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Original Article

Assessing the potential impacts of climatic factors on food- and water-borne diseases in Taiwan

Jia-Zhen Li[1], Hsin-Chieh Tsai[1], Szu-Chieh Chen[1,2*]

[1] *Department of Public Health, Chung Shan Medical University, Taichung City, Taiwan*
[2] *Department of Family and Community Medicine, Chung Shan Medical University Hospital, Taichung City, Taiwan*

Purpose: Global warming has caused extreme climates and affected the environment, increasing incidence of infectious diseases. The pathogenic mechanisms of Food- and Water-borne diseases, such as number of pathogens and growth temperature range, might also be affected. We evaluated the correlation between several climatic factors and the occurrence of Food- and Water-borne diseases in Taipei City and New Taipei City.
Methods: Weekly cases of Amoebic dysentery, Bacillary dysentery, Acute hepatitis A, Severe complicated *enterovirus* infection, Typhoid fever, and *Listeria* from 2009 to 2019 were adopted from the Taiwan Centers for Disease Control (Taiwan CDC). Mean, maximum, and minimum temperature, relative humidity (RH), and weekly accumulated rainfall were investigated as climatic factors. Generalized linear models with a Poisson distribution were used for regression analysis to explore correlations.
Results: The cumulative number of cases reached a ten-year high in 2016 with the incidence rate 4.8 per 100,000 population. The cumulative trends of the order of diseases in two cities over the past ten-year were similar in Taipei City and New Taipei City. All correlations were significant (P value <0.05) except for weekly accumulated rainfall. Significant correlations exist between the number of disease cases and the individual climatic factors of mean, maximum, and minimum temperature, and RH.
Conclusion: In multivariate models using all or all but one climatic factors, mean and maximum temperature were generally found to have significant correlations (P<0.05) for food- and water-borne disease.

Keywords: Climatic factors, Food- and Water-borne diseases, Notifiable infectious diseases, Subtropical, Regression model

1. Introduction

It is estimated that global warming caused by human activities has resulted in global temperatures about 1.0°C (0.8°C–1.2°C) above pre-industrial levels. The increase may reach 1.5°C between 2030 and 2052 if it continues at the current warming rate (IPCC, 2021) (1). Smith et al. (2) noted that climate would affect air and water temperature as well as rainfall, thus affecting the number, growth range, and survival rate of food- and water-borne disease pathogens in crops, livestock, and the environment. Climate change is expected to effect on the increase the frequency of extreme weather events and might also affect the incidence of food- and water-borne infectious diseases (3-7). Meanwhile, World Health Organization (WHO) reported that about 600 million people worldwide (one in ten of the global population) has contracted disease every year by intake contaminated food or drinking contaminated water, and 420,000 of them died (8).

* Corresponding Author: Szu-Chieh Chen
Address: No.110, Sec.1, Jianguo N. Rd., Taichung City, Taiwan.
Tel: +886-4-24730022 ext 12110
E-mail: scchen@csmu.edu.tw

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Several studies have suggested an association between climate change and food- and water-borne disease (9-13). In South Korea, Park et al. (11) documented that the combination of temperature, relative humidity (RH), precipitation, isolation, and cloudiness was significantly associated with *Salmonellosis* (P value < 0.01), vibriosis (P value < 0.05), and enterohemorrhagic *Escherichia coli* O157:H7 infection (P value < 0.01). In Singapore, temperature had an immediate and lagged positive effect on *Salmonella* infections (14). Aik et al. (4) also presented that RH was positively correlated with risk of diarrhea. In Canada, the prevalence of *E.* coli and *Salmonella* was correlated with both precipitation and temperature metrics, in that *Campylobacter* is the most likely food-borne bacteria studied whose occurrence in meat products affected by climatic changes in Canada (2,15). In Spain, Morral-Puigmal et al. (9) indicated that precipitation showed a protective association with gastroenteritis hospitalizations. They highlight that gastroenteritis more likely to be food-borne and associated with hot temperatures. Furthermore, in Hong Kong, higher temperature was strongly positively associated with *Salmonella* hospitalizations (10).

Taiwan is located in both subtropical and tropical regions with relatively high temperature and RH year-round (16). Most research to date has focused on extreme rainfall with several illness. For example, Chou et al. (13) documented that the maximum temperature (max. temp.) and extreme rainfall days were strongly related to diarrhea-associated morbidity (13); the max. temp. contributed 52% and 63% to morbidity, respectively, in predicting the dynamics of diarrhea disease for children (0-14 years) and older adult (40-64 years) group (13). A later report by Chen et al. (17) documented that a statistically significant association was found between different forms of extreme precipitation and diseases, including *enterovirus* infection, Japan encephalitis, scrub typhus, dengue fever, and *leptospirosis*. Recently, Huang et al. (18) conclude that more diseases of eyes, skin and gastrointestinal (GI) tract could be diagnosed after the flood with the incidence rate ratios (IRR) of diseases within 10 days after floods were 1.15 (95% CI = 1.10-1.20) for eyes, 1.08 (95% CI = 1.05-1.10) for skin, and 1.11 (95% CI = 1.08-1.14) for GI tract. However, a growing body of database evaluated the predominant food- and water-borne diseases such as Amoebic dysentery, Acute hepatitis A and Bacillary dysentery (19). Hence, the aim of the present study was to examine the combined effects of climate factors and the incidence of 7 food- and water-borne diseases in Taiwan during 2009-2019.

2. Materials and methods

2.1. Disease selection

Data of food- and water-borne disease cases from 2009 to 2019 were obtained from Taiwan Centers for Disease Control (19). Figure 1 shows the ranking by cumulative cases of all food- and water-borne notifiable infectious diseases in Taiwan. The order was Amoebic dysentery (3,244 cases, 34%), Acute hepatitis A (2,660 cases, 27%), Bacillary dysentery (1,783 cases, 18%), Acute flaccid paralysis (491 cases, 5%), Severe complicated *enterovirus* infection (434 cases, 4%), Typhoid fever (329 cases, 3%) and *Listeria* (326 cases, 3%). The above diseases, accounted for 94% of all food- and water-borne diseases. Thus, in this study, we excluded the lower cases of diseases. Therefore, the weekly data of cases of food- and water-related diseases (including Amoebic dysentery, Acute hepatitis A, Bacillary dysentery, Acute flaccid paralysis, severe complicated *enterovirus* infection, Typhoid fever, and *Listeria*), between 2009–2019, were obtained from the Taiwan Centers for Disease Control (19).

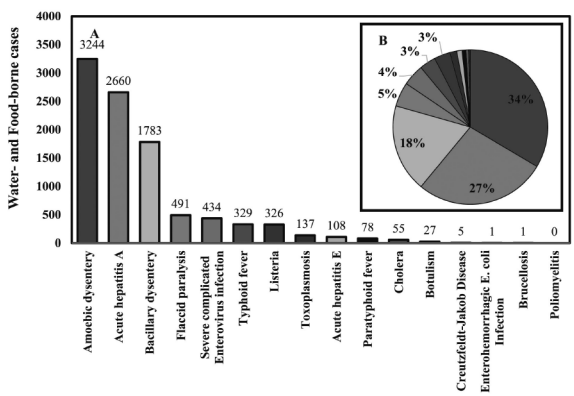


Figure 1. (A) The cumulative number of food- and water-borne notifiable cases in Taiwan from 2009 to 2019; (B) The contribution percentage (%) of the specific infection for total cases of food- and water-borne notifiable infectious diseases.

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2.2. Study area

Taiwan is located in both subtropical and tropical regions with relatively high temperature and RH year-round, with a land area 36,193 km2 and population of 23.5 million (20). The study area was chosen based on the incidence (per 100,000 person-years) and number of cases of the food- and water-borne diseases for the period 2009–2019. Hence, Taipei City had the highest incidence rate with 4.98 (per 100,000 person-years) and 1,464 confirmation cases, while New Taipei City had the highest number of confirmed cases with 1,968 cases and 4.51 (per 100,000 person-years) (details in Appendix Table 1).

2.3. Climatic factors

Weekly temperature (mean, maximum and minimum) (°C), RH (%), and weekly accumulated rainfall (mm) in Taipei City and New Taipei City were obtained from the observations of 6 (Yangming, Shilin, Zhongshan, Wanhua, Guting, and Songshan station) and 12 monitor stations (Banqiao, Sanchong, Cailiao, Yonghe, Xinzhuang, Xindian, Tamsui, Xizhi, Tucheng, Linkou, Fuguijiao, and Wanli station) of Taiwan Environmental Protection Agency (21), respectively (Figure 2). The daily meteorological data were converted to weekly basis. The average weekly maximum temperature was calculated form the

Appendix Table 1. Annual incidence rate (per 100,000 person-years) and number of cases of food- and water-borne diseases in Taiwan's counties and cities from 2009 to 2019.

Administrative regions	Incidence rate (per 100,000 person-years)	Number of cases
Hwalien County	7.14	263
Taoyuan City	5.21	945
Taipei City	**4.98**	**1464**
New Taipei City	**4.51**	**1968**
Yilan County	4.14	228
Keelung City	3.90	161
Taichung City	3.66	1084
Hsinchu City	3.48	166
Hsinchu County	3.33	197
Tainan City	3.16	626
Chiayi County	3.05	176
Kaohsiung City	2.88	857
Taitung County	2.77	68
Miaoli County	2.67	164
Nantou County	2.28	128
Changhwa County	2.12	301
Yunlin County	1.97	152
Pingtung County	1.89	176
Chiayi City	1.51	45
Kinmen County	1.14	14
Penghu County	0.45	5

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Appendix Table 2. Contributed percentage for selected seven food- and water-borne diseases in Taiwan in spring (Mar–May), summer (Jun–Aug), fall (Sep–Nov), and winter (Dec–Feb) from 2009 to 2019.

Food- and water-borne diseases	Spring (Mar–May)	Summer (Jun–Aug)	Fall (Sep–Nov)	Winter (Dec–Feb)
Acute hepatitis A	0.26	0.27	0.24	0.23
Amoebic dysentery	0.25	0.26	0.26	0.24
Bacillary dysentery	0.25	0.23	0.27	0.25
Typhoid fever	0.28	0.23	0.24	0.24
Acute flaccid paralysis	0.27	0.25	0.22	0.26
Severe complicated *enterovirus* infection	0.26	**0.38**	0.20	0.16
Listeria	**0.34**[a]	0.29	0.18	0.19

[a] Bold indicates the percentage larger than 30%.

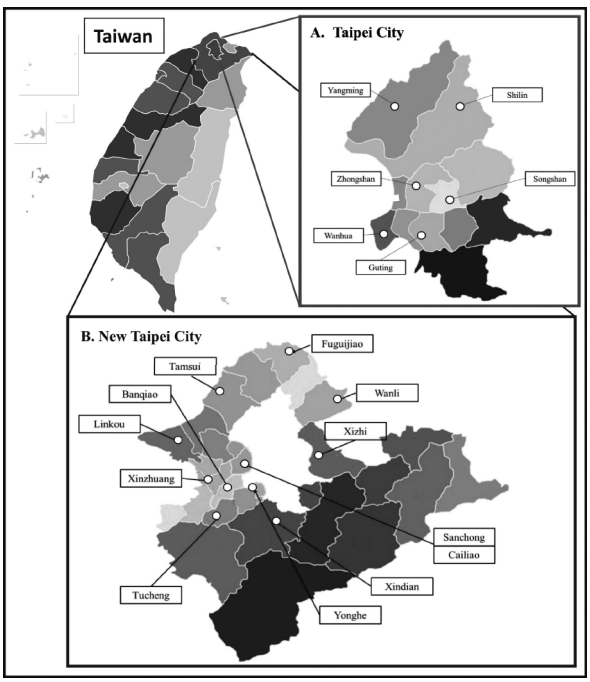


Figure 2. Locations of weather stations in (A) Taipei City and (B) New Taipei City, respectively.

daily record. The weekly accumulated rainfall was calculated the summation of daily rainfall.

2.4. Statistical analysis

A Generalized Linear Model (GLM) with a Poisson distribution was developed to quantify the relationship between climate parameters and the number of reported food- and water-borne disease cases from 2016 to 2019. The available weather data lacked rainfall data from 2009-2014 and also included some missing values for 2015. Therefore, only data from 2016 to 2019 were used to model the correlation between the climatic factors and the number of food- and water-borne cases. To build a robust model, this study estimated Candidate models were ranked by Akaike Information Criterion (AIC). AIC was used to compare model fit before and after adjustment for autocorrelation (22).

Correlations between summed incidence of all diseases and climatic factors were first modeled separately, as shown in equations (1)-(5):

$$\log(Y)= \beta_0 + \beta_1\alpha_1 \quad (1)$$
$$\log(Y)= \beta_0 + \beta_1\alpha_2 \quad (2)$$
$$\log(Y)= \beta_0 + \beta_1\alpha_3 \quad (3)$$
$$\log(Y)= \beta_0 + \beta_1\alpha_4 \quad (4)$$
$$\log(Y) = \beta_0 + \beta_1\alpha_5 \quad (5)$$

We then modeled the correlation between all climatic factors together and the number of cases, using equation (6):

$$\log(Y) = \beta_0 + \beta_1\alpha_1 + \beta_2\alpha_2 + \beta_3\alpha_3 + \beta_4\alpha_4 + \beta_5\alpha_5 \quad (6)$$

Finally, each of the climatic factors was individually removed from equation (6), yielding equations (7)-(11).

$$\log(Y) = \beta_0 + \beta_2\alpha_2 + \beta_3\alpha_3 + \beta_4\alpha_4 + \beta_5\alpha_5 \quad (7)$$
$$\log(Y) = \beta_0 + \beta_1\alpha_1 + \beta_3\alpha_3 + \beta_4\alpha_4 + \beta_5\alpha_5 \quad (8)$$
$$\log(Y) = \beta_0 + \beta_1\alpha_1 + \beta_2\alpha_2 + \beta_4\alpha_4 + \beta_5\alpha_5 \quad (9)$$
$$\log(Y) = \beta_0 + \beta_1\alpha_1 + \beta_2\alpha_2 + \beta_3\alpha_3 + \beta_5\alpha_5 \quad (10)$$
$$\log(Y) = \beta_0 + \beta_1\alpha_1 + \beta_2\alpha_2 + \beta_3\alpha_3 + \beta_4\alpha_4 \quad (11)$$

where Y denotes the number of food- and water-borne cases; α_1 is mean temperature (°C), α_2 is maximum temperature (°C), α_3 is minimum temperature (°C), α_4 is weekly accumulated rainfall (mm), and α_5 is RH (%).

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Statistical significance was evaluated at the 5% level. All analyses were performed in SAS 9.4 software.

3. Results

3.1. Characteristics of food- and water-borne disease

Total number of cases which we selected from 2009 to 2019 in New Taipei City was 1,968, consisting of Acute hepatitis A (723 cases), Amoebic dysentery (532 cases), Bacillary dysentery (526 cases), Typhoid fever (65 cases), Acute flaccid paralysis (70 cases), Severe complicated *enterovirus* infection (77 cases) and *Listeria* infection (48 cases) (Figure 3A). However, the number of food- and water-borne cases in Taipei City were consisting of Acute hepatitis A (524 cases), Amoebic dysentery (474 cases), Bacillary dysentery (312 cases), Typhoid fever (49 cases), Acute flaccid paralysis (40 cases), Severe complicated *enterovirus* infection (28 cases) and *Listeria* infection (29 cases) (Figure 3A). The cumulative trends of the order of diseases in two cities over the past ten years

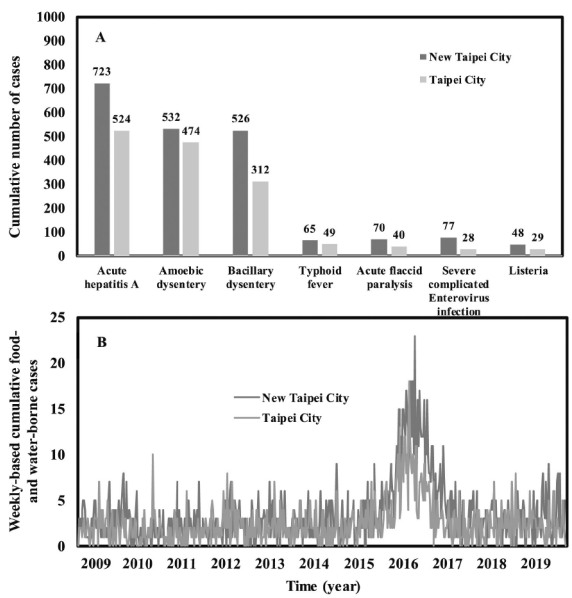


Figure 3. (A) The cumulative number of food- and water-borne notifiable cases in Taipei City and New Taipei City from 2009 to 2019; (B) The ten-year time series analysis of weekly cumulative notifiable cases which consists of Acute hepatitis A, Amoebiasis, Bacillary dysentery, Typhoid fever, Acute flaccid paralysis, Severe complicated enterovirus infection and Listeria infection

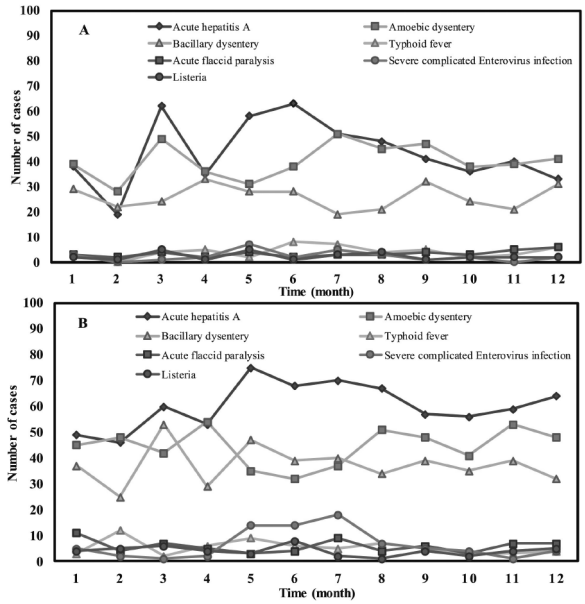


Figure 4. (A) The monthly cumulative number of seven selected food- and water-borne diseases in (A) Taipei City and (B) New Taipei City from 2009 to 2019.

was similar (Figure 3A). The ten-year time series analysis of weekly confirmed cases shown that there was a peak in 2016. Since June 2015, Taiwan has been experiencing hepatitis A epidemics. The cumulative number of cases reached a ten-year high in 2016 with the incidence rate 4.8 per 100,000 populations (23) (Figure 3B). Moreover, the analyses outputs revealed that number of cases of food- and water-borne illness in March and June have been the highest rates of diseases compared to other seasons in Taipei City and in May and July have been the highest rates of diseases in New Taipei City, respectively (Figure 4).

3.2. Characteristics of climate factors

Figure 5 and Figure 6 show the cumulative number of food- and water-borne notifiable cases and climate factors in two study areas. Results show the variation of weekly temperature in Taipei City, with mean, maximum, and minimum temperature of 23±5 (mean ± SD, °C), 25±4 and 20±6, respectively (Table 1). Mean weekly accumulated rainfall was 8 mm and 21 mm, for Taipei City and New Taipei City, respectively. Highest weekly accumulated rainfall was 43 mm and 295 mm, respectively. Meanwhile, season of autumn and winter were likely to present the higher intense rainfall. It also shows weekly RH, with a mean value of 75% and a standard deviation

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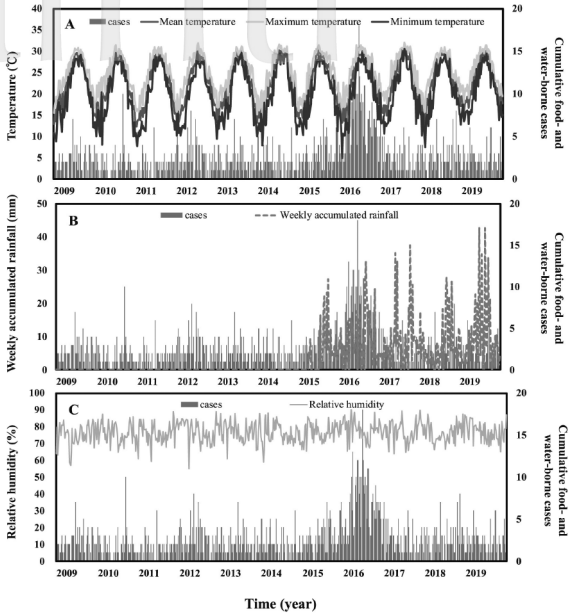


Figure 5. The cumulative number of food- and water-borne notifiable cases and (A) Weekly maximum, mean, and minimum temperatures, (B) Weekly accumulated rainfall, and (C) Relative humidity (RH) in Taipei City.

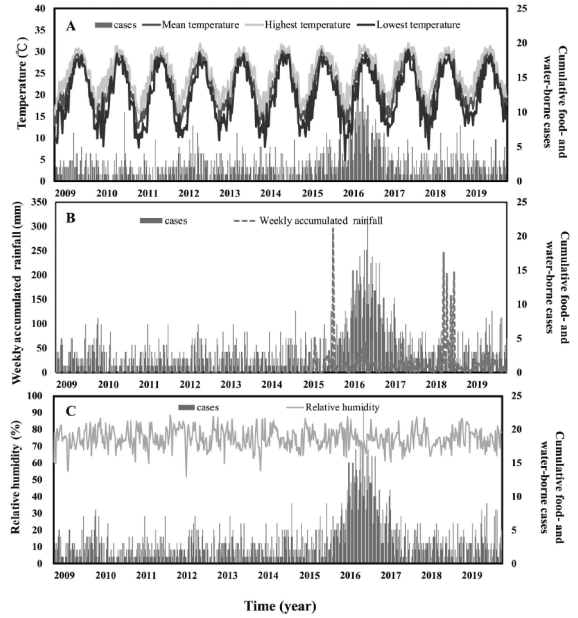


Figure 6. The cumulative number of food- and water-borne notifiable cases and (A) Weekly maximum, mean, and minimum temperatures, (B) Weekly accumulated rainfall, and (C) Relative humidity (RH) in New Taipei City.

Table 1. The mean, standard deviation (SD), maximum (max.), and minimum (min.) value of each climatic factor in Taipei City and New Taipei City.

Variables	Statistics	Taipei city	New Taipei city
Mean temperature (°C)	Mean±SD	23±5	23±5
	Min–Max	11–31	12–32
Maximum temperature (°C)	Mean±SD	25±4	26±5
	Min–Max	13–32	15–33
Minimum temperature (°C)	Mean±SD	20±6	21±6
	Min–Max	5–31	5–33
Weekly accumulated rainfall (mm)	Mean±SD	8±8	21±37
	Min–Max	0–43	0–295
Relative humidity (%)	Mean±SD	77±6	75±6
	Min–Max	64–90	61–88

of 6% (see Table 1).

3.3. Generalized linear models

The coefficients of individual climatic factors and number of cases in New Taipei City (Table 2). Results show β0, β1 and P values for each climatic factor and the number of cases in New Taipei City, from equations (1)-(5). All correlations were significant (P value <0.05) except for weekly accumulated rainfall. However, the weekly accumulated rainfall model had the lowest AIC (1391) among models. The results of equation (6) shows for correlations between

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Table 2. The coefficients of individual climatic factors and number of cases

Variables	Taipei City				New Taipei City			
	β_0	β_1	P value	AIC	β_0	β_1	P value	AIC
Mean temperature	0.7252	0.0215	**0.0047****	0.7252	1.2803	0.0158	**0.0092****	1395
Maximum temperature	0.5611	0.0260	**0.0036****	0.5611	1.0893	0.0217	**0.0017****	1392
Minimum temperature	0.9091	0.0153	**0.0196***	0.9091	1.3774	0.0130	**0.0131***	1396
Weekly accumulated rainfall	1.2533	-0.0031	0.5007	1.2533	1.6807	-0.0012	0.2478	1391
Relative humidity	1.7403	-0.0067	0.3022	1.7403	2.4710	-0.0109	0.0376*	1398

* P value < 0.05 ; ** P value < 0.01

Table 3. β_1 and P values of the equations for all climatic factors and the number of cases in Taipei City and New Taipei City.

Variables	Taipei City		New Taipei City	
	β_1	P value	β_1	P value
β_0	-0.1182	0.8793	1.1090	**0.0468***
Mean temperature	0.0763	0.1823	-0.1759	**0.0104***
Maximum temperature	0.0118	0.7785	0.1533	**0.0004****
Minimum temperature	-0.0530	0.0826	0.0550	0.1114
Weekly accumulated rainfall	-0.0077	0.4879	-0.0020	0.3658
Relative humidity	0.0055	0.1524	-0.0053	0.0790
AIC	1061		1375	

* P value < 0.05 ; ** P value < 0.01

Table 4. β_1 and P-values of the equations with one deleted climatic factor in New Taipei City.

	Model (7)		Model (8)		Model (9)		Model (10)		Model (11)	
	β	P value	β	P value	β	P value	β	P value	β	P value
β_0	1.0551	0.0601	1.4714	**0.0075****	0.9810	0.0764	1.4066	**0.0083****	0.6595	**0.0099****
Mean temperature	-	-	0.0364	0.2497	-0.0773	**0.0110***	-0.1871	**0.0061****	-0.1693	**0.0131***
Maximum temperature	0.0541	**0.0078****	-	-	0.1116	**0.0013****	0.1529	**0.0004****	0.1510	**0.0005****
Minimum temperature	-0.0230	0.1300	-0.0158	0.5578	-	-	0.0606	0.0796	0.0531	0.1236
Weekly accumulated rainfall	-0.0021	0.0531	-0.0020	0.0735	-0.0021	0.0638	-	-	-0.0022	**0.0489***
Relative humidity	-0.0037	0.5259	-0.0041	0.4825	-0.0047	0.4204	-0.0077	0.1723	-	-
AIC	1380		1386		1376		1387		1374	

* P value < 0.05 ; ** P value < 0.01

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all climatic factors and number of cases. Here only mean, maximum, and minimum temperature showed significant correlations (0.0468, 0.0104, and 0.0004, respectively) (Table 3).

Table 4 shows the results of equations (7)-(11) with one deleted climatic factor each. Significant correlations were found for maximum temperature in equation (7) P value <0.05 (0.0078); mean and maximum temperature in equation (9) P value <0.05 (0.0110 and 0.0013, respectively); mean and maximum temperature in equation (10) P value <0.05 (0.0061 and 0.0004, respectively); and mean and maximum temperature and weekly accumulated rainfall in equation (11) P value <0.05 (0.0131, 0.0005, and 0.0489, respectively). There was little difference in AIC between models. The AIC (1374) of equation (11) was smaller than the AIC (1375) of Table 3. Across equations (7)-(11), mean and maximum temperature generally showed significant correlations to climate variables (P<0.05).

4. Discussion

In the present study, disease morbidity was strongly associated with meteorological conditions. Temperatures play a particularly important role (10,11,13,14). For instance, Park et al. (11) found EHEC O157:H7 infection significantly correlated with minimum temperature. Another study found hot temperatures increased the risk of hospitalizations due to gastroenteritis (relative risk (RR) = 1.21, 95% confidence interval (CI): 1.09, 1.34) (9). In our study, that the individual factors of mean, maximum, and minimum temperature were significantly correlated with total number of cases of Food- and Water-borne infectious diseases in New Taipei City in the univariate models. Mean and maximum temperature generally also showed significant correlations in the multivariate models using all but one climatic factor. Mean temperature and maximum temperature associated with disease in equations (1)-(2) (Table 3).

For precipitation, most of previous research have found opposite result and a lot of evidences have support the role of extreme rainfall in the dynamics diarrhea (10,13). Extreme rainfall was defined as daily accumulative rainfall exceeding 40 mm. The morbidity of diarrhea-associated was strongly correlated with extreme rainfall days at lag one (r2 = 0.28) and two months (r2 = 0.35) (13). More hospitalizations were observed for small amounts of rainfall relative to none, with 0.02 mm and 0.14 mm associated with 1.30 (95% CI 1.01–1.67) and 1.34 (95% CI 0.98–1.84) times the risk of hospitalizations, respectively (10). However, we used weekly

Table 5. β_1 and P value of the equations with one deleted climatic factor in Taipei City.

	Model (7)		Model (8)		Model (9)		Model (10)		Model (11)	
	β	P value	β	P value	β	P value	β	P value	β	P value
β_0	-0.1339	0.8629	-0.0531	0.9431	0.0356	0.9633	0.3912	0.5697	0.3730	0.2434
Mean temperature	-	-	0.0891	**0.0087****	-0.0052	0.8789	0.0787	0.1653	0.0739	0.1937
Maximum temperature	0.0570	**0.0214***	-	-	0.0376	0.3527	0.0036	0.9301	0.0105	0.8013
Minimum temperature	-0.0201	0.2579	-0.0559	0.0515	-	-	-0.0532	0.0807	-0.0525	0.0839
Weekly accumulated rainfall	0.0053	0.1397	-0.0075	**0.4951***	-0.0077	0.1490	-	-	-0.0059	0.2080
Relative humidity	0.0050	0.5299	0.0054	0.1597	0.0054	0.4992	0.0001	0.9863	-	-
AIC	1061		1059		1062		1061		1060	

* P value < 0.05 ; ** P value < 0.01

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accumulated rainfall as the weather factors for the study. We found that the individual factors of weekly accumulated rainfall were not significantly correlated with total number of cases of Food- and Water-borne infectious diseases. While in equations (8) (Table 5) could found the association between weekly accumulated rainfall and total number of cases of Food- and Water-borne illness.

Several studies have demonstrated that Food- and Water-borne diseases were influenced by RH [4,10,13,24]. RH was positively associated with the risk of diarrheal disease with a 1-week delay (4). Moreover, RH (45%) had higher proportional contribution to the diarrhea-associated morbidity (13). High RH (99th percentile, 96%) are positively associated with Salmonella hospitalizations. Conversely, in our research statistical analysis showed RH were not significantly associated with total number of cases of Food- and Water-borne infectious diseases.

Our study had several limitations. First, previous studies found time lag effect in the model climatic factors. Time-series analysis, adjusting for time-vary potential confounders in a negative binomial regression model (4,14). Moreover, Wang et al. (10) used time-series regression model adjusting for season and time trend were constructed employing distributed lag non-linear models and generalized additive models. Regarding rainfall was positively associated Salmonella infection for the first 6 days (day 0–5) but negatively associated this disease for day 6–30. While, this association was only statistically significant during the 15th-22nd lagged day (10). Second, we did not consider gender or age in our analysis. For example, the impact of maximum temperature on diarrhea-associated morbidity appeared primarily among children (0-14 years) and older adults (40–64 years), and had less of an effect on adults (15–39 years) (13). The incidence of Food- and Water-borne disease infections was highest among patients with the age group of ≤5 years and peaked in summer (24).

Third, our study variable weather data lacked rainfall data from 2009-2014 and also included some missing values for 2015. In the future, sourcing of climatic data could be based on additional institutions (such as the Central Weather Bureau) to make them more complete. The effect of climatic factors on individual diseases should be the focus of further studies. Fourth, the mechanisms underlying the relationship between Food- and Water-borne disease incidence and climate change are not fully understood. Furthermore, there are complex interplay of different factors, including human behavior and pathogen prevalence in animal reservoirs, and pathogen survival patterns in the environment (11). Thus, we suggest study in the future could consider more comprehensive.

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