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RESEARCH ARTICLE

The effect of meteorological variables on salmonellosis incidence in Kermanshah, West of Iran: a generalized linear model with negative binomial approach

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Abstract

Purpose Salmonella is one of the main causes of gastroenteritis, and its incidence may be affected by meteorological variables. This is the first study about the effect of climatic factors on salmonella incidence in Kermanshah, Iran.

Methods Data about salmonellosis cases in Kermanshah were inquired from Center for Communicable Disease Control, at the Ministry of Health and Medical Education of Iran, for the 2008 to 2018 time-frame. Meteorological variables including maximum, minimum and mean of temperature and humidity, sunshine hours and rainfall were inquired for the same time frame. Negative binomial generalized linear models (GLM) were used to assess the effect of meteorological variables on the weekly incidence of salmonellosis.

Results During the years under study, 569 confirmed cases were registered in Kermanshah province. Study results showed a 3 % increase in salmonellosis incidence, after 1 % increase in minimum humidity in the week before (incidence rate ratio (IRR): 1.03; 95 % confidence interval (CI):1.02–1.05) and also a 4 % increase in incidence for 1 °C increase in mean temperature in the same week (IRR: 1.04; 95 % CI:1.02–1.06).

Conclusions Increase in minimum humidity and mean temperature may have a role in increasing the incidence of salmonellosis in Iran.

Keywords Forecasting · Generalized linear model · Negative binomial regression · Salmonellosis · Environment · Iran · Kermanshah

Introduction

Salmonella bacteria are one of the leading causes of diarrheal disease in the world [1]. The natural bacterial reservoirs of salmonella are animals and the environment [2]; and food is the main source for human infection [3]. A meta-analysis about the incubation period of this disease showed that the average incubation period is from 7 to 21 days. The minimum reported incubation period was 2 and the maximum was 41 days [4]. A study done in Iran, showed the most prevalent serotypes of *Salmonella spp.* isolated were *Enteritidis* (37 %), *Typhimurium* (35.3 %), and *Infantis* (21.1 %); and chicken and cattle were identified as the most likely sources of transmitting the infection to humans [5]. Around the world, about 11–20 million people get typhoid every year, and about 128,000 to 161,000 people die from the disease. Poor and unsanitary communities are more likely to acquire the disease [6].

Numerous studies have shown an association between climate and food born disease such as salmonellosis [7–11].

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Previous studies have shown associations between high temperatures [11–14], rainfall and humidity [8, 14–16] with the incidence of Salmonellosis, but with different magnitudes and lag lengths. A study conducted in Yazd, Iran reported a IRR of 1.14 (95 % CI:1.10–1.19) for the monthly incidence of foodborne illnesses, per each percent increase in relative humidity and 1.05 (95 % CI:1.02–1.08), per each millimeter increase in rainfall in the same month [17].

Due to the complex and multi-factorial nature of salmonella infections, which might also be related to human behavior and environmental factors, the impact of meteorological factors on disease progress is relatively difficult to predict [18]. In recent years, several studies have used statistical models to evaluate the effect of environmental factors on salmonellosis [10, 11, 14, 19–22].

Figure 1 illustrates the incidence of salmonellosis in different provinces of Iran during 2008–2018. Two provinces which were Lorestan and Kermanshah had the highest incidence; however, the number of registered cases was more in Kermanshah province, and therefore, in this study the data of Kermanshah was inquired.

The climate of Kermanshah is moderate and mountainous. It rains mainly in winter and is moderately warm in summer [23]. It is one of the relatively wet parts of Iran. According to the De Martonne climate index, this region has a Mediterranean climate [24]. Understanding the quantitative impact of meteorological variables on disease incidence can help policy makers predict disease outbreaks and allocate medical facilities and financial resources more appropriately.

Materials and methods

Study design

This ecological study was performed on salmonella surveillance data from Kermanshah Province, Iran.

Study setting

The population of Kermanshah province was 1,952,435 according to the 2016 national census, and about 2.5 % of Iran's population lives in this province. The area of this province was 24,998 km^2 (or 9652 square miles). Kermanshah is one of the 31 Iranian provinces and is located in the west of Iran. The geographical coordinates of Kermanshah province are from 45º20′39″ E to 48º1′58″ E and from 33º37′8″ N to 35º17′8″N.

Meteorological data

The meteorological data used in this study were inquired from the Kermanshah city synoptic meteorological station.

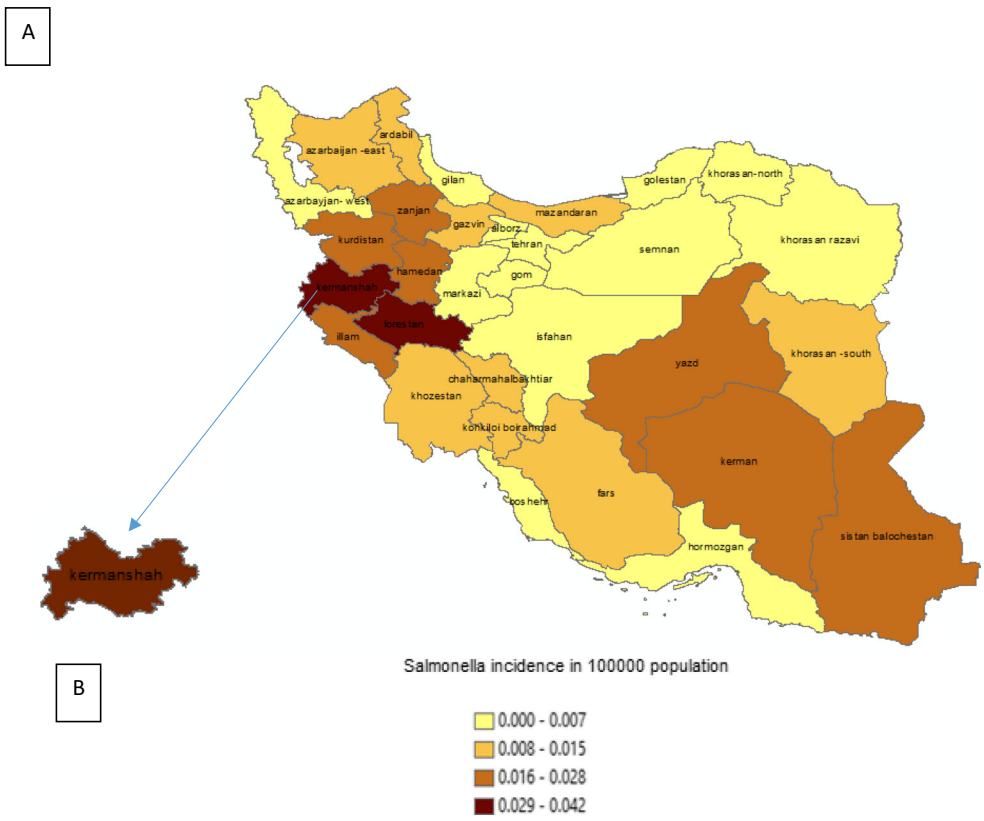

Fig. 1 The incidence of salmonella cases in different provinces of Iran during 2008–2018 (A), Kermanshah province (B)

These variables included mean, maximum and minimum of daily ambient air temperature, daily rainfall, daily sunshine, daily mean, daily minimum and maximum relative humidity, from 2008 to 2018. Meteorological data were all inquired on a daily basis, and weekly data were calculated. The maximum and minimum humidity recorded in the week, and the maximum and minimum temperature recorded in the week, were used. Rainfall and sunshine hours were the sum of daily values.

Outcome measure

Salmonellosis incidence data for the 2008 to 2018 period were inquired from the Center for Communicable Disease Control, at the Ministry of Health and Medical Education of Iran. Salmonellosis incidence data is recorded as suspicious, probable and definite cases in this database.

Suspected cases are patients which have symptoms including fever for more than a week, headache, nausea and vomiting, abdominal pain, weakness, dizziness, rose spots on the trunk, constipation, diarrhea, and enlarged liver or spleen.

Probable cases are suspected cases that in addition to the symptoms mentioned above, have one or two of the following signs as well. (1) A Widal test showing 4 times increase in the somatic O antigen titer within 2 weeks. (2) Existence of cases of disease among the people surrounding the patient or in the area.

Confirmed cases are probable cases with one or both of the following signs. (1) A positive salmonella culture in samples taken from blood, bone marrow, urine, feces, Rose spots, or duodenal secretions. (2) Finding the specific antigen in urine or serum[25].

The time of disease onset used in this study, was the time that the first symptoms appeared, not the time the diagnosis was made. The total number of cases (which means the sum of suspicious, probable and definite cases) in the province was used as the outcome variable.

Statistical analysis

Spearman's rank correlation coefficient was calculated to determine the correlation between salmonellosis case counts and each meteorological variable. Collinearity was checked by calculating the variance inflation factor (VIF) for each predictor variable in the regression models. VIF is an index that shows how much the variance (the square of the estimated standard deviation) of an estimated regression coefficient increases because of collinearity [26]. Meteorological variables and the number of cases on consequent days, may be well related to each other. Therefore, Generalized Linear Models that take into account the correlation between observations was used. A negative binomial approach was chosen, because the count of salmonella cases was over-dispersed, and the variance was greater than the mean [27]. The Vuong test was employed to determine whether the negative binomial (NB) regression model fits the data better than the zero inflated negative binomial (ZINB) regression model or not [28]. This test did not suggest that the ZINB model was a better fit (p-value = 0.41). Therefore, NB generalized linear models with lags were used. In the negative binomial regression, that belongs to the GLM family, the mean (μ) of the response variable Y is defined as an exponential of the independent variables called X, and $\mu = e^{x\beta}$. In this equation, β is the regression coefficient. When there are several independent variables, such as x_1, x_2…., x_n the regression equation is written as follows:

$$\ln(yi) = \alpha + \sum_{j=1}^{r} x_{ij}\beta_{ij} + \epsilon i$$

In this equation, α is the intercept, ϵ is the error, which is independent of all random variables and has a distribution of (1, 1/φ). It is assumed that the predictors only affect the response variable. Because of the overdispersion, the NB uses a parameter called φ, which makes the variance of the dependent variable Y equal to $\mu + \mu\ \varphi^2$. The best fit model is determined by selecting the predictors that are significantly correlated with the response variable, i.e., have significant coefficients with a P value less than the significance level, [29], which in this study was 5 %.

The model used in this study, included meteorological variables and their first k lagged values, as the predictor variables. As the incubation period of salmonella is 2–41 days [4]; therefore, k was assumed to be 1 to 6 weeks.

The best model was determined based on the lowest Akaike information criteria (AIC). All statistical analysis was performed using the STATA statistical software version 16.

Results

A total of 4957 cases of salmonellosis had been registered during 2008–2018, in the whole country (Iran) and the incidence rate in the country was 6.8 in 100,000 population. During this time 569 cases (11.5 % of total country cases) had been recorded in Kermanshah province.

The mean age of the cases was 27.49 ($\pm$ 17.53) and the median of age was 25 years. 58 % of the cases were female and 57 % were from rural areas. Table 1 illustrates the demographic characteristic of salmonellosis cases in Kermanshah province.

The annual incidence rate of salmonellosis for Kermanshah province ranged from 14.04 to 100,000 population in 2010 to 0.5 per 100,000 population in 2016 (Fig. 2). The monthly number of salmonellosis cases are presented in Fig. 3.

Table 1 Demographic characteristics of salmonella cases in Kermanshah province from 2008 to 2018

Variables		No. of cases (%)
Gender	Male	236 (41)
	Female	333 (59)
Age	Under one years old	8 (1.4)
	1–5	70 (12.3)
	6–20	122 (21.5)
	21–60	345 (60.6)
	>60	24 (4.2)
Residence	Urban	244 (43)
	Rural	325 (57)
Toilet situation	Sanitary toilets	501 (88)
	Non- Sanitary toilet	68 (12)
Water situation	Sanitary water	523 (92)
	Non- Sanitary water	46 (8)

Table 2 shows the descriptive statistics of meteorological variables of Kermanshah.

Significant correlations were detected between the weekly count of salmonella cases and weekly mean temperature ($r = 0.12$, P-value < 0.01) and minimum humidity ($r = 0.1$, P-value < 0.01). Therefore, the GLM was fitted using these two independent variables. VIF was checked and there was no significant collinearity between these two variables. According to the calculated cross-correlation functions, minimum humidity with 1-week lag and mean temperature without lag had a significant relation with salmonellosis incidences and were added to the GLM. We observed a 3 % increase in the incidence of salmonellosis associated with 1 % increase in minimum weekly humidity (incidence rate ratio (IRR):1.03; 95 % confidence interval (CI):1.02–1.05), in the week before; and also a 4 % increase in the incidence associated with 1 °C increase in mean weekly temperature (IRR:1.04;95 %CI:1.02–1.06) in the same week. Table 3 shows the estimates of GLM for weekly salmonellosis incidence in Kermanshah Province.

Discussion

In this study, negative binomial generalized linear models were performed to quantify the relation between meteorological variables and salmonellosis cases in Kermanshah province. The present study showed that salmonellosis incidence was related to the mean temperature of the same week. Similarly, in Maryland, by using negative binomial generalized estimating equations (GEE), the risk of salmonellosis increased 4.1 % per each unit increase in extreme temperature events [20]. The rate of hospitalization due to salmonellosis in Hong Kong was also shown to be directly correlated with increase in daily temperature, and the relative risk of hospitalization comparing 30.5 to 13 °C was 6.13 (CI 95 %: 3.53–10.67) [13]. Another study from Bangladesh examined the relation between the weekly number of typhoid cases and meteorological variables by generalized linear Poisson regression models allowing for overdispersion, and showed that for every 1 °C increase in temperature, the incidence of typhoid cases increased 14.2 % [30]. A study from Singapore using negative binomial time series regression models on a weekly scale, showed a 4.3 and 6.3 % increase in reported salmonellosis cases in the same week, and 3 weeks later respectively, per 1° C increase in mean ambient air temperature [11]. A study from Australia which was also done on a weekly basis, used four regression methods and found an association between the incidence of salmonellosis and 2-week lagged maximum temperature in the standard Poisson regression model (ß=0.015, CI: 0.003,0.027), in multiple linear regression (ß=0.02, CI: 0.01,0.03), in seasonal autoregressive integrated moving average and (ß=0.025, P < 0.0001) in autoregressive adjusted Poisson regression (ß=0.017, CI: 0.011,0.024) [8]. In

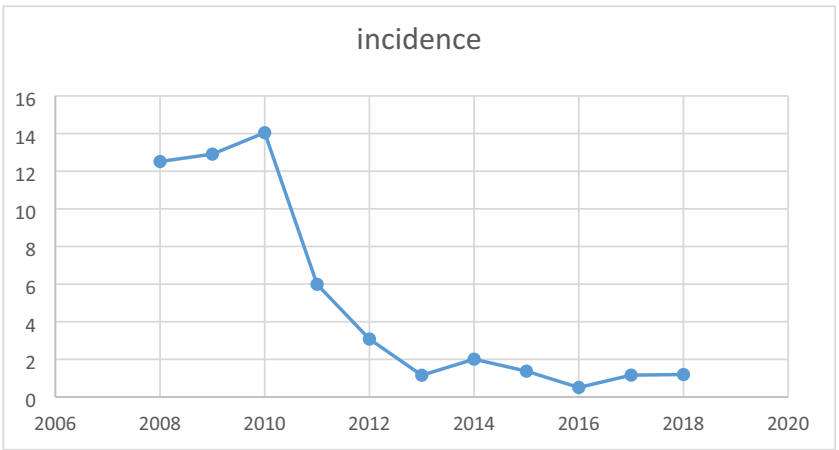

Fig. 2 Annual incidence of salmonellosis in Kermanshah province during 2008–2018

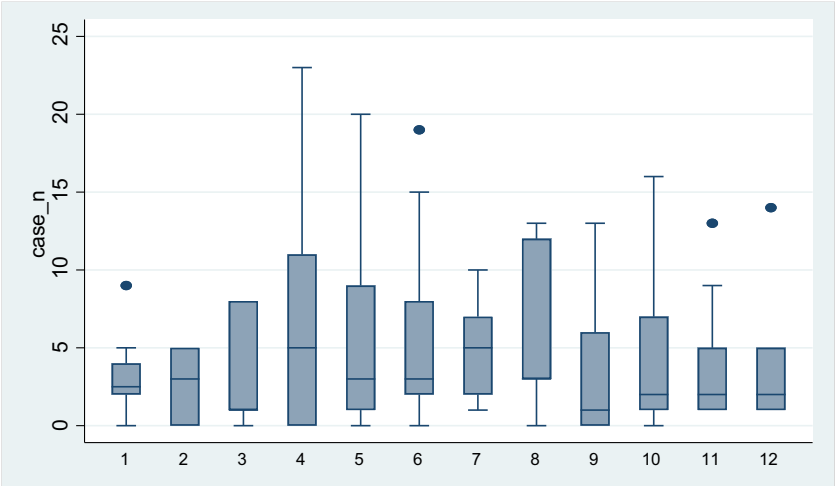

Fig. 3 Box plot of monthly salmonellosis incidence in Kermanshah province,2008–2018

a study conducted in Kazakhstan, by using time series analysis, for every 1 °C increase in temperature, the incidence of Salmonellosis increased 5.3 % (2.1–8.6 %) in the same month [10].

There are numerous studies that have shown an increase in Salmonellosis incidence due to increased temperature [20, 31, 32]. Bacterial proliferation and survival on foods such as poultry, eggs, vegetables and fruits in warm weather can partly explain the relation between increased ambient temperature and salmonellosis [33, 34]. Temperature has a profound effect on the growth of *Salmonella spp*., and in vitro the growth of this bacterium is observed at temperatures between 7.5 and 48 °C, and the highest growth rate is observed at 37 °C [35]. In the absence of appropriate interventions, ambient temperature rises, can increase bacteria reproduction in various edible products [22, 36]. Increase in ambient air temperature may also affect people's behavior, and for example increase their tendency to eat raw food such as fruits or vegetables, which may contain bacteria [37]. Storage and preparation of food may take several weeks and during this time, bacterial contamination may occur unintentionally because of temperature increase [11].

The results of this study showed that the minimum humidity in the week before, was positively associated with the number of cases of salmonellosis. A study in Singapore showed, 1.3 % decrease in salmonellosis cases with 1 % increase in mean relative humidity, after 6 weeks (IRR: 0.987, 95 % CI: 0.981, 0.994) [11]. In Yazd, Iran the IRR of foodborne illness was 1.14 per each percent increase in relative humidity [17]. In Hong Kong, higher hospitalization rates of salmonella were associated with elevated relative humidity above 60 %, for a period of 17 days [38]. Other laboratory studies have reported that Salmonella bacteria proliferation on food, increases at high relative humidity (96 %) at 10 °C [39], and up to 10 days at 22 °C and 97 % relative humidity [40]. However, relative humidity was not significantly associated with Salmonella cases in some other studies [8, 16, 41]. Increase in relative humidity may increase the pathogen load and survivability of pathogens on surfaces and foods, and increase the risk of salmonellosis.

It seems like, the impact of rainfall on the incidence of salmonellosis varies depending on the region, since the results of studies in different tropical, subtropical and Mediterranean regions have shown contradictory results [8, 14, 15].

Table 2 Descriptive statistics of meteorological variables on a weekly basis in Kermanshah province from 2008 through 2018

	Mean (SD)	Min	P(1st)	P(25th)	Median	P(75th)	P(99th)	Max
Mean temperature	16.7 (10)	-15.6	-0.8	8.2	15.8	25.6	34.4	67
Minimum temperature	7.7 (7.3)	-8.2	-6.2	1.7	8.3	14	20	22.4
Maximum temperature	24.4 (10.6)	2.5	5.1	14.8	23.4	34.7	41.1	42
Mean humidity	40.6 (21.6)	9	9.7	19	40	59.3	81	91
Minimum humidity	12.6 (10.5)	0	1	4	9	19	43	62
Maximum humidity	71.7 (26.3)	21	23	46	86	96	100	100
Rainfall	6.7 (14.1)	0	0	0	0.1	7.1	75	109
Sunshine	54.6 (19.3)	5.8	13	40	53.6	71.6	87.6	134

Table 3 The point estimates and standard errors of regression coefficients of salmonellosis incidence from negative binomial generalized linear models

Variables	IRR	Std.Err	z	P >| z|	[95% CI]
Minimum humidity lagged 1 week	1.03	0.008	4.63	< 0.001	1.02–1.05
Mean temperature	1.04	0.008	5.00	< 0.001	1.02–1.06
Intercept	0.31	0.07	-5.06	< 0.001	0.19–0.48
Number of obs	569				
Deviance	522.15				
Pearson	504.4				
family	Neg. binomial				
AIC	2.75				
Link function	Log				

However, in the present study, the incidence of cases did not show any association with rainfall.

The incidence of salmonella is affected by several factors, including socio-economic factors, urbanization, food hygiene and safe water, and climate factors. The annual incidence of salmonellosis in Kermanshah province has declined over the 11 years under study. This may be due to increase in safe water and sanitary toilets, and human interventions. Rural improvement programs can play an important role in preventing gastrointestinal infections, including salmonellosis [42].

One of the limitations of the present study is that only climatic factors were assessed, and other factors that might have been related were not investigated. Also, there might have been under-reporting of the disease, from public centers and private offices.

Although in this study humidity and temperature had an effect on the incidence of salmonellosis, but because this disease is multifactorial and several factors such as water and wastewater status and general hygiene affect its incidence, therefore, the results of this study have limited generalizability.

Conclusions

Increase in mean ambient temperature and minimum humidity may be directly related to the incidence of salmonellosis in Kermanshah, Iran. This information can help predict the outbreaks of this disease in the future, and help allocate resources efficiently.

Authors contribution NK suggested the topic, was the main supervisor, and helped in writing and editing the final manuscript. SN acquired the data, cleaned the data, analyzed the data and prepared the initial draft. BB provided scientific advice and edited the final article. YJ supervised data analysis, provided statistical consultation and edited the final manuscript. HD helped in inquiring meteorological data, cleaning the data, and writing the manuscript.

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Code availability STATA software version 16.

Declarations

Conflict of interest The authors declare that they have no competing interests.

Ethics approval The study proposal was approved by the Ethics Committee of Kerman University of Medical Science. Ethics Code: IR.KMU.REC.1397.231.

Consent to participate Not applicable.

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