoning, along with *Salmonella* and *Staphylococcus aureus*. In 1998, the number of confirmed cases of *V. parahaemolyticus* was 28.6%, ranking top among all food poisoning cases in the year [9].

Global warming affects not only the land, but also the marine environment, causing sea temperature to rise. Therefore, climate change has emerged as the greatest threat to humans. Climate change includes rising temperatures and changes in precipitation patterns, an increased frequency and intensity of extreme weather events, ocean warming and acidification, and changes in the transport pathways of complex pollutants [10–14]. These phenomena of climate change affect the ecology and growth of microbes, and the physiology and host susceptibility of plants and animals, which implies food safety can become endangered and may ultimately threaten human health and survival.

Vibrio bacteria are increasing and spreading worldwide. They have spread to the polar regions, in both the Northern and Southern Hemispheres. According to a recent report, they were observed in areas where they were previously absent or rarely reported [15]. There are concerns that the spread of Vibrio bacteria will potentially increase exposure to consumers of seafood. Moreover, the rise in the air temperature and sea temperature of Korea appears to be much faster than the global average [16,17].

The increase in and spread of Vibrio bacteria worldwide are thought to be related to climate change. However, there is still limited information on the relationship between climate-influencing factors and the occurrence of *V. parahaemolyticus*, as well as the isolation rate of Vibrio bacteria. Accordingly, this study aimed to provide information on the harmful factors caused by climate change in Korea. The researchers explore long-term data on trends in the occurrence of *V. parahaemolyticus* food poisoning and climatic factors in Korea and then analyze their correlation to determine whether climate change has influenced the occurrence of these bacteria. As a result, this study will ultimately help to control their occurrence and ensure food safety.

2. Methods

2.1. Data Sources

The statistical data on food poisoning occurrences reported by the Korean Ministry of Food and Drug Safety and the Korea Disease Control and Prevention Agency were obtained on their homepage [18,19]. From the data source, yearly and monthly data on the occurrence of *V. parahaemolyticus* from 2002 to 2017 were extracted and used for the study. The current database provides information from the year 2002. The purpose was to identify long-term annual trends in *V. parahaemolyticus* food poisoning by observing differences in their occurrence due to monthly fluctuations in the air temperature and sea temperature in Korea, which has four distinct seasons. The researchers used data from the automatic weather system of the Korea Meteorological Administration (KMA) during the same period [20]. One can obtain access to the data on the homepage of KMA if the audience declares the intent to use the data for research purposes. The researchers relied on official sources in our study, as the researchers believe they are the most reliable. The extracted data were temperature (average, maximum, and minimum temperatures), precipitation and number of days with precipitation, and humidity by year therein, which are the climatic factors of the study.

2.2. Data Analysis and Statistical Processing

In this study, trends in the occurrence of *V. parahaemolyticus* food poisoning during the study period were analyzed. Pearson's correlation analysis was used to find the relationship between climatic factors and the occurrence of *V. parahaemolyticus* food poisoning. A regression analysis was performed to determine the extent to which climatic factors influenced the occurrence. There were no missing values in the data used. Excel (Microsoft Corporation, Redmond, WA, USA) and SPSS for Windows 22.0 (IBM Corporation, Armonk, NY, USA) were used for the data analysis and statistical processing. The statistical significance level of the analysis was set at $p < 0.05$.

3. Results

3.1. Trends in the Occurrence of V. parahaemolyticus Cases

The trend of occurrence of *V. parahaemolyticus* food poisoning in Korea is shown in Figure 1e. The total number of food poisoning outbreaks reported between 2002 and 2017 was 4273, resulting in 112,590 cases. During the period, the total number of *V. parahaemolyticus* food poisoning outbreaks was 244, and this number accounted for about 7%, on average (varying 1.5–16.3% by year), of the total number of food poisoning outbreaks. Also, during the period, the number of cases affected by *V. parahaemolyticus* was 4798, which was a relatively wide range from 0.4 to 11.6%, varying by year for the total number of food poisoning cases. *V. parahaemolyticus* food poisoning outbreaks accounted for 14.4% of all bacterial food poisoning outbreaks and was the third most common causative bacteria after pathogenic *Escherichia coli* and *Salmonella*.

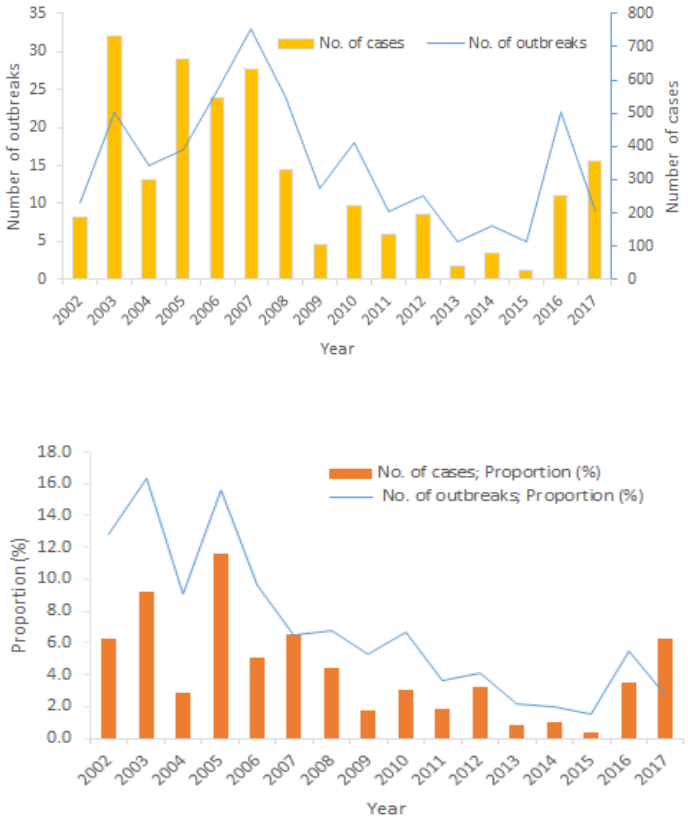

Figure 1. The occurrence of *V. parahemolyticus* food poisoning in Korea from 2002 to 2017: number of outbreaks and cases (**upper**) and proportion of outbreaks and cases (**lower**). Source of data: NIFS; KODC.

The monthly occurrence of *V. parahaemolyticus* food poisoning outbreaks is shown in Figure 2). During the study period, the monthly occurrence showed an apparent increase/decrease by season. In detail, the occurrence began to increase in May, jumped up in August, reached its peak in September, and decreased greatly in October. Occurrence was rare in November, December, and January. Occurrences began to appear again in February, with one case each in February, March, and April.

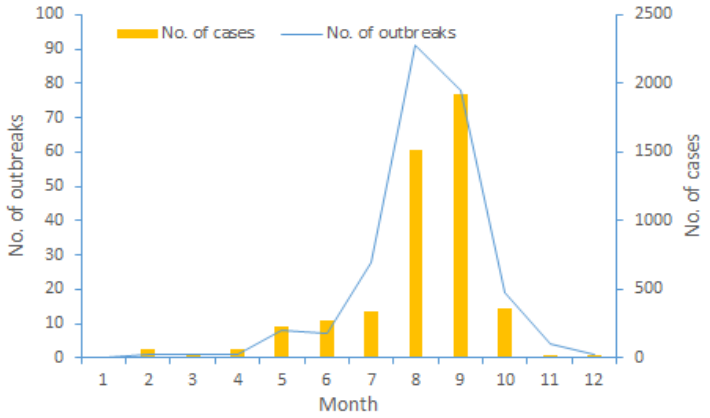

Figure 2. The occurrence of *V. parahemolyticus* food poisoning in Korea by month over the past years (2002~2017). Source of data: KMA.

In terms of the number of cases, the number was largest in September. Observing the occurrence at a monthly rate, the occurrence rates in July, August, and September were 11.5%, 37.3%, and 32.0%, respectively, concentrated in these three months; their sum was 80.8%. During the period, the monthly ratios of cases were 7.0%, 31.6%, and 40.0%, respectively.

3.2. Changes in Climatic Factors

From the observed data during the study period, the changes in climatic factors, namely, temperature (average, maximum, and minimum), precipitation, number of days with precipitation, and humidity, were investigated. They are tabulated in Table 1. For the 16 years of the study period, not only the average temperature, but also the maximum and minimum temperatures increased. During the period, precipitation ranged from 939.2 to 1856.1 mm, and it was 964.4 mm in 2017, which was greatly reduced compared to 1463.1 mm in 2002. There were not monotone changes in the number of days with precipitation. There was little change in humidity from year to year.

Table 1. Changes in the climatic factors of Korea from 2002 to 2017.

Year	Average Temp. (°C)	Maximum Temp. (°C)	Minimum Temp. (°C)	Precipitation (mm)	No. of Days with Rainfall	Daytime Hours	Relative Humidity (%)
2002	12.6	18.1	7.8	1463.1	105.0	2284.3	66
2003	12.5	17.7	8.0	1856.1	120.7	2055.0	68
2004	13.2	19.0	8.2	1454.6	101.4	2336.7	65
2005	12.4	17.9	7.6	1285.3	102.5	2286.4	65
2006	12.9	18.4	8.3	1420.3	103.8	2073.3	67
2007	13.3	18.7	8.7	1442.1	113.9	1937.1	69
2008	13.0	18.5	8.2	989.7	101.2	2114.4	67
2009	13.0	18.6	8.2	1203.0	105.6	2121.9	66
2010	12.7	18.0	8.1	1442.9	126.1	1970.4	68
2011	12.4	17.7	7.8	1620.5	113.1	2058.8	66
2012	12.3	17.6	7.8	1471.9	115.9	2189.5	66
2013	12.9	18.4	8.2	1162.4	111.1	2335.0	68
2014	13.1	18.6	8.4	1158.4	111.7	2231.1	68
2015	13.5	18.9	8.7	939.2	112.9	2277.1	69
2016	13.6	18.9	9.0	1264.1	109.5	2243.5	69
2017	13.1	18.8	8.1	964.4	100.0	2482.0	66

Source of data: KMA.

3.3. Relationship between the Occurrence of V. parahaemolyticus Food Poisoning and Climatic Factors

The correlation between the occurrence of *V. parahaemolyticus* food poisoning outbreaks and climatic factors was analyzed, and the results are presented in Table 2. The number of *V. parahaemolyticus* food poisoning outbreaks was found to have a significant positive correlation with the average temperature, maximum and minimum temperatures, precipitation, number of days with precipitation, and humidity ($p < 0.001$). On the other hand, the climatic factor of daytime hours showed a significant negative correlation with the number of *V. parahaemolyticus* food poisoning outbreaks ($p < 0.01$).

Table 2. Results of Pearson's correlation analysis between the climatic factors and occurrence of *V. parahemolyticus* food poisoning.

Factors	No. of Outbreaks	Average Temp. (°C)	Maximum Temp. (°C)	Minimum Temp. (°C)	Precipitation (mm)	No. of Days with Rainfall	Daytime Hours	Relative Humidity (%)
No. of outbreaks	1.000	0.469 ***	0.451 ***	0.489 ***	0.442 ***	0.400 ***	−0.242 **	0.509 ***
Average temp. (°C)	0.469 ***	1.000	0.996 ***	0.996 ***	0.679 ***	0.602 ***	−0.041	0.788 ***
Maximum temp (°C)	0.451 ***	0.996 ***	1.000	0.986 ***	0.637 ***	0.549 ***	−0.028	0.747 ***
Minimum temp. (°C)	0.489 ***	0.996 ***	0.986 ***	1.000	0.713 ***	0.643 ***	−0.114	0.829 ***
Precipitation (mm)	0.442 ***	0.679 ***	0.637 ***	0.713 ***	1.000	0.873 ***	−0.472 ***	0.737 ***
No. of days with rainfall	0.400 ***	0.602 ***	0.549 ***	0.643 ***	0.873 ***	1.000	−0.578***	0.725 ***
Daytime hours	−0.242 **	−0.041	0.028	−0.114	−0.472 ***	−0.578 ***	1.000	−0.532 ***
Relative humidity (%)	0.509 ***	0.788 ***	0.747 ***	0.829 ***	0.737 ***	0.725 ***	−0.532 ***	1.000

**: $p < 0.01$, ***: $p < 0.001$. The shaded areas are overlapping parts.

A regression analysis was performed to find the level of influence of each climatic factor on the number of *V. parahaemolyticus* food poisoning outbreaks and the results are tabulated in Table 3. In the multiple regression analysis, the researchers examined the multicollinearity of the independent variables (climatic factors) from the variance expansion factor (variance inflation factor, VIF), and found that multicollinearity did not exist with VIF = 1.000. As a result, the minimum temperature, maximum temperature, and precipitation were explanatory variables that significantly affected the outbreaks ($p < 0.01$), and the minimum temperature appeared to have the most impact.

Table 3. Results of multiple regression analysis.

	Unstandardized Coefficients		t	Sig.	VIF
	B	Std. Error			
(Constant)	6.822	1.820	3.748	0.000	
Minimum temperature	0.807	0.166	4.853	0.000	0.016
Precipitation	−0.015	0.003	−4.882	0.000	0.337
Maximum temperature	−0.496	0.161	−3.081	0.002	0.019

4. Discussion

4.1. Ket Findings

In Korea, the highest number of *V. parahaemolyticus* outbreaks was recorded in the late 1990s (1998) [9]. As in the results of this study in Section 3, the occurrence of *V. parahaemolyticus* food poisoning outbreaks shows an overall trend of decreasing since 2009. In the yearly trends, the incidence of *V. parahaemolyticus* food poisoning has been relatively decreasing

since 2009. The reason for such trend is hardly found in the literature or reports. The Korea Disease Control and Prevention Agency (KDCA) is in charge of food poisoning/infectious disease control. The KDCA have been strengthening hygiene rules and promoting public awareness of food poisoning at the national level since 2004. It is assumed that such efforts of the KDCA contribute to this decreasing trend.

However, during the study period, the number of *V. parahaemolyticus* food poisoning outbreaks ranked in third place among bacterial food poisonings, along with pathogenic *E. coli* food poisoning and *Salmonella* food poisoning. In addition, *V. parahaemolyticus* food poisoning outbreaks occurred intensively in July, August, and September (summer in Korea), accounting for 80.8% of all outbreaks, and resulted in a large number of cases accounting for 78.6% in the three months. These statistics suggest that stronger promotional activities and improvements in consumer awareness about *V. parahaemolyticus* food poisoning are needed in seasons of rising temperatures. Given that *V. parahaemolyticus* food poisoning outbreaks occurred in all months except January, the possibility that outbreaks may occur throughout the year in the future cannot be ruled out, so more action will be necessary to prevent it.

This study shows that the temperature in Korea has increased significantly over the past 16 years (2002–2017). The maximum, average, and minimum temperatures increased by 0.7 °C, 0.5 °C, and 0.3 °C, respectively, in 2017 compared to 2002. Also, the number of *V. parahaemolyticus* food poisoning outbreaks was found to have a significant correlation with most climatic factors, including temperature. It is generally known that bacterial food poisoning occurs more often in summer than in other seasons, and this is the case in Korea as well in the past [11,21,22]. A pattern of seasonality in *V. parahaemolyticus* levels in seawater and oysters was observed in another study, like the trend in this study, where the outbreaks of *V. parahaemolyticus* food poisoning showed seasonality [23].

This study specifically investigated the occurrence of *V. parahaemolyticus* food poisoning in Korea and various climatic factors for the first time. The outbreaks were significantly correlated with climatic factors, and among them, minimum temperature was found to be the most significant.

The results of this study are also supported by several studies in recent years. It has been suggested that a warming trend in sea surface temperatures is linked to the spread of Vibrios [24]. It has also been shown that changes in climatic conditions are associated with increased frequencies of *V. parahaemolyticus* and *V. vulnificus* in aquatic ecosystems [25]. A novel view of the quantitative relationship between climate change and food poisoning by *V. parahaemolyticus* in Taiwan was reported [26].

From the results of this study, the researchers again emphasize that climate change, especially warming, has a significant impact on the occurrence of *V. parahaemolyticus* food poisoning in Korea. The results are supported by reports that show a correlation between the monthly air temperature and sea surface temperature at nine locations in the East Sea, South Sea, and West Sea of Korea 10 years ago [16,17]. There are claims that two important environmental factors controlling the bacterial dynamics in coastal areas are temperature and salinity [27,28]. The concentration of Vibrio bacteria in seawater is generally higher in summer than in winter due to its growth pattern. On the other hand, there are reports that the difference in the growth rate of Vibrio bacteria due to salinity is significant only when the temperature is low [29]. This study does not determine the relationship between the appearance of *V. parahaemolyticus* in seawater and salinity due to the lack of relevant data sources throughout the whole study period. There is a report showing a positive correlation with temperature and a negative correlation with salinity, which is about the isolation rate of pathogenic Vibrios from seawater specimens in coastal areas of South Korea in 2016 [30].

Since 2005, Korea has operated Vibrio Net (surveillance project for pathogenic Vibrio bacteria in the marine environment) [31,32]. Vibrio-Net Korea monitors seawater for pathogenic Vibrio bacteria in seawater near the coast of Korea, but only provides limited data on the appearance of Vibrio bacteria, especially *V. vulnificus*. Under these circumstances, this study had limitations and was unable to quantify the relationship between the

occurrence of *V. parahaemolyticus* food poisoning and the concentration of Vibrio bacteria in seawater. Just as long-term meteorological data are provided in Korea, if accumulated seawater Vibrio monitoring data were also provided for the public to view, the researchers could produce more in-depth research outputs on the effects of climate change. These data could also be widely utilized as educational materials for the public.

4.2. Limitations

This study has a few limitations; some of them are described above. First, the researchers were unable to quantify the relationship between the occurrence of *V. parahaemolyticus* food poisoning and the concentration of Vibrio bacteria in seawater. Next, the relationship between the salinity of seawater and the concentration of Vibrio bacteria was not presented.

These limitations were due to the lack of data for the whole study period. The researchers do not rule out that there may be variables other than the main variables used in the correlation analysis of this study. Also, the seasonal pattern of the occurrence of *V. parahaemolyticus* food poisoning was discussed, but the statistical correlation was not analyzed. The researchers did not discuss causation in this study. By considering these limitations, future research can provide a more comprehensive analysis.

5. Conclusions

This study was performed to investigate the occurrence and characteristics of *V. parahaemolyticus* food poisoning in Korea over the past 16 years (2002–2017) and its relationship with climatic factors. The researchers used Korea's official statistical data for all data, including the number of food poisoning outbreaks, number of cases, and climate variables. A trend analysis, Pearson's correlation analysis, and regression analysis were used to determine the relationship between the occurrence of *V. parahaemolyticus* food poisoning and climatic factors. During the study period, the number of *V. parahaemolyticus* food poisoning outbreaks ranked in third place among bacterial food poisonings in Korea. *V. parahaemolyticus* food poisoning occurred intensively in summer (between July and September) and in all months except January. In terms of climatic factors, average temperature, maximum and minimum temperatures, precipitation, number of rainy days, and humidity showed a significant positive correlation with the number of *V. parahaemolyticus* food poisoning outbreaks ($p < 0.001$), but daytime hours showed a significant negative correlation ($p < 0.01$). Additionally, minimum temperature was shown to be the most important variable in the outbreaks of *V. parahaemolyticus* food poisoning ($p < 0.01$)). The analysis results of this study suggest that the occurrence of *V. parahaemolyticus* food poisoning in Korea is particularly related to climate change due to warming around the Korean Peninsula. As seafood contamination is expected to accompany the mutation of Vibrio bacteria contamination in seawater, it is necessary to pay attention to the hygiene and ensure the safety of fish and shellfish along with the rise in temperature. These results are based on the data observed in Korea. When applied to other regions, further factors may be considered.

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Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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