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Climate variations and salmonellosis in northwest Russia: a time-series analysis

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SUMMARY

Associations between monthly counts of all laboratory-confirmed cases of salmonellosis in Arkhangelsk, northern Russia, from 1992 to 2008 and climatic variables with lags 0–2 were studied by three different models. We observed a linear association between the number of cases of salmonellosis and mean monthly temperature with a lag of 1 month across the whole range of temperatures. An increase of 1 °C was associated with a 2·04% [95% confidence interval (CI) 0·25–3·84], 1·84% (95% CI 0·06–3·63) and 2·32% (95% CI 0·38–4·27) increase in different models. Only one of the three models suggested an increase in the number of cases, by 0·24% (95% CI 0·02–0·46) with an increase in precipitation by 1 mm in the same month. Higher temperatures were associated with higher monthly counts of salmonellosis while the association with precipitation was less certain. The results may have implications for the future patterns of enteric infections in northern areas related to climate change.

Key words: Climate – impact of, salmonellosis.

INTRODUCTION

Salmonellosis is a bacterial disease commonly manifested by an acute enterocolitis with sudden onset of headache, fever, abdominal cramps, diarrhoea, nausea and vomiting caused by *Salmonella* bacteria. The first symptoms usually occur 12–72 h after infection. While most individuals recover without treatment, morbidity and associated costs of salmonellosis are high [1]. Although deaths from foodborne infections are uncommon, *Salmonella* infection causes more deaths than any other foodborne pathogen in England and Wales [2]. According to estimates, more than 5 million cases occur every year in the USA alone, although less than 1% of cases are usually reported even in industrialized countries [1]. In Russia, there were more than 118 000 registered cases of salmonellosis in 1992, but since then the overall incidence has decreased from 79·9/100 000 in 1992 to 36·2/100 000 in 2008 [3].

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Several studies have reported associations between climatic variables and the number of cases of salmonellosis [4–9] or food poisoning [10, 11]. Most of the studies assessed the effects of temperature alone [4, 7–9] while a few also included data on precipitation in the models [4, 5]. D'Souza *et al.* observed that a 1 °C increase in temperature in the previous month was associated with an increase in the number of cases of salmonellosis ranging between 4·1 % in Perth and 11·0 % in Brisbane [4]. Similar associations, but with a lag of 2 weeks have been reported by Zhang *et al.* [5]. The effect of temperature varied between the settings in Australia: while in subtropical Brisbane the temperature lag was 2 weeks, in tropical Townsville the association with temperature was observed in the same month [6]. In European countries, however, no obvious pattern related to either geography or mean summer temperatures was found [7]. Moreover, while in Australia, no threshold was apparent and the relationship was approximately linear across the whole temperature range [4–6], in a few European countries, certain thresholds below which there was no effect of temperature were detected [7]. In Canada, the results varied between the provinces – while positive, although less pronounced than in Australia, an association was observed between temperature with lags 0–6 weeks and weekly salmonellosis counts in Alberta, while no association was found in Newfoundland-Labrador [8]. The threshold value of temperature in Alberta was −10 °C while in European countries it varied between −2 °C in the Czech Republic and 13 °C in Estonia [7, 8]. The above-mentioned studies raised concern that climate change in general and rising average temperatures in particular may increase the risk of foodborne infections in the future. This concern was addressed in the study by Lake *et al.*, who observed that in England and Wales the effect of temperature had decreased over time suggesting that adaptation strategies aimed at reducing pathogen concentration in food and improvement of food hygiene could counterbalance the effects of global warming [9].

Although most studies have reported associations between temperature and salmonellosis, the existing differences in data aggregation, modelling approaches, treatment of outbreaks and imported cases as well as the fact that almost all the studies have been performed in Australia, North America or EU countries warrants replication of the results in other settings.

This study aimed to investigate associations between the number of reported cases of salmonellosis and ambient air temperature and precipitation in one of the northernmost Russian cities.

METHODS

Arkhangelsk is a regional capital city in northwest Russia (64° 32′ N, 40° 32′ E) with a population of ~348 000 in 2010 (Fig. 1). It lies on both banks of the northern Dvina River near to its exit into the White Sea and according to a Köppen–Geiger classification has a sub-arctic climate characterized by long, usually cold winters, and short, cool to mild summers [12].

Monthly counts of all laboratory-confirmed cases of *Salmonella* infection in the city for 1992–2008 were obtained from the Regional Infectious Diseases Surveillance Centre (Rospotrebnadzor). Data on a weekly or daily basis were not collected for the whole study period and therefore were not used in the study. Cases linked to outbreaks were identified in the records and excluded from the analyses since the effects of climatic factors on outbreaks may differ from their effects on sporadic cases [4–5, 7]. The population of the city for each year was obtained from the regional Medical Information Analytical Centre (MIAC). Data on mean monthly ambient air temperature and monthly precipitation were retrieved from the regional branch of the Russian Hydrometeorological Service (Roshydromet).

Associations between mean monthly temperature, precipitation and salmonellosis notifications were studied by negative binomial regression to allow for overdispersion in the data [13]. Monthly counts of laboratory-confirmed cases were used as a dependent variable. A logarithm of the population size was included in the model as an offset. Given that the effects of high temperature on case counts may be delayed up to 9 weeks [7], we used mean monthly temperature with lags of 0–2 months. Similarly, the monthly amount of precipitation was included with lags of 0–2 months. Year-to-year variations during the study period were modelled by fitting a polynomial of time. A cubic polynomial was sufficient to model a long-term trend and higher-order polynomials did not further improve the model fit. Seasonal variations were modelled using sine and cosine functions for a period of 12 months. Robust standard errors were calculated for all estimates to adjust for heterogeneity in the model. To control for autocorrelation in the outcome variable, first- and second-order autoregressive terms were included in the model (model 1). The analyses were repeated using indicator dummy

Fig. 1. Map of the Arctic region. Arkhangelsk is indicated by an arrow.

variables for each month and year (model 2) as an alternative method to control for long-term and seasonal effects as in other studies [7].

In addition, as in previous studies [5, 7] a 'hockey-stick' model was fitted to the data. This model assumes no effect of temperature on salmonellosis counts below the threshold and a linear relationship above the threshold. We used the 'nl' program in Stata to estimate a threshold temperature [14]. Moreover, a curvilinear relationship between temperature, precipitation and number of notified cases of salmonellosis was modelled by fitting cubic splines with three knots placed at quartiles of the distribution of each continuous variable using the 'uvrs' estimation program [15].

Finally, we repeated our analyses using detrended and deseasonalized logarithms of case counts as dependent variables and deseasonalized data on temperature and precipitation as independent variables in least squares regression (model 3) as described in

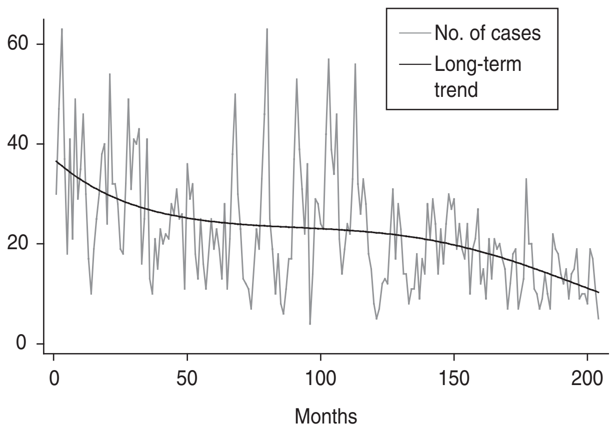

Fig. 2. Number of cases of salmonellosis and estimated long-term trend in Arkhangelsk, 1992–2008.

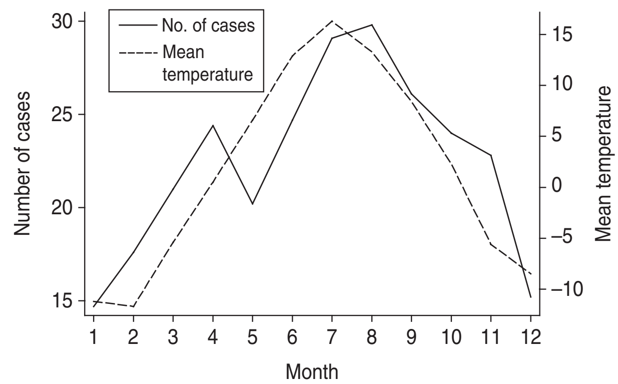

Fig. 3. Seasonal pattern of mean monthly number cases of salmonellosis and mean monthly temperature in Arkhangelsk, averaged for each month for the period 1992–2008.

detail previously [9]. Interaction terms between sequential time variables and climatic variables with lags were added to test whether the effect of temperature had changed over time [9].

All analyses were performed using Stata 10.0 software (StataCorp, USA).

RESULTS

The overall number of laboratory-confirmed cases of salmonellosis during the 17-year period of observation was 4627. After excluding cases linked to outbreaks this number decreased to 4585. The average monthly temperature ranged between −11·6 °C in February and 16·3 °C in July. The lowest mean monthly temperature was −21·7 °C in February 2008 while the highest was 19·7 °C, registered in July 2003. Monthly precipitation varied from 1·4 mm in April 2002 to 151·7 mm in July 1995; mean annual precipitation was 616 mm. No long-term trends were observed for either temperature or precipitation during the 17-year period.

Figure 2 illustrates a clear periodic pattern of salmonellosis notifications in Arkhangelsk. Moreover, the number of cases decreased in both the early and mid-1990s and mid-2000s with stagnation over a few years in between. The highest average number of cases occurred in August, 1 month after the peak temperature in July. The second less pronounced peak occurred in April. The lowest number of cases was observed for December–February. Figure 3 summarizes the seasonal pattern averaged across 17 years of observation.

Multivariable modelling of the salmonellosis counts using polynomial long-term trend and seasonality modelled by trigonometric functions (model 1) showed that temperature in the previous month was significantly related to outcome. An increase of 1 °C was associated with an increase in the monthly number of cases by 2·04% [95% confidence interval (CI) 0·25–3·84]. Model 2, in which year-to-year and seasonal variations were modelled using indicator dummy variables, yielded similar results: an increase of 1 °C was associated with an increase in the monthly number of cases by 1·84% (95% CI 0·06–3·63). In addition, in this model a 1-mm increase in precipitation was associated with a 0·24% (95% CI 0·02–0·46) increase in salmonellosis counts in the same month.

No thresholds for the effects of either temperature or precipitation were detected by the hockey-stick model. The results of modelling curvilinear relationship between the studied climatic variables and the monthly number of salmonellosis cases are presented in Figure 4. No significant deviations from linearity were detected for any of the climatic variables.

Analysis of associations between detrended deseasonalized logarithms of salmonellosis counts and deseasonalized values of temperature and precipitation yielded results close to those in model 1: an increase in mean monthly temperature of 1 °C was associated with a 2·3% (95% CI 0·38–4·27) increase in the number of cases of salmonellosis in the next month. No interactions between climatic variables and time were observed. The results of all three models are presented in detail in Table 1.

DISCUSSION

The results of this northernmost study, and the first Russian study, suggest a linear relationship between

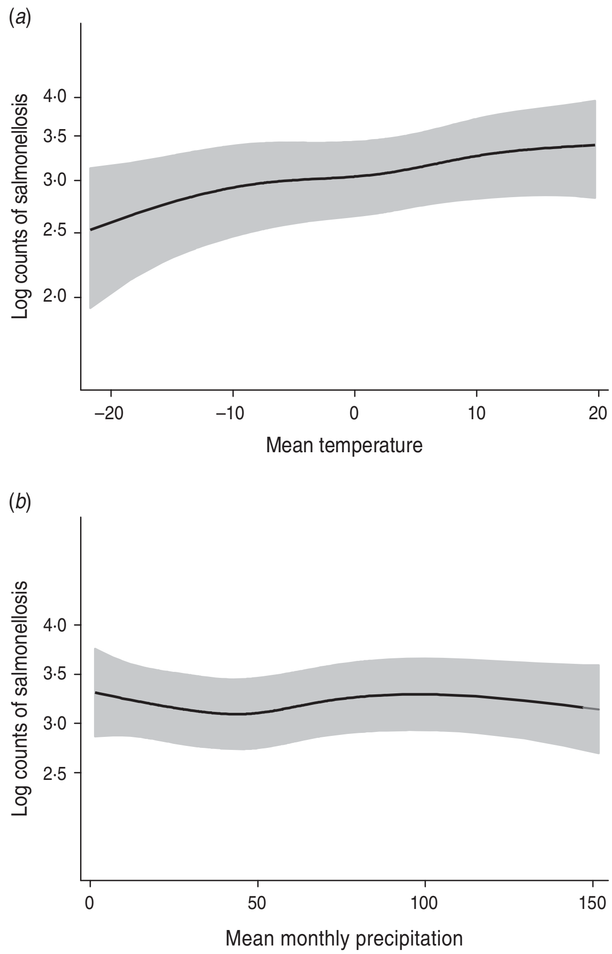

Fig. 4. Relationship between (*a*) salmonellosis and temperature with lag 1 and (*b*) relationship between salmonellosis and precipitation with lag 0. Both models are adjusted for covariates as in Table 1. Grey areas represent 95% confidence intervals.

monthly counts of salmonellosis and mean temperature in the previous month across the whole temperature spectrum with no threshold values. Moreover, one of the models suggested an association between monthly counts of salmonellosis and precipitation, but this association was not replicated in other models.

Our results are generally in line with findings from other parts of the world. D'Souza *et al.* [4] also observed an association between monthly cases of salmonellosis and temperature in the previous month in five Australian cities, although the effect was much more pronounced and varied between 5% and 10% increase in the number of cases for each 1 °C increase in temperature. Other Australian studies have also reported positive associations between temperature and salmonellosis, although both the effect and lags varied between the settings: in subtropical Brisbane, the effect of temperature was delayed 2 weeks while in tropical Townsville the effect of temperature was observed in the same month [6]. Moreover, much greater effects than those found in our study were observed using several different statistical models [5]. Interestingly, similar to studies from Australia [4–6], we could not identify the threshold under which the effect of temperature was not present. However, no thresholds were found in many European countries, e.g. Spain, Switzerland, Slovak Republic, Poland, Scotland and Denmark [7]. Moreover, no associations between temperature and salmonellosis were found in Denmark, Slovak Republic and the Canadian province of Newfoundland-Labrador [7, 8]. The latter was the northernmost study until now, but it included only 986 cases of *Salmonella* infection and did not have sufficient power to detect small effects, which were observed in Alberta (1·2% increase for each 1 °C increase). Lake *et al.* have recently provided evidence not only on the effect of ambient air temperature on salmonellosis and other enteric infections in England and Wales, but also calculated that this effect has reduced over the last decades as a result of preventive measures aimed at reducing pathogen levels in major food groups and improving food hygiene at the domestic and institutional levels, which can be considered as effective adaptation strategies to threats posed by climate change [9]. Our results suggest that the effect of temperature on the number of salmonellosis cases in Arkhangelsk was constant over time.

The associations between precipitation and enteric infections are much less certain even in the same country: while in Adelaide, an inverse association between salmonellosis and rainfall in the same month was observed, the same authors reported a positive association in both Brisbane and Townsville [6]. Contamination of drinking water as a consequence of heavy rainfall is likely to be a plausible explanation of that positive association. However, the association observed in the present study may also be spurious since it was found only in one of the three models. Moreover, almost no cases of salmonellosis were linked to water in Arkhangelsk during the study period. Further, the growth of *Salmonella* is greatly reduced in temperatures <15 °C [16]. Given that the temperatures in Arkhangelsk are below this range for the most part of the year, transmission through drinking water seems unlikely.

The main strength of our study is the use of a complete database for all laboratory-confirmed cases

Table 1. *Percent change in monthly salmonellosis counts per 1 °C increase in mean temperature and 1 mm increase in precipitation per month*

	Model 1*		Model 2†		Model 3‡	
	% change	95% CI	% change	95% CI	% change	95% CI
Temperature						
Lag 0	0·71	−1·30 to 2·71	0·65	−1·23 to 2·54	1·28	−0·64 to 2·20
Lag 1	2·04	0·25 to 3·84	1·84	0·06 to 3·63	2·32	0·38 to 4·27
Lag 2	−0·01	−1·79 to 1·65	−0·15	−1·93 to 1·62	0·33	−1·62 to 2·28
Precipitation						
Lag 0	0·13	−0·08 to 0·34	0·24	0·02 to 0·46	0·16	−0·08 to 0·40
Lag 1	−0·09	−0·31 to 0·13	−0·10	−0·30 to 0·10	−0·05	−0·29 to 0·19
Lag 2	−0·06	−0·29 to 0·15	−0·03	−0·27 to 0·21	−0·08	−0·32 to 0·15

CI, Confidence interval.

* Negative binomial regression adjusted for variables in the table, first- and second-order autocorrelations, seasonal variations and long-term trend modelled using trigonometric functions and polynomials.

† Negative binomial regression adjusted for variables in the table, first- and second-order autocorrelations, seasonal variation and long-term trend modelled as dummy variables.

‡ Linear regression on logarithmically transformed detrended deseasonalized counts and deseasonalized climatic variables adjusted for first- and second-order autocorrelations.

in the city from the same reliable source for a 17-year period. Moreover, given that the effects of climatic factors on outbreak-related cases may be different from those on sporadic cases, we identified all registered outbreaks and all outbreak-related cases were excluded from the analysis.

Another advantage of our study is the use of several statistical models to ensure comparability of the results with most of the published studies. Using trigonometric functions has been considered appropriate for controlling for seasonal fluctuations [5] as well as using polynomials for modelling long-term trends [4]. However, using binary variables for each year and month provided better goodness-of-fit in our study, although at the expense of statistical power. Comparison of predictive abilities of the models is beyond the scope of this paper and is presented in detail elsewhere [5]. While there is no consensus about which model is best, several analytical strategies including different approaches to modelling long-term and seasonal variations have been applied in different studies [4–9]. Zhang *et al.* reported that the SARIMA model was superior to Poisson or linear models [5], but limited sample size in their study did not allow us to use this method. The fact that the association between temperature and salmonellosis in Arkhangelsk was found in all models including model 3, which produces the most conservative estimates [9], suggests robustness of the association.

Nevertheless, we recommend interpreting the results with caution taking into account potential limitations of the study. Underreporting of the number of cases of salmonellosis is a common limitation of all similar studies which use data obtained from passive surveillance systems. Although we used laboratory-confirmed data from a reliable source, it is likely that the numbers of cases used in this study represent only the tip of the iceberg. The degree of underreporting varies both between and within countries. For example, only one out of 15 cases of salmonellosis is reported in Australia [17] and in many industrialized countries only 1% of all cases are registered [1]. It can be speculated that this proportion of reported cases is unlikely to be higher in Russia, although no studies have been published to support this hypothesis. Moreover, the registered cases may not be representative of all cases of salmonellosis in the city [18]. Given the tremendous social changes in Russia after the break-up of the Soviet Union, the completeness of reporting may vary over time. However, the use of corrections for long-term trends could at least partly eliminate this effect on the estimates. It is also unlikely that underreporting correlated with temperature or precipitation [9, 10]. Registration routines changed several times during the study period, but they were mostly associated with the inclusion of increasing amounts of detailed information and changes in laboratory techniques and reporting forms rather than in changes in reporting the number of cases *per se*. Lack of data on outbreaks or incomplete identification of them was mentioned as a limitation in several studies [4, 6–7]. In our study, we manually searched for all outbreaks using all available medical documentation and excluded all cases related to outbreaks from the analysis, although given changes in the routines of reporting outbreaks during the study period, some of the outbreaks might remain unregistered and therefore unidentified. The data available for analysis did not allow identification of travel-related cases, but these were almost non-existent in Arkhangelsk during the study period. Travel has a very clear seasonal pattern in Arkhangelsk with peaks during summer months, thus adjustment for seasonality in the analysis would remove the effects of travelling. Moreover, in other studies, where this information was available, exclusion of travel-related cases did not influence the results [7]. Contrary to the most recent studies, in which weekly counts of salmonellosis were used [5–11], we were only able to use monthly counts because all data for routine reporting from the regional surveillance centre is aggregated by month. However, given the relatively lower number of weekly cases, monthly aggregation seems appropriate and was used in other studies [4, 6–7]. In addition, there are more than 2000 serotypes of *Salmonella* with different sensitivity to climatic variables [17]. Although the present study does not distinguish between serotypes, more than 70% of all reported cases of salmonellosis in Arkhangelsk are attributable to *S.* Enteritidis, making contribution of other salmonellae to the observed pattern rather limited.

Average temperatures in the Russian Arctic are increasing faster than in the rest of the country and our results may have public health implications in terms of potential increase of the number of cases of salmonellosis and other enteric infections in the future if the temperature continues to rise. Temperature may affect contamination at any point along the food chain. Association with temperature with lags of 0–1 week are considered to reflect bacterial growth near the place of consumption while longer lags, e.g. 1 month as in our study may suggest deficiencies in food hygiene during production, processing and distribution rather than food preparation before consumption [9, 11]. However, lagged association in our study may also be partly attributed to reporting delays, because the surveillance system uses the date of laboratory confirmation, not the date when the first symptoms occurred before aggregating the data; however, in most cases the difference between the dates did not exceed 1 week. Warmer outdoor temperatures, particularly during the warm season, may also increase the likelihood of getting salmonellosis or other enteric infections through increased consumption of barbecued food, fresh salads or through outdoor recreational activities (e.g. hiking, swimming) or other activities that increase the likelihood of contact with salmonellae in the environment. The Russian tradition of preparation of large amounts of foods in advance, combined with a potential for inadequate storing, particularly in rural areas, may also contribute to an increase in the number of cases of salmonellosis in the future. However, the incidence of salmonellosis changes more rapidly than the climate and the baseline incidence of infection is the most important determinant of the effect of climate on enteric infections [19]. For example, in most countries, including Russia, a considerable decrease in the incidence of salmonellosis was observed during the last decade due to the introduction of measures to control *S.* Enteritidis in poultry [20].

Replications of our results are required before generalizing the findings to other urban areas in high latitudes. Using the exact dates of symptom onset instead of monthly aggregated data to reduce the influence of delays is recommended for future studies. Moreover, given that more information is now collected in Russia than was available for the whole observation period in this study, studies from larger settings including information on patients' sociodemographic factors and *Salmonella* serotypes are warranted.

CONCLUSIONS

Higher temperatures may be associated with higher monthly counts of salmonellosis even in high latitudes while the association with precipitation is less certain. The results may have implications for the future patterns of enteric infections in the northern areas related to climate change.

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coordinates the projects, contributing to the implementation of the WHO regional work plan on climate change and health. It also has provided technical assistance, guidance, training and expertise. In each country, a multisectoral steering committee is established, and a project coordinator oversees implementation at the national level. Country coordinators are supported by WHO/Europe. All activities are being implemented in collaboration with the BMU and the national Governments of the seven countries.

DECLARATION OF INTEREST

None.

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