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ORIGINAL RESEARCH

Incidences of Waterborne and Foodborne Diseases After Meteorologic Disasters in South Korea

Wonwoong Na, MD, Kyeong Eun Lee, MD, Hyung-Nam Myung, PhD, Soo-Nam Jo, PhD, Jae-Yeon Jang, PhD

Abstract

BACKGROUND Climate change could increase the number of regions affected by meteorologic disasters. Meteorologic disasters can increase the risk of infectious disease outbreaks, including waterborne and foodborne diseases. Although many outbreaks of waterborne diseases after single disasters have been analyzed, there have not been sufficient studies reporting comprehensive analyses of cases occurring during long-term surveillance after multiple disasters, which could provide evidence of whether meteorologic disasters cause infectious disease outbreaks.

OBJECTIVES This study aimed to assess the nationwide short-term changes in waterborne and foodborne disease incidences after a meteorologic disaster.

METHODS We analyzed cases after all 65 floods and typhoons between 2001 and 2009 using the Korean National Emergency Management Agency's reports. Based on these data, we compared the weekly incidences of *Vibrio vulnificus* septicemia (VVS), shigellosis, typhoid fever, and paratyphoid fever before, during, and after the disasters, using multivariate Poisson regression models. We also analyzed the interactions between disaster characteristics and the relative risk of each disease.

FINDINGS Compared with predisaster incidences, the incidences of VVS and shigellosis were 2.49-fold (95% confidence interval, 1.47-4.22) and 3.10-fold (95% confidence interval, 1.21-7.92) higher, respectively, the second week after the disaster. The incidences of VVS and shigellosis peaked the second week postdisaster and subsequently decreased. The risks of typhoid and paratyphoid fever did not significantly increase throughout the 4 weeks postdisaster. The daily average precipitation interacted with VVS and shigellosis incidences, whereas disaster type only interacted with VVS incidence patterns.

CONCLUSIONS The incidences of VVS and shigellosis were associated with meteorologic disasters, and disaster characteristics were associated with the disease incidence patterns postdisaster. These findings provide important comprehensive evidence to develop and support policies for managing and protecting public health after meteorologic disasters.

KEY WORDS waterborne diseases, foodborne diseases, communicable diseases, disasters, Republic of Korea

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All of the authors participated in data analysis and writing. The authors declare no conflicts of interest.

From the Department of Preventive Medicine and Public Health, School of Medicine, Ajou University, Suwon, Korea (WN, KEL, J-YJ); Department of Ecology Research, ChungNam Institute, Gongju, Korea (H-NM); Gyeonggi Infectious Disease Control Center, Seongnam, Korea (S-NJ). Address correspondence to J.-Y.J. (free5293@gmail.com).

INTRODUCTION

The Intergovernmental Panel on Climate Change's Fifth Assessment Report projected that climate change could increase the number of regions with heavy precipitation and risk of flooding on a regional scale.[1] Increased urbanization and subsequent reduction in vegetation, agricultural lands, and low-lying areas can also increase meteorologic disaster severity.[2,3] The potential magnitude and extent of the effects of meteorologic disasters on various economic sectors suggest that governments should establish ways to proactively combat the negative impact, including preventive measures or a monitoring system. To that end, a quantitative assessment of the effects on the national incidences of infectious diseases may help predict the effects of future climate change–induced meteorologic disasters. Furthermore, possible effects of climate change on human health may influence the public's perception of these issues and greenhouse gas reduction policies. However, very few studies have quantitatively assessed the effects of meteorologic disasters on public health.[4-6]

Meteorologic disasters can directly cause death or injury, and they can also increase infectious disease outbreaks by weakening a community's health delivery capabilities and changing the hygienic environment.[7-10] There have been numerous reported instances of changes in infectious disease prevalence after meteorologic disasters, such as after the 2004 Bangladesh flood, when >350,000 patients experienced diarrhea after being infected with *Escherichia coli*, *Shigella*, or *Vibrio cholerae*.[11] The number of patients with diarrhea also increased after the December 2004 tsunami in Thailand.[12] Furthermore, a cholera outbreak was observed in Haiti after the 2010 earthquake; this outbreak was enhanced by water contamination that was related to heavy rainfall.[13] Similar effects have also been observed in developed countries, such as increases in *Vibrio vulnificus* septicemia (VVS) cases and norovirus infections after Hurricane Katrina (in the United States), in addition to the increased incidence of gastrointestinal illness after a flood in Massachusetts.[14-16]

Thus, it is clear that meteorologic disasters may significantly affect infectious disease outbreaks in specific regions, although nationwide effects of meteorologic disasters cannot be easily quantified using the data in those reports. Infectious disease incidence can be linked to regional sanitation and health response capabilities,[17] which further complicates analysis at a national level. Although specific meteorologic disasters in isolated regions may provide general evidence of the need for coordinated responses, they provide insufficient data for designing national response strategies and determining the appropriate resource investment. Therefore, national, long-term, and comprehensive assessments of numerous meteorologic disasters and their effects on national health are needed to develop national climate change policies and health response measures.

Among the available nationwide studies, Curriero et al[18] analyzed American meteorologic disasters from 1948-1994 and reported that disasters were related to infectious disease outbreaks. Thomas et al[19] also analyzed meteorologic disasters over a 27-year period in Canada, using the same method, and reported that disasters may be a risk factor for infectious disease outbreaks. In addition, Ni et al[6] analyzed floods that occurred in 3 Chinese cities between 2004 and 2009 and found that the number of patients with diarrhea increased by 66% after each flood. Although these studies could inform public policy, their findings were limited in terms of the specific regional characteristics or specific disease. Because various waterborne infectious diseases (eg, cholera, VVS, shigellosis, typhoid fever, and paratyphoid fever) that are related to meteorologic disasters have different transmission methods and latency periods, it is necessary to individually analyze each disease.[9]

When formulating policies to prevent infectious diseases and making appropriate quarantine arrangements for exposed patients, it is not sufficient to examine individual meteorologic disasters and their related epidemics. In addition, because each individual meteorologic disaster is associated with varied regional conditions, such as the affected population, urbanization, natural environment, or public health capacity, analysis of individual disasters does not provide enough evidence to support changes in public policy. Public policy should be informed by knowledge of how infectious disease incidence increases after a disaster and what conditions can influence this incidence. Therefore, a comprehensive long-term analysis of various infectious diseases, their specific incidences, regional effects, and other related factors is urgently needed. By identifying the infectious diseases that are associated with meteorologic disasters within administrative regional units, it would then be possible to compile information regarding the factors that can increase or decrease their incidences. Thus, we analyzed the change in the incidence of several infectious diseases after meteorologic disasters in Korea (2001-2009) to determine the influence of meteorologic disasters. In addition, we examined whether or not the type of meteorologic disaster or the characteristics of the affected regions affected infectious disease incidences.

METHODS

In this study we defined meteorologic disasters as heavy rain or typhoons that resulted in property damage or loss of human life. Over the study period (2001-2009), 65 disasters were recorded in the annual disaster reports published by the National Emergency Management Agency.[20] For this study, we extracted disaster-related statistics, including onset date, duration, and affected regions, from these reports. This study evaluated 16 distinct administrative regions: Seoul, Incheon, Daejeon, Daegu, Gwangju, Ulsan, and Busan, which were defined as metropolitan regions, and Gyeonggi, Gangwon, Chungbuk, Chungnam, Gyeongbuk, Gyeongnam, Jeonbuk, Jeonnam, and Jeju, which were defined as provinces.

In annual disaster reports, disasters that concurrently affect several administrative regions are initially recorded as a single meteorologic disaster. However, if a single meteorologic disaster causes loss of human life in multiple administrative regions, each region is considered to have experienced a different disaster. Therefore, a single meteorologic disaster that affected multiple areas was considered a distinct disaster in each of the affected administrative regions, although disasters that occurred within a 7-day span and within the same region were categorized as a single event. All meteorologic disasters were categorized as either heavy rain or typhoon, and disasters were classified as heavy rain if heavy rain and a typhoon were simultaneously recorded.

Using meteorologic data from the Korean Meteorologic Administration, we calculated the average daily precipitation for each disaster and region. In addition, we used data from the National Statistical Office to determine the population of each region for each year, and we analyzed data from the surveillance system for legal infectious diseases (administered by the Korean Center for Disease Control and Prevention) to identify the incidences of VVS, shigellosis, typhoid fever, and paratyphoid fever. In this system, infectious disease data are reported by >240 Korean primary health centers, and the cases include both laboratory-confirmed and clinical diagnoses. Because the infectious disease reporting system is a passive surveillance system (based on each clinic's voluntary reporting), variations according to days of the week were possible. Therefore, we used weekly observational units to adjust for this variation for "disaster periods": the weeks before, during, and after the disaster. When another disaster occurred within 2-4 weeks after the previous disaster ended, the overlapping weeks between the 2 disasters were excluded from the analysis. For the predisaster period, we choose 1 week before the occurrence of a disaster instead of 2 or more weeks to avoid increasing the number of cases that were excluded as a result of overlap in the study period between each disaster case.

For this study, we built 4 multivariate log linear models, with 1 for each individual disease, based on an assumed Poisson distribution. In each model, the incidence rate was defined as the number of cases per million person-years, and the annual population and observation period were included in the model as offset variables. The dependent variable was the reported incidence of the relevant disease, and we selected and entered various independent variables, which included the disaster period, type of disaster, region, average daily precipitation, and duration of the disaster. The disaster type, region, average daily precipitation, and duration of the disaster were control variables. Based on disease incidence before the disasters, an exponential β coefficient was calculated for each disaster period, and the 95% confidence interval (CI) for this value was also obtained. The exponent of the β coefficient was reported as the relative risk. Using this model, we compared the relative risk in the week before the disaster (the reference period) to the relative risks during the disaster and during each of the 4 weeks after the disaster.

We also assumed that the changing patterns for the relative risk during each disaster period would differ according to the involved region and the type and size of the disaster. Therefore, to evaluate these factors, we stratified data according to the type of disaster and the involved region. Furthermore, we assessed correlations the disaster duration and daily precipitation, which combined to indicate the scale of the disaster. To account for these interaction effects, we added an interaction term for disaster duration and weekly period, or for average precipitation and weekly period, into the 4 disease-specific regression models, which provided 8 unique models (2 per disease) that we used to evaluate whether or not the scale of the disaster influenced the incidence pattern of each disease. For these analyses, disaster duration was categorized into 3 groups (1-4 days, 5-13 days, and ≥14 days), and the average daily precipitation data were grouped into tertiles.

SPSS software (Version 19.0, SPSS Inc., Chicago, IL) was used for all statistical analyses.

The data that we evaluated in this study did not contain any personal information. Furthermore, the Ajou Hospital institutional Review Board reviewed the study protocol and confirmed that ethical approval was not required.

RESULTS

A total of 312 meteorologic disasters occurred within the administrative regions during the study period (Table 1). The average disaster duration was 8.7 days, and the average cumulative precipitation for each region during a meteorologic disaster was 209.4 mm. To identify the baseline incidences for each disease, we calculated the reported incidences (per million person-years) for each infectious disease during the week before each disaster. The baseline reported incidences were 2.82 cases per million person-years for VVS, 3.44 cases per million person-years for shigellosis, and 3.96 cases per million person-years for typhoid fever. However, the baseline reported incidence rate for paratyphoid fever was considerably lower, at 0.78 cases per million person-years.

The relative risks for each infectious disease during each weekly disaster period, compared with incidences the week before the disaster, are shown in Figure 1. The relative risk for VVS peaked during the second week after the disaster at 2.49 (95% CI, 1.472-4.223). The relative risk remained elevated, at 2.01 (95% CI, 1.137-3.554), during the third week and subsequently decreased during the fourth week to a risk similar to the baseline risk.

The data were also stratified and analyzed according to the type of region (Table 2). The relative risks of VVS in provinces increased to 2.4 (95% CI, 1.306-4.403) and 1.98 (95% CI, 1.023-3.822) during the second and third weeks after the disaster, respectively, although no significant increase was identified during the fourth postdisaster week. However, the relative risk in the metropolitan cities tended to increase until the second week (relative risk, 2.90; 95% CI, 0.976-8.613), decrease during the third week (relative risk, 2.14; 95% CI, 0.664-6.883), and increase again during the fourth week (relative risk, 4.07; 95% CI, 1.380-12.022).

The differences in risk were more prominent when we stratified the analyses according to the disaster type. After heavy rain disasters, the relative risk of VVS increased during the first (3.13; 95% CI, 1.459-6.727) and second weeks (5.06; 95% CI, 2.409-10.639), decreased slightly during the third week (3.72, 95% CI 1.683-8.208), and rose again during the fourth week (4.15; 95% CI, 1.842-9.336). There was no significant change in the relative risk of VVS after typhoons.

The relative risk of shigellosis increased to 3.1 (95% CI, 1.209-7.924) during the second week after disaster and subsequently decreased (Fig. 1). After stratification of analysis according to region, the relative risks of shigellosis in metropolitan cities and provinces peaked during the second week and subsequently decreased (Table 2). There was no statistically significant increase in relative risk in metropolitan cities, although the relative risk in provinces increased significantly to 2.84 (95% CI, 1.207-6.679) during the second week. Similar patterns were noted when the relative risk of shigellosis was stratified according to the disaster type. The relative risk of shigellosis rose to 3.34 (95% CI, 0.999-11.148) during the second week after heavy rain and subsequently decreased. Although the relative risk after typhoons peaked at 2.39 (95% CI,

Table 1. General Characteristics of Meteorologic Disasters in the Republic of Korea (2001-2009)

	N (%)	Mean	SD	Range
Cases	312			
Type of disaster				
Heavy rain	222 (71.2)			
Typhoon	90 (28.8)			
Type of region				
Metropolitan*	105 (33.7)			
Province†	207 (66.3)			
Duration of the disaster (d)		8.7	7.4	1-36
Daily average precipitation (mm)		32.37	23.22	0.70-143.18
Cumulative precipitation (mm)		209.44	160.08	1.98-852.53
Disease incidence rate before the disaster (per million person-year)				
VVS		0.054	0.254	0.0-2.974
Shigellosis		0.066	0.230	0.0-1.593
Typhoid fever		0.076	0.224	0.0-1.788
Paratyphoid fever		0.015	0.082	0.0-0.716

SD, standard deviation; VVS, *Vibrio vulnificus* septicemia.

* Metropolitan areas: Seoul, Incheon, Daejeon, Daegu, Gwangju, Ulsan, and Busan.

† Provinces: Gyeonggi-do, Gangwon-do, Chungcheongbuk-do, Chungcheongnam-do, Gyeongsangbuk-do, Gyeongsangnam-do, Jeollabuk-do, Jeollanam-do, and Jeju Special Self-Governing Province.

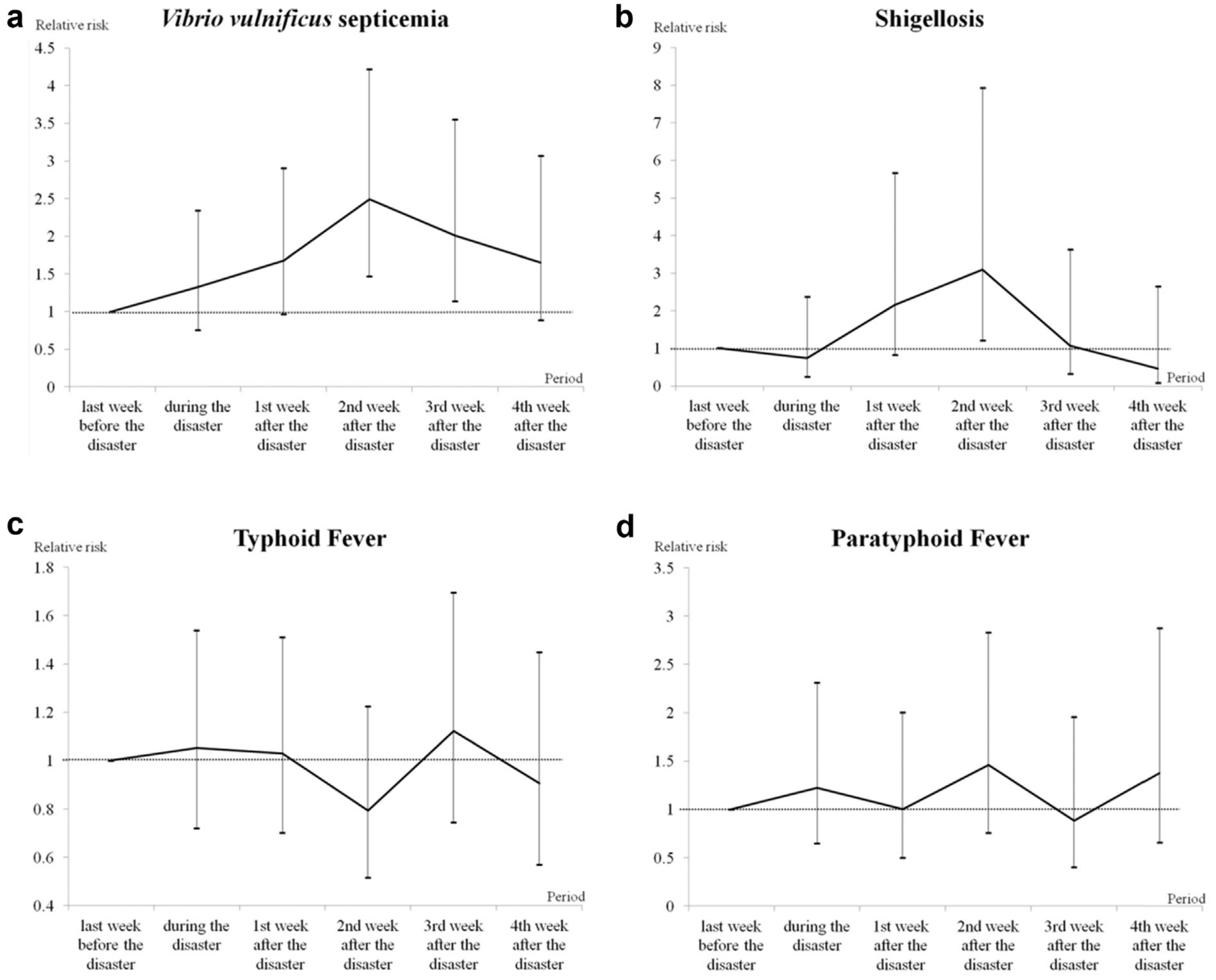

Figure 1. **Changes of relative risk for weekly incidence of (a) *Vibrio vulnificus* septicemia, (b) shigellosis, (c) typhoid fever, and (d) paratyphoid fever during and after disaster.**

0.907-6.289) during the second week and subsequently decreased, the increase was not statistically significant.

When we analyzed all cases of typhoid fever, no weekly period had significant differences in incidence compared with the baseline (Fig. 1). In addition, although the relative risk of typhoid fever was slightly higher in metropolitan cities compared with that in the provinces, this difference was not statistically significant (Table 2). No significant change in the relative risk of typhoid fever was identified when analysis was stratified according to disaster type. Similar to other diseases, the relative risk of paratyphoid fever peaked during the second week (1.46; 95% CI, 0.756-2.829), although this difference was not statistically significantly (Fig. 1). In addition, no other stratified analyses revealed significant changes in the relative risk for paratyphoid fever (Table 2).

Finally, we investigated whether disaster duration and average daily precipitation during the disaster correlated with the relative risk for each weekly period (Table 3). Although the disaster duration had no effect on the relative risk of VVS, the relative risk of VVS was significantly elevated for the second precipitation tertile during the second week after the disaster, compared with the lowest tertile. In addition, the relative risk of shigellosis was also significantly elevated in the second precipitation tertile compared with the lowest tertile during the third week after the disaster, and the relative risk of paratyphoid fever was higher in the

Table 2. Relative Risk for the Weekly Incidence of VVS, Shigellosis, Typhoid Fever, and Paratyphoid Fever During and After the Disaster

	Type of Region						Type of Disaster					
	Metropolitan Cities			Provinces			Heavy Rain			Typhoon		
	RR	95% CI	*P*	RR	95% CI	*P*	RR	95% CI	*P*	RR	95% CI	*P*
VVS												
Disaster period	1.107	0.342-4.004	.802	1.375	0.721-2.621	.334	1.945	0.888-4.257	.096	1.328	0.600-2.942	.484
1st wk	1.375	0.411-4.604	.606	1.750	0.937-3.268	.079	3.133	1.459-6.727	.003	0.800	0.366-1.750	.576
2nd wk	2.899	0.976-8.613	.055	2.398	1.306-4.403	.005	5.062	2.409-10.639	<.001	1.000	0.478-2.092	1.000
3rd wk	2.138	0.664-6.883	.203	1.978	1.023-3.822	.042	3.717	1.683-8.208	.001	0.920	0.420-2.013	.834
4th wk	4.073	1.380-12.022	.011	0.980	0.426-2.253	.962	4.147	1.842-9.336	.001	0.377	0.130-1.087	.071
Shigellosis												
Disaster period	0.904	0.078-10.534	.936	0.673	0.228-1.990	.474	0.841	0.207-3.410	.808	0.533	0.091-3.136	.487
1st wk	2.737	0.333-22.472	.349	1.875	0.771-4.561	.166	2.585	0.767-8.71	.125	1.167	0.385-3.531	.785
2nd wk	3.640	0.458-28.938	.222	2.839	1.207-6.679	.017	3.337	0.999-11.148	.050	2.389	0.907-6.289	.078
3rd wk	1.448	0.120-17.430	.771	0.863	0.263-2.833	.808	1.194	0.258-5.533	.821	0.625	0.160-2.435	.498
4th wk	0.992	0.055-18.021	.996	0.182	0.017-1.969	.161	0.489	0.052-4.619	.533	0.319	0.056-1.821	.198
Typhoid fever												
Disaster period	1.541	0.765-3.104	.226	0.858	0.551-1.335	.497	1.052	0.675-1.640	.822	1.140	0.547-2.375	.726
1st wk	1.100	0.517-2.340	.805	1.000	0.653-1.532	1.000	1.120	0.716-1.752	.620	0.789	0.374-1.667	.535
2nd wk	1.250	0.582-2.684	.566	0.611	0.363-1.027	.063	0.907	0.548-1.499	.703	0.526	0.226-1.225	.137
3rd wk	1.517	0.718-3.203	.275	0.955	0.587-1.551	.851	1.305	0.808-2.106	.276	0.688	0.303-1.564	.372
4th wk	1.054	0.441-2.520	.906	0.863	0.505-1.476	.591	0.984	0.560-1.730	.956	0.708	0.312-1.610	.410
Paratyphoid fever												
Disaster period	1.118	0.510-2.449	.781	1.355	0.526-3.494	.529	1.408	0.680-2.918	.357	0.925	0.239-3.572	.909
1st wk	0.625	0.232-1.683	.353	1.375	0.532-3.556	.511	1.273	0.58-2.792	.547	0.400	0.080-1.998	.264
2nd wk	1.535	0.684-3.444	.299	1.380	0.511-3.731	.525	1.769	0.824-3.798	.143	0.800	0.220-2.906	.735
3rd wk	0.636	0.219-1.844	.405	1.185	0.392-3.579	.764	1.066	0.430-2.640	.890	0.480	0.096-2.408	.373
4th wk	1.270	0.516-3.126	.603	1.485	0.491-4.495	.484	1.840	0.800-4.235	.152	0.493	0.098-2.469	.389

All results were adjusted using a generalized linear model for the type of disaster, type of affected region, duration of the disaster, and daily average precipitation during the disaster. The model assumed a Poisson distribution.

95% CI, 95% confidence interval; RR, relative risk (ratio of the incidence in the disaster period to the incidence in the week before the disaster); VVS, *Vibrio vulnificus* septicemia.

third precipitation tertile during the first week after the disaster compared with the lowest tertile. However, neither of the variables exerted interaction effects on typhoid fever outbreak patterns.

DISCUSSION

We conducted this study to examine whether or not the incidence patterns of waterborne and foodborne infectious diseases change after meteorologic disasters. Our results indicate that the incidences of VVS and shigellosis significantly increased after disasters.

People develop VVS after consuming incompletely cooked seafood that is contaminated with *V vulnificus* or when a wound is exposed to seawater with a high concentration of *V vulnificus*.[21] In addition, studies have reported relationships between typhoons or heavy rainfall and the multiplication of *V vulnificus*, which indicates that infection is associated with these meteorologic disasters.[22,23] Furthermore, Kim et al[24] reported that the incidence of VVS correlated with monthly precipitation. They also suggested that the low salinity of seawater caused by the influx of unsalinated water after heavy precipitation might create a favorable environment for *V vulnificus* multiplication.[24] In the present study, we also noted that the reported VVS incidence increased predominately in areas that received heavy precipitation and not in areas that experienced typhoons. In addition, daily precipitation correlated with VVS incidence, which confirms the findings of previous studies.[24]

When we stratified our analysis according to region type, we noted that relative risk of VVS in metropolitan cities increased up to the fourth week after the disasters, whereas the risk in provinces peaked in the second week after the disasters.

Table 3. Correlations Between Disaster Duration and Daily Average Precipitation and the Weekly Relative Risk for VVS, Shigellosis, Typhoid Fever, and Paratyphoid Fever

	Disaster Duration (Reference: 1-4 d)						Daily Average Precipitation (Reference: First Tertile [<20.03 mm])					
	5-13 d			≥14 d			Second Tertile (20.03-35.22 mm)			Third Tertile (>35.22 mm)		
	RR	95% CI	*P*	RR	95% CI	*P*	RR	95% CI	*P*	RR	95% CI	*P*
VVS												
Disaster period	0.882	0.314-2.482	.812	0.674	0.141-3.225	.621	0.791	0.228-2.750	.713	1.375	0.436-4.340	.587
1st wk	0.834	0.314-2.221	.717	0.633	0.185-2.169	.467	0.783	0.355-1.731	.546	0.569	0.204-1.591	.283
2nd wk	0.624	0.246-1.584	.321	1.653	0.565-4.833	.358	2.775	1.135-6.784	.025	1.610	0.545-4.757	.389
3rd wk	1.485	0.708-3.113	.295	1.400	0.471-4.157	.545	1.476	0.722-3.017	.286	0.877	0.355-2.166	.776
4th wk	1.588	0.638-3.950	.320	1.670	0.476-5.864	.424	1.747	0.726-4.203	.213	1.076	0.377-3.070	.891
Shigellosis												
Disaster period	1.116	0.257-4.844	.884	1.533	0.198-11.864	.682	1.446	0.308-6.783	.640	1.177	0.195-7.084	.859
1st wk	0.571	0.094-3.469	.543	0.767	0.092-6.408	.806	1.119	0.270-4.642	.877	0.779	0.125-4.863	.789
2nd wk	0.665	0.233-1.896	.445	0.882	0.174-4.474	.879	2.687	0.965-7.484	.059	0.392	0.072-2.126	.278
3rd wk	0.333	0.096-1.148	.082	2.150	0.493-9.374	.308	14.066	3.182-62.184	<.001	3.182	0.500-20.245	.220
4th wk	1.326	0.243-7.246	.745	1.152	0.107-12.422	.907	2.293	0.442-11.889	.323	0.771	0.091-6.535	.811
Typhoid fever												
Disaster period	1.613	0.837-3.107	.153	1.964	0.715-5.398	.191	0.840	0.400-1.762	.644	1.711	0.779-3.757	.181
1st wk	1.269	0.593-2.715	.539	1.374	0.508-3.720	.532	0.755	0.405-1.408	.376	1.140	0.541-2.399	.731
2nd wk	1.799	0.934-3.462	.079	2.201	0.819-5.914	.118	0.734	0.363-1.484	.389	1.244	0.570-2.717	.584
3rd wk	0.840	0.361-1.952	.685	1.867	0.641-5.440	.253	0.999	0.432-2.313	.998	1.168	0.458-2.983	.745
4th wk	1.194	0.563-2.534	.644	1.520	0.509-4.542	.453	1.205	0.556-2.614	.637	1.159	0.476-2.823	.746
Paratyphoid fever												
Disaster period	0.753	0.254-2.238	.610	0.269	0.044-1.636	.154	1.231	0.354-4.284	.744	1.367	0.336-5.565	.663
1st wk	0.944	0.293-3.038	.922	0.633	0.143-2.801	.547	1.216	0.424-3.490	.716	3.664	1.262-10.639	.017
2nd wk	1.035	0.294-3.641	.958	1.282	0.274-5.991	.752	0.836	0.242-2.888	.778	1.260	0.320-4.964	.741
3rd wk	0.929	0.333-2.593	.889	0.472	0.098-2.263	.348	0.524	0.141-1.945	.334	1.233	0.367-4.145	.734
4th wk	1.061	0.175-6.414	.949	1.789	0.27-11.858	.546	2.888	0.767-10.87	.117	0.593	0.061-5.782	.653

All results were adjusted using a generalized linear model for the type of disaster, type of affected region, duration of the disaster, and daily average precipitation during the disaster. The model assumed a Poisson distribution.

95% CI, 95% confidence interval; RR, relative risk (ratio of the incidence in the disaster period to the incidence in the week before the disaster); VVS, *Vibrio vulnificus* septicemia.

Interestingly, most of the provincial regions (8 of 9) included a coastal region, whereas only 2 of the metropolitan cities included a coastal region. Therefore, it is possible that proliferation of *V vulnificus* increased after precipitation reduced the salinity of the coastal seawater, which increased the number of VVS outbreaks in the provinces. Because the metropolitan areas were mainly inland, there was likely decreased direct exposure to seawater in these areas, which would indicate that the metropolitan outbreaks were affected by secondary issues, such as the distribution of contaminated seafood. However, these hypotheses remain speculative.

Unlike *V vulnificus*, shigellosis, typhoid fever, and paratyphoid fever are transmitted via the fecal-to-oral route.[25,26] Therefore, the concentration of pathogens in regional water sources is a key determinant of the disease incidence. Interestingly, Righetto et al[27] used cholera as a model of infectious disease and suggested that the influx of water (eg, via increased precipitation) ultimately reduces the concentration of pathogens, which thereby reduces infectious disease incidence. Li et al[28] have also reported a precipitation-dependent decrease in Chinese outbreaks of bacillary dysentery. However, we identified an increase in shigellosis incidence during the second week after the disasters. Similar to our findings, Chen et al[4] reported that heavy rain was associated with increased shigellosis incidence. This discrepancy regarding the effect of precipitation on the incidence of shigellosis may be related to increased seasonal precipitation creating a prolonged dilutive effect, which thereby reduces the incidence of shigellosis. On the other hand, short-term typhoons and periods of heavy rain may cause disease outbreaks by facilitating contamination of water sources. Additionally, high resident density in shelters after a meteorologic disaster may also promote disease transmission.[10]

Previous studies have reported that typhoid fever and paratyphoid fever are likely to occur after a meteorologic disaster.[7-10] In addition, Vollaard et al[29] reported that flooding was a risk factor for typhoid and paratyphoid fever in Indonesia. In this study, we did not identify any significant increase in the reported incidences of typhoid and paratyphoid fever after disasters as we did for shigellosis. This difference may be attributed to regional differences in the ability to manage infectious diseases. According to one study of infectious diseases in South Korea, typhoid fever has an annual incidence of 200-400 cases. However, after the rapid decrease in paratyphoid fever incidence during the 1970s, fewer than 100 cases have been reported each year. In contrast, very few cases of shigellosis were diagnosed in the 1980s, although the incidence of shigellosis has since increased to 400 patients in 2004.[30] Although we noted similar incidence rates for typhoid fever and shigellosis during the week before the disaster, the ability to prevent shigellosis appears to be reduced in the postdisaster setting compared with that for typhoid fever and paratyphoid fever.

If the absence of a clear increase in the disease incidence is related to the predisaster public health level, subsequent destruction of public health infrastructure may increase disease incidence. However, the incidences of typhoid fever and paratyphoid fever may also increase in response to increased variability in precipitation and climate as a result of climate change.[31] Dewan et al[32] have reported that the incidence of typhoid fever in Bangladesh increased by 4.6% for every 0.1 m increase in water levels above a 4-m threshold. Thus, it is plausible that the increasing intensity of meteorologic disasters as a result of ongoing climate change may have increasingly negative effects on public health infrastructure, which may ultimately result in increased incidences of typhoid and paratyphoid fever. In addition, typhoid fever incidence can be influenced by various environmental and sociological conditions, such as distance from water bodies, level of urbanization, sociodemographic conditions, and meteorologic disasters.[3,32,33] Therefore, additional studies are needed to determine the precise effect of disasters on the incidence of typhoid fever.

Recent studies have also attempted to comprehensively evaluate the quantitative effects of meteorologic disasters on public health. Ni et al[6] recently reported that the flood-related relative risk of diarrhea was 1.66 (95% CI, 1.52-1.82) in their analysis of 3 areas over a 6-year period. Chen et al[4] also analyzed 15 years of data from Taiwan and calculated the relative risk of infectious disease relative to precipitation. We believe that similar studies are urgently needed in Korea because they provide important comprehensive evidence to develop and support policies for managing and protecting public health after meteorologic disasters.

In addition, comprehensive quantitative assessments are needed to judge the success or failure of these policies. In Korea from 2001-2009 there were 52 heavy rains, 13 typhoons, and 18 floods.[20] The incidence of these disasters may continue to increase in the near future because of climate change. In this context, our study quantitatively analyzed outbreak patterns for waterborne and foodborne infectious diseases after meteorologic disasters, and our results provide fundamental data to facilitate the development of public health responses to these disasters. VVS and shigellosis incidences sharply increased after disasters, which suggests the need for active public health responses to these diseases immediately after similar disasters. In addition, the relative risk of VVS increased after periods of heavy precipitation, although not after typhoons, and lasted longer in metropolitan cities compared with provinces. Therefore, public health responses should also consider these disaster characteristics. As mentioned earlier, the mechanisms through which meteorologic disasters influence the incidence of infectious disease may involve increasing pathogens, changing the natural environment, destroying public health infrastructure systems, or displacing people. Further research into the underlying mechanism might be needed to develop and strengthen public health policies related to disasters.

One of the limitations of the present study is the possibility that calculated incidence rates were lower than the actual rates because our infectious diseases data were obtained via a passive monitoring system that is based on voluntary reporting by clinics.[34] However, our dataset was obtained from the official South Korean infectious disease monitoring records that are representative of the general population, which should reduce any bias related to low reporting rates. In addition, we compared the relative risk in each period with that in the predisaster period instead of to the absolute incidence rates, which should also reduce the risk of any bias.

The incidence rates during the week before a disaster might also have been affected by the previous disaster, which is another study limitation. For example, although the greatest influence on VVS and shigellosis was noted in the second week after disasters, disaster-related effects on VVS were also identified in the third and fourth postdisaster weeks. Therefore, the effect of 1 disaster may have affected the predisaster period for the subsequent disaster, thereby resulting in underestimation of the relative risk after the subsequent disaster. Therefore, our analysis may have underestimated the relative risk of infectious diseases in the postdisaster period, although this limitation likely does not weaken the finding of the present study.

This study is also limited by the lack of correction for disaster year in the statistical models. Unfortunately, this variable might act as a confounding factor, because unique events or improvements in public health policies and infrastructure can occur over time. However, our analysis evaluated relatively short 6-week periods, and it is unlikely that major public health policy changes could have been implemented during those periods. In addition, if we had incorporated any hypothetical yearly enhancements in public health infrastructure or reductions in infectious diseases as a result of environmental improvements, it is likely that the correlation with meteorologic disasters would have become even stronger. Therefore, we do not believe that this limitation significantly affected the findings.

Despite these limitations, the present study also has several strengths. First, to our knowledge, few studies have analyzed all meteorologic disasters that occurred within all regions of a single nation over an extended period. In this context, our comprehensive analysis included 312 meteorologic disasters in 16 Korean regions over a 9-year period. Second, we compared disease incidences before and after the meteorologic disasters, whereas previous studies have only determined that meteorologic disasters are risk factors for infectious disease.[6,18,19] Therefore, our study provides a unique perspective by examining changes in infectious disease incidences before, during, and after meteorologic disasters. Thus, we believe that our methodology can be used in future research designed to assess diverse effects of meteorologic disasters on public health.

In conclusion, heavy rain and typhoons were associated with increased incidences of VVS and shigellosis during the second week after the disasters, which were 2.5-fold and 3.1-fold greater than the baseline incidences, respectively. The incidences of both diseases began to decrease after the second postdisaster week. In addition, our findings suggest that the disease-specific incidence patterns may vary according to the disaster type or amount of precipitation. Finally, we did not identify a significant increase in the incidences of typhoid fever and paratyphoid fever after disasters, although additional research is needed to confirm. Because the intensity and severity of meteorologic disasters are likely to increase as a result of climate change, these findings can provide fundamental data for the support and development of public health policies.

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