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Analysis of the correlation between the incidence of food-borne diseases and climate change in Hungary

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Abstract— It is increasingly accepted globally, that many food-borne diseases are associated with climate change. The goal of the present research is to investigate whether changes in the annual number of the registered food-borne diseases in Hungary can be correlated to any climate parameter, as it is reasonable to suppose that it can be linked to climate change. Ten climate parameters and indices were examined as potential influencing factors. A multiple linear regression model was employed, using the backward elimination method to find the climate factors that have a significant effect on the annual number of food-borne diseases. It was found that the annual mean temperature was the only significant predictor of the annual number of registered food-borne diseases, and that 22.0% of the total variance in the annual number of food-borne diseases can be explained by the annual mean temperature. It should be noted that this relationship is negative, given that they are derived from time series with opposite trends. This phenomenon may be explained by the process of evolution and adaptation of the infecting fauna.

Key-words: annual number of food-borne diseases, climate factors, correlation, multiple regression, Hungary

1. Introduction

Probably climate change is one of the most urgent problems of humanity to solve, because it affects several parts of our current way of life. The Sixth Assessment of the *IPCC* (2021) gives accurate details about the physical driving forces of climate change and summarizes the possible effects that it is likely people will have to meet in the future. Global climate change probably cannot be prevented (*Fawzy et al.,* 2020; *van Meijl et al.,* 2018); therefore, adaptation and mitigation are in the priority.

It has long been recognized that increasing food-borne diseases are correlated with climate change through microbial adaptation by natural selection (*van de Venter*, 2000). Climate change should exacerbate the challenges for the public health sector for both food-borne and water-borne diseases (*Cissé,* 2019). Rises in air and water temperature, extreme precipitation events, seasonal changes, and the storms, droughts, and flooding associated with climate change will clearly have implications for food- and water-borne diseases in Europe. One obvious example is the adverse effect of high air temperatures on food quality during transport, storage, and handling (*EEA*, 2016). The most prevalent food-borne disease in Europe is campylobacteriosis, and this is known to be associated with several meteorological variables. Peaks in the incidence of campylobacteriosis may shift in time, as it displays strong seasonality, thereby making it subject to any changes in climate. Rise in temperature also have a pronounced impact on the occurrence of salmonellosis and food poisoning notifications in Europe (*ECDC*, 2012).

A rise in mean global temperature may be expected, bringing about a concomitant increase in the incidence of food-borne diseases (*Cullen*, 2009). The WHO considers that warming and changes in precipitation are already claiming human lives and climate-health relationship pose increasing health risk, as many human diseases are linked to climate fluctuation (*Patz et al.*, 2005) and overexploitation (*Patz et al.,* 2008). Climate conditions strongly affect the incidence and transmission of many water-borne and food-borne diseases (*Schuster-Wallace et al.*, 2014). Changing climate alters the living conditions for every species, and this includes pathogens, and will affect different food-borne parasites in various ways (*Utaaker* and *Robertson*, 2015). Food is a conventional vector for pathogens to reach hosts. Street food is a major source of food-borne diseases, and increasing temperature is likely only to intensify this, by accelerating the growth rates of microorganisms (*Bastien-Olvera et al.*, 2017). *Lake* (2017) examined the likely impact of climate change upon food-borne diseases in the UK and found a strong positive association between *Salmonella* spp. cases and ambient temperature. Infection with *Salmonella* spp. leads to diarrhoea, fever, and abdominal cramps, usually 1–3 days after the initial infection. Symptoms generally last for 4–6 days, but in some cases, the person affected may need to be hospitalized. It must be said, however, that the relationship between changing climatic conditions and food-borne diseases is still poorly understood (*Kim et al.*, 2015). This relationship and, hence, any impacts on any associated illnesses are uncertain, making it difficult to estimate which pathogens will be affected and what changes might occur (*Lake* and *Barker*, 2018). A linear association can be demonstrated between the environmental temperature and the number of reported cases of *Salmonella* spp. infections above a threshold of 6 °C as found by *Kovats et al.* (2004).

Fluctuations in climatic conditions are a frequent phenomenon in the history of the Earth, but the ongoing climate change is supposed to be accelerated by the human activity. A warming trend may be clearly seen in data obtained by CarpatClim for the Carpathian region between 1961 and 2010 (*Lakatos et al.*, 2016), and temperature extremes show significant changes in the Carpathian region over the same period, in particular the increasing incidence of warm nights (*Lakatos et al.*, 2016). Not only warming is to be projected in the region, but also severe modifications in precipitation (*Kis et al.*, 2017; *Bartholy et al.*, 2015; *Pongrácz et al.,* 2014). Therefore, the intensity and frequency of extreme precipitation events in the region has increased (as measured on the basis of extreme indices) during the 20th century in the Carpathian Basin (*Bartholy* and *Pongrácz*, 2005). Regional climate model outputs suggested that considerably less precipitation should be expected in summer, with a rising frequency of drought. In winter, slightly more rainfall is to be projected. It should be kept in mind that more recent studies warned that hydroclimate projections for East-Central Europe diverge to a great extent, and those models, which better represent land-atmosphere feedbacks actually project less summer drying in the near future (*Topál et al.,* 2020). Modification of the intra-annual distribution of the precipitation is supposed. The frequency of heavy precipitation is projected to decrease in summer, but to rise in the other seasons (*Bartholy* and *Pongrácz,* 2010).

Changes in annual mean temperature projected for the Carpathian Basin based on model runs by four different regional models (ALADIN, REMO, PRECIS, RegCM) are 1.1–1.9 °C for 2021–2050 and 3.1–4.0 °C for 2071–2100 (the reference period is 1961–1990). These model runs projects (-7) – 0% change in annual precipitation to 2021–2050 and (-21) – +3% for 2071–2100 with the same reference period (*Krüzselyi et al.,* 2011).

The aim of the present research is to investigate whether the annual number of registered food-borne diseases may correlate to any climatic factor, as it is supposed that it can be linked to climate change. Ten climate parameters and indices are examined as potential impact factors. While the evolution of food-borne diseases depends on various factors, in this research other potentially influencing factors were not examined.

2. Material and methods

6.1 Data used

The climate data time series were provided by the Hungarian Meteorological Service. These time series were derived from the *CARPATCLIM Database* (2013) and represent extrapolated gridded and homogenized data covering the territory of Hungary for the period 1961–2010. The following climatic data and extreme indices were used: annual mean temperature (°C), annual precipitation sum /R/ (mm), annual mean relative humidity (%), annual total number of days when the daily maximum temperature was higher than 30 °C (days), annual total number of days when the daily minimum temperature was higher than 20 °C (days), annual total of number of days when the daily precipitation sum was higher than 10 mm (days), annual absolute maximum of diurnal precipitation (mm), duration of the longest dry period during a year (days), duration of the longest wet period during a year (days), annual maximum of 5-day-long precipitation sums /RX5/ (mm).

The Hungarian Public Health Service provided the time series of the total annual number of food-borne diseases between 1961 and 2010. Covering a short period between 2011 and 2017, a detailed database also provided information on the number of food-borne diseases classified according to bacteria genus.

6.2 Statistical methods

Multiple linear regression was fitted to the data and backward-elimination method was used, in which the annual total number of food-borne diseases was chosen as the dependent variable. As predictors, the climatic data and climate extreme indices were used. For the details of the statistical method see *Aczel* and *Sounderpandian*, 2006; *Helsel* and *Hirsch*, 2002; *Osborne* and *Waters,* 2002. The goal was to estimate whether the number of food-borne diseases correlated with any of the ten climate factors selected for examination. As a preliminary requirement, the normal distribution of the dependent variable was checked using the Kolmogorov-Smirnov test at a significance level of 5%. The dependent variable fulfilled this requirement. Although it could have been an approach to consider numerous parameters (e.g., *O'Brien*, 2007) to backward eliminate the different predictors, however, the significance of the partial regression coefficient was chosen as the bottleneck parameter at 5% significance level.

3. Results

A multiple linear regression model was used to investigate if any of the predictor parameters have a significant effect on the total annual number of food-borne diseases. Applying the backward-elimination method based to the results of the *t*-test's *p*-values, all the while paying attention to the potential multi-collinearity of the predictors, the multiple linear regression model was reduced to a simple linear regression model (*Appendix 1*), in which the annual mean temperature is a significant predictor of the annual number of food-borne diseases. The linear correlation coefficient is -0.486, and therefore, the relationship is negative between variables. The adjusted coefficient of determination means that 22.0% of the variance of the annual number of food-borne diseases is explained by the annual mean temperature (*Appendix 1*). As only one significant independent variable was found among the ten predictors examined, in the course of the final check, the linear relationship between the two variables was explored (*Fig. 1a*), the normal distribution of the residuals was analyzed, and homoscedasticity was visually controlled (*Fig. 1b*). The normality of the residuals was tested using the Kolmogorov-Smirnov test, and it can be accepted that the residuals followed a significantly normal distribution (the *p*-value was 0.2). All these checks fulfilled the requirements.

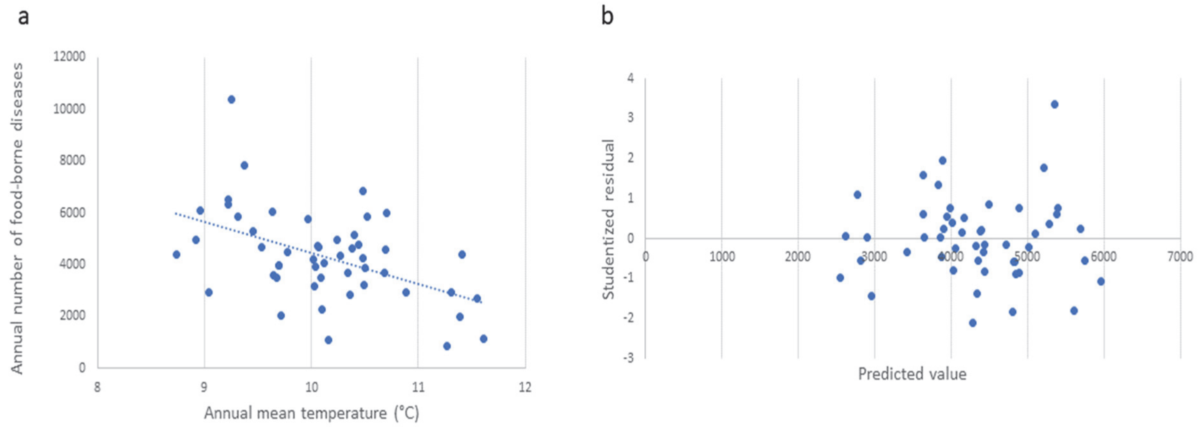

Fig. 1. Linear relationship between the variables (a) and check for homoscedasticity (b).

Between 1961 and 2010, a negative correlation can be detected: as the annual mean temperature rises, the annual number of registered food-borne diseases decreases over the examined time period (*Fig. 2*). Unfortunately, only indirect evidence of this theory can be found as detailed information about the vectors causing food-borne diseases are obtained for the period of 2011–2017.

As the annual mean temperature was the only significant predictor of the annual number of registered food-borne diseases, the question arises of whether the significance of this relationship is enhanced in time. The examined time series was therefore split into two equally long segments. Between 1961 and 1985 the regression model is not significant, and the annual mean temperature as predictor is not significant. Between 1986 and 2010, however, the regression model is significant at a significance level of 5%, and annual mean temperature is a significant predictor at a significance level of 10%. These results suggest the enhancing influence of annual mean temperature. For the years 1981–2010, annual mean temperature remained the only significant predictor of the annual number of registered food-borne diseases.

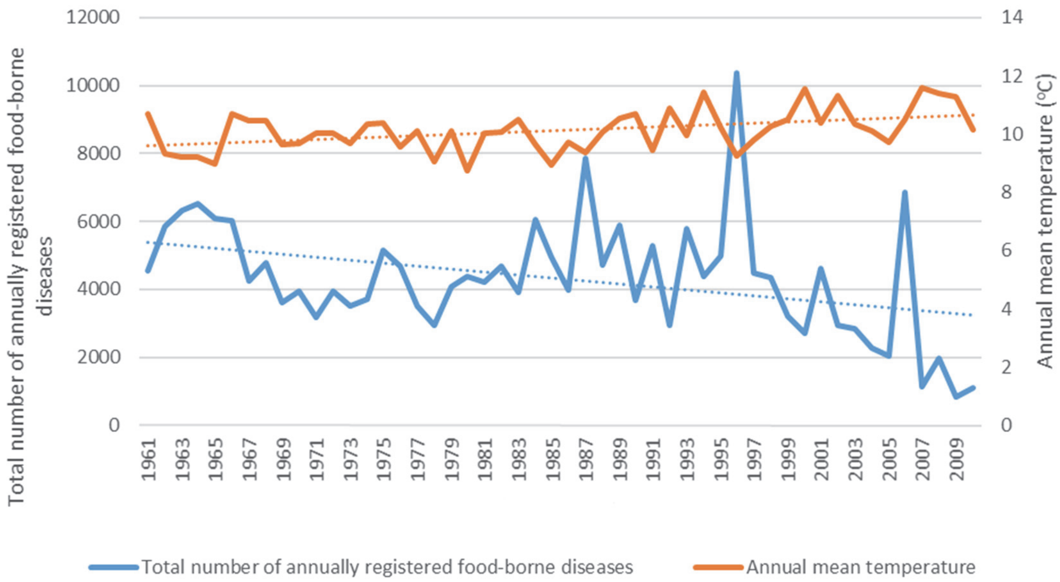

Fig. 2. Tendencies in time of the examined variables.

The share of salmonellosis (light blue) noticeably decreased, while that of the *Calici virus* (dark grey) infections increased with time and between 2015 and 2017 *Clostridium perfingens* (light green) appeared, not having been present previously (*Fig. 3*). Despite the relatively short period for which the detailed data by bacteria genus are available (2011–2017), they clearly indicate a change in the type and frequency of occurrence of bacteria causing food-borne diseases. The *Salmonella* spp. has been the most common food borne disease bacteria in Hungary in recent decades. The frequency of occurrence of salmonellosis decreased during this period, while types of food-borne bacteria previously not encountered locally have appeared. The frequency of occurrence of *Clostridium botulinum* and *Clostridium perfingens* increased between 2015 and 2017. The *Salmonella* spp. is a mesophilic bacterium, but *Clostridium botulinum* and *Clostridium perfingens* are thermotolerant bacteria.

From 2011 to 2017, detailed monthly data on the number of food-borne diseases were provided by the Hungarian Public Health Service. The question arises of whether seasonal patterns can be found in the monthly data that might be linked to temperature changes. The absence of any typical seasonal pattern in the monthly number of food-borne diseases can be seen in *Fig.4*.

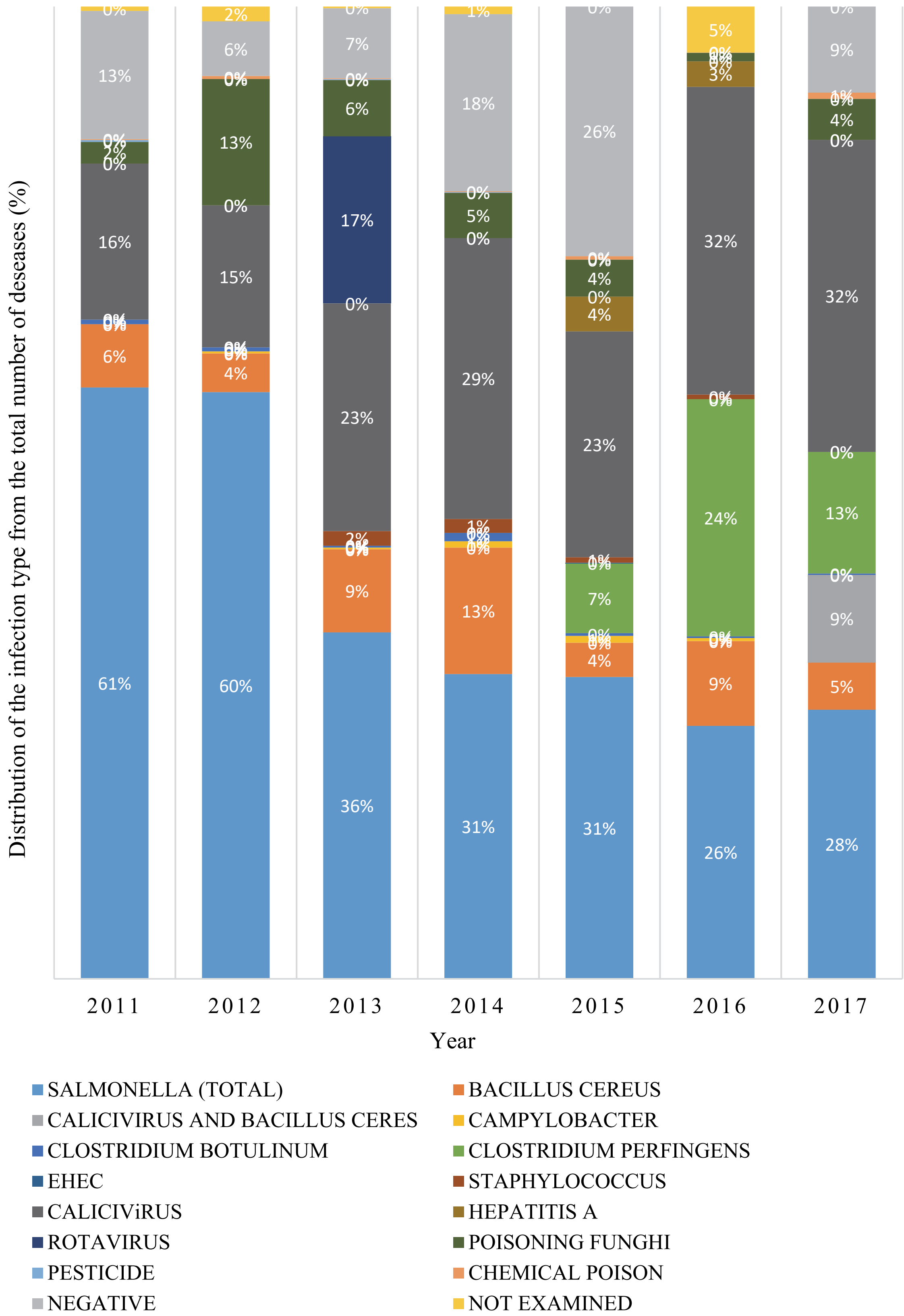

Fig. 3. Distribution of the different infecting vectors in the annual number of registered food-borne diseases.

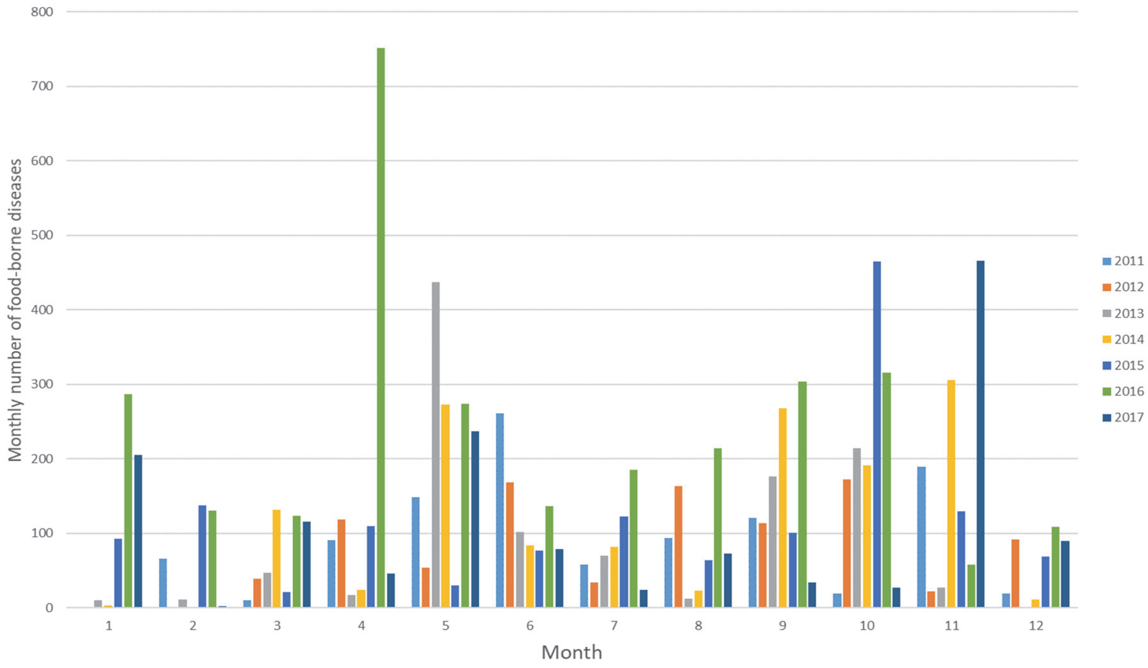

Fig. 4. Monthly number of food-borne diseases year-by-year between 2011 and 2017.

As no typical seasonal pattern can be discerned, an interesting question was to see the changes of the annual distribution of the number of food-borne diseases on a monthly basis, even if the period in question (2011-2017) is short. *Fig. 5* lends some support to the validity of this approach.

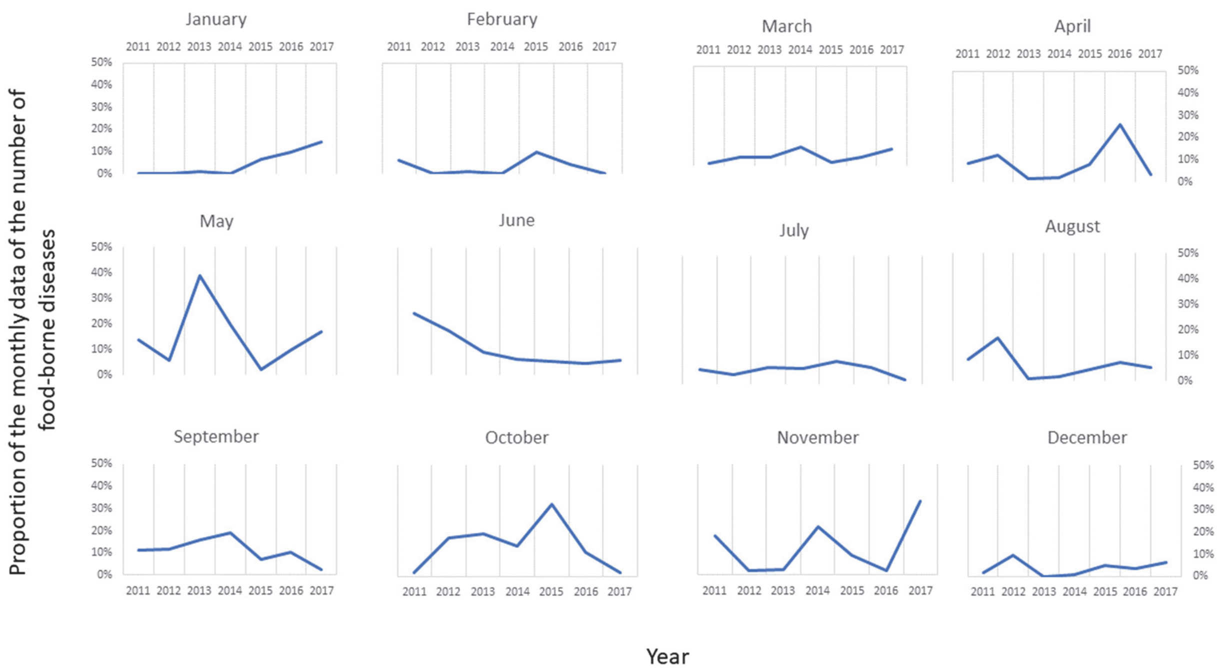

Fig. 5. Proportion (%) of the monthly data of the number of food-borne diseases (2011–2017).

It is interesting to note the varying degrees to which the number of food-borne diseases displays a seasonal pattern, as shown in *Fig. 6*. The seasons are as follows: spring: March, April, May; summer: June, July, August; autumn: September, October, November; and winter: December, January, February. In the seasonal data, temperature rises in the summer and winter may cause favourable conditions in winter and limiting conditions in summer. The proportion of the number of diseases in summer declines, while in winter it increases. These phenomena should be linked to the temperature changes due to climate change.

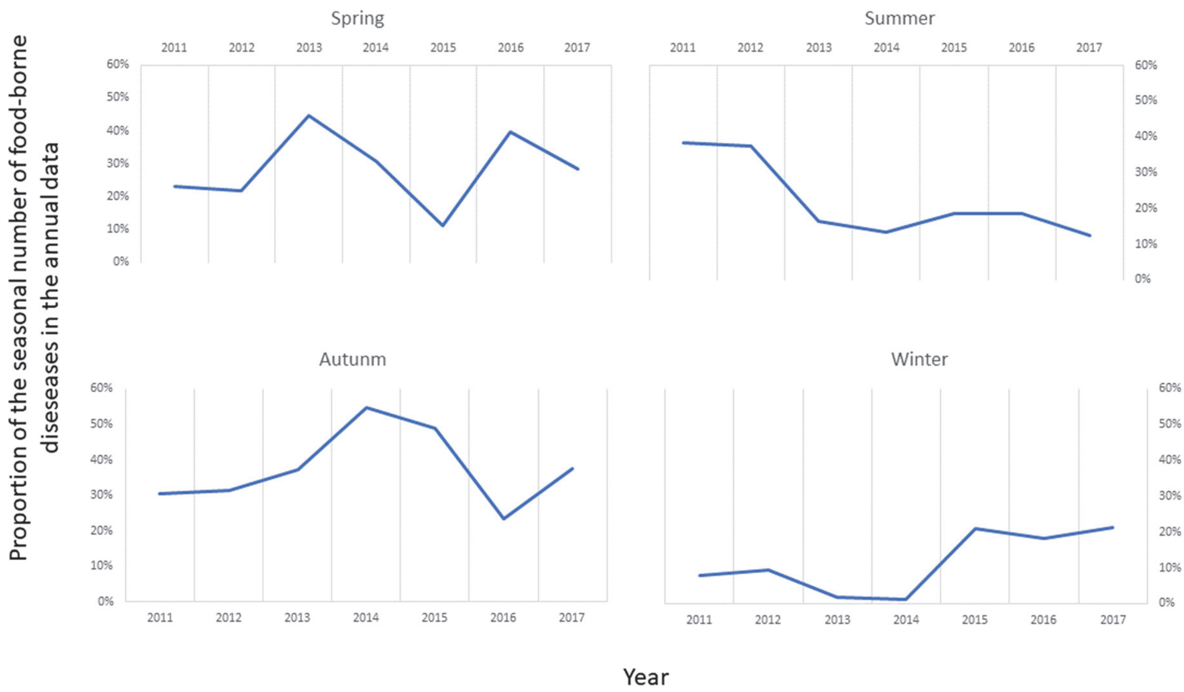

Fig. 6. The proportion of the seasonal number of the food-borne diseases in the annual data (2011–2017).

4. Discussion

A significant relationship has been revealed between the annual mean temperature and the number of food-borne diseases based on annual data (1961–2010). Several studies, mentioned below, have already focused on the relationship between temperature and food-borne diseases, and it has been found that climate change, as well as other factors such as globalization and land cover change, contribute to outbreaks of transboundary animal diseases – some transmissible to humans – that can affect food and nutrition security, as well as livestock rearing and trade. For a better understanding of the processes over time, the dataset of 50 years was divided into two parts (1961–1985 and 1986–2010). The result suggests the enhancing effect of the annual mean temperature. Because of the explanation of the results, the distribution by the infection type of the annual total number of food-borne diseases was analyzed between 2011 and 2017. Unfortunately, this detailed information had not been registered previously. Between 2011 and 2017, the monthly number of the food-borne diseases was available, besides the annual data. The frequency of occurrence of *Clostridium botulinum* and *Clostridium perfingens* increased between 2015 and 2017. The share of salmonellosis noticeably decreased, while that of the *Calici virus* infections increased with time. Between 2015 and 2017 *Clostridium perfingens* appeared, not having been present previously. Climate change can contribute to bring novel vectors into temperate regions (*Newell et al.,* 2010).

Analyzing the proportion of the seasonal and monthly numbers of food-borne diseases within the annual data, it can be concluded that the rise in temperature is projected to be above yearly average in the winter months, and the ratio of diseases occurring in January is likely to increase rapidly. This may indeed be proof of the influence of rising temperature, as the temperature conditions more closely coincide with those to which the infecting bacteria is accustomed and in which it thrives. In June the ratio decreases. It is reasonable to assume that the summer months are supposed to be warmer and warmer (*Bartholy et al.,* 2011), and therefore, it is possible that this increase in temperature will put it beyond the "comfort zone" of the bacteria which constitute the typical infecting species.

There is a direct correlation between the environment and the organisms from which food is produced and the impact of food safety on human health and economic well-being. Meanwhile, food-borne pathogens in the food chain are affected by complex interactions between the environment, microorganisms, and reservoir hosts (*EC*, 2007). Increases in temperature may speed up the growth of pathogens and/or parasites that exist at least part of their life cycle outside of their host, negatively affecting livestock (*Rojas-Downing et al.,* 2017). Climate change may induce shifts in the pattern of the spread of disease, or even introduce new diseases in areas where livestock had never before been exposed to them (*Thornton et al.*, 2009). Pathogens in charge of human disease can originate in animal stock on farms, from contamination during food processing or transportation, or during the commercial or home preparation of food. There is proof that the growth and dissemination of the accountable microorganisms can be affected by the weather (*MMWR*, 1999, *Rose et al.*, 2000; *Curriero et al.*, 2001, *Rose et al.*, 2001). A study in the United Kingdom found an association between temperature and food poisoning (*Bentham et al.*, 1995).

5. Conclusions

Ten meteorological parameters and extreme indices were analyzed in regression statistics (multiple linear regression backward elimination) to the annual number of food-borne diseases in Hungary in the period of 1961–2010. The adjusted coefficient of determination was 22.0% and had an increased value in the period 1981–2010. Of the ten parameters examined, only the annual mean temperature was found to be a significant predictor, and then the correlation is negative between the annual mean temperature and the annual number of food-borne diseases. Intra-annual examination could be carried out in depth only for the period of 2011–2017, and it was found that changes in temperature do indeed have an influence on the annual distribution of the number of diseases. Temperature rises in summer and winter are likely to have a twofold effect, in that while they create more favorable conditions in winter for bacteria, they also play a limiting role in summer, as it may be observed in the incidence of food-borne diseases, which is actually declining in summer, but increasing in winter.

The scarcity of the data available is certainly places limits on how definite any conclusions drawn may be, but even this examination of a dataset covering a short period of time gives a clear indication of the changes occurring. While further research is required, as a preliminary conclusion, it may be stated that where there is a rise in temperature, the modification of intra-annual peaks in the incidence of diseases is to be expected.

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Appendix 1

Detailed results of the step-by-step calculations of the backward-elimination method

Step	Number of predictor parameters	Parameters involved in the regression model	*p*-value of ANOVA	Se	Residuals follow normal distribution	Significant parameter (α=5%)	*p*-value of t-test	Parameter eliminated	Reason	Adjusted R^2
1	10	annual mean temperature; annual mean relative humidity; Tmax higher than 30; Tmin higher than 20, R higher than 10 mm; absolute max of diurnal precipitation; longest dry period; longest wet period; RX5	0.061	1578.87	yes	annual mean temperature	0.04	annual precipitation sum	multicollinearity; insignificant parameter	0.169
2	9	annual mean temperature; annual mean relative humidity; Tmax higher than 30; Tmin higher than 20, R higher than 10 mm; absolute max of diurnal precipitation; longest dry period; longest wet period; RX5	0.037	1559.15	yes	annual mean temperature	0.029	Tmax higher than 30	multicollinearity; insignificant parameter	0.189
3	8	annual mean temperature; annual mean relative humidity; Tmin higher than 20; R higher than 10 mm, absolute max of diurnal precipitation; longest dry period; longest wet period; RX5	0.045	1580.7	yes	annual mean temperature	0.047	RX5	multicollinearity; insignificant parameter	0.167

Appendix 1. continue

Step	**Number of predictor parameters**	**Parameters involved in the regression model**	***p*-value of ANOVA**	**Se**	**Residuals follow normal distribution**	**Significant parameter (α=5%)**	***p*-value of t-test**	**Parameter eliminated**	**Reason**	**Adjusted R^2**
4	7	annual mean temperature; annual mean relative humidity, Tmin higher than 20; R higher than 10 mm; absolute max of diurnal precipitation; longest dry period; longest wet period	0.025	1561.8	yes	annual mean temperature	0.044	annual mean relative humidity	multicolline arity; insignificant parameter	0.187
5	6	annual mean temperature; Tmin higher than 20; R higher than 10 mm; absolute max of diurnal precipitation; longest dry period; longest wet period	0.01691	1556.135	yes	annual mean temperature	0.0033	Tmin higher than 20	multicolline arity; insignificant parameter	0.192
6	5	annual mean temperature, R higher than 10 mm; absolute max of diurnal precipitation. longest dry period. longest wet period	0.0124	1556.852	yes	annual mean temperature	0.0001 25	absolute max of diurnal precipitati on	multicolline arity; insignificant parameter	0.192
7	4	annual mean temperature; R higher than 10 mm; longest dry period longest wet period	0.0066	1547.9	yes	annual mean temperature	0.0002 2	longest wet period	insignificant parameter with highest p-value	0.201
8	3	annual mean temperature; R higher than 10 mm; longest dry period	0.0026	1533.5	yes	annual mean temperature	0.0002	longest dry period	insignificant parameter with highest p-value	0.216
9	2	annual mean temperature; R higher than 10 mm	0.001044	1527.88	yes	annual mean temperature	0.0002 3	R higher than 10 mm	insignificant parameter with highest p-value	0.222
10	1	annual mean temperature	0.000344	1528.94	yes	annual mean temperature	0.0003 44	–	–	0.220