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Projected burden of disease for *Salmonella* infection due to increased temperature in Australian temperate and subtropical regions

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ABSTRACT

Objective: This study aimed to project the future disability burden of *Salmonella* infection associated with increased temperature in future in temperate and subtropical regions of Australia in order to provide recommendations for public health policy to respond to climate change.
Methods: Years Lost due to Disabilities (YLDs) were used as the measure of the burden of disease in this study. Regions in temperate and subtropical Australia were selected for this study. Future temperature change scenarios in the study were based on Australian projections, developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO). YLDs for *Salmonella* infection in 2000 were calculated as the baseline data. YLDs for *Salmonella* infection in 2030 and 2050 under future temperature change scenarios were projected based on the quantitative relationship between temperature and disease examined in previously published regression models. Future demographic change was also considered in this analysis.
Results: Compared with the YLDs in 2000, increasing temperature and demographic changes may lead to a 9%–48% increase in the YLDs for *Salmonella* infection by 2030 and a 31%–87% increase by 2050 in the temperate region, and a 51%–100% increase by 2030 and an 87%–143% increase by 2050 in the subtropical region, if other factors remain constant.
Conclusion: Temperature-related health burden of *Salmonella* infection in Australia may increase in the future due to change in climate and demography in the absence of effective public health interventions. Relevant public health strategies should be developed at an early stage to prevent and reduce the health burden of climate change.

1. Introduction

Enteric infection is a significant public health problem in both developing and developed countries. According to a recent report from the Australian Government, the total national cost of food-borne illness is estimated at 1.25 billion Australian dollars each year (Abelson et al., 2006). It is reported that food-borne illness leads to 1.2 million visits to medical practitioners in Australia, over 300,000 prescriptions for antibiotics, and 2.1 million days of work lost each year (Abelson et al., 2006). In Australia, *Salmonella* is one of the most common agents responsible for food-borne disease outbreaks, with 7,842 notified cases in 2004. This notification rate (39.0/100,000) represented a 4.9% increase compared with the mean rate of the previous six years (OzFoodNet Working Group, 2005).

The relationship between enteric infections and climate variation has been documented by limited studies conducted in Europe, the US, Asia and Australia (D'Souza et al., 2004; Kovats et al., 2004; Patrick et al., 2004; Rose et al., 2001; Tam et al., 2006). A reported dose–response relationship suggests that each 1 °C increase in temperature may be related to a 5% increase in the risk of severe diarrhea (Checkley et al., 2000). An Australian study, based in Queensland, also showed a positive association between *Salmonella* infection and temperature (D'Souza et al., 2004). Increased temperature and poor hygiene can affect the whole chain from food production to food on the table, including producing, processing, transport, preparation or storage and even in kitchen, allowing pathogens to multiply and leading to more patients of enteric infections. However, only few studies have been conducted projecting the future disease burden associated with a changing climate, which is necessary for health research prioritization, health resource allocation, infrastructure establishment, and development of a health response mechanism.

The burden of disease (BoD) is a quantitative index to measure health status and relevant attributed risk factors in a given population. BoD studies can answer the question: 'How big is this health problem?' so as to provide information for policy-makers and stakeholders by highlighting main health problems. BoD studies have been carried out at global, national and regional levels, using summary measures such as Disability Adjusted Life Years (DALYs) to combine information

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on mortality and morbidity in a single health indicator. Environmental burden of disease studies estimates the burden of disease from major environmental risk factors, such as climate change. DALYs are used to estimate climate change-attributable health burden in the future. One DALY can be thought of as one year of 'healthy' life lost, which is calculated by the sum of years of life lost due to premature mortality (YLL) and the equivalent 'healthy' years of life lost due to disability (YLD) (Mathers et al., 1999; Murray and Lopez, 1996).

Australia has unique geographic characteristics and diverse climatic regions, which makes it vulnerable to climate change manifested by rising sea levels, floods, droughts and heat waves (Pittock, 2003). It is therefore important for Australia to understand the current and projected climate-related health burden. Although Australia completed its first national burden of disease study in 1999 (Mathers et al., 1999) and sub-national burden of disease studies have been conducted in several Australian states, such as Queensland (Pike et al., 2002) and South Australia (South Australian Department of Health, 2004), climate change has not been investigated in these studies as a risk factor. Furthermore, no study has been conducted to assess the health burden due to climate change in different regions with different climatic characteristics.

This study aims to project the health burden of *Salmonella* infections under future scenarios for climate and population change in different climatic regions in Australia. Given the considerable assumptions and uncertainties in the methodology in all burden of disease studies, the scenario-based projection in this study will generate a broad picture of possible trends in the morbidity burden from *Salmonella* infections associated with future climate change. The ultimate purpose of this study is to provide scientific evidence for policy makers, practitioners and local communities in order to reduce future risks of climate change and take relevant action at an initial stage.

2. Methods

2.1. Background information

Two Australian regions with different climatic characteristics, the state of South Australia with a 1.5 million population, in a temperate climatic zone, and the city of Brisbane in the state of Queensland with a 1.7 million population and a humid subtropical climate, were chosen as the study regions. Except the varying local climate conditions, the two regions of Australia were selected to make the study areas comparable in terms of the number of cases and the total population.

2.2. Calculating the years of life lost due to disability (YLDs)

Because of the very low death rate of *Salmonella* infection in Australia (only 7 confirmed deaths from the 11,785 cases of *Salmonella* infection notified for South Australia over 1990–2010), YLDs have been estimated by this study as the indicator of the health burden of disease. The calculation of the YLDs from *Salmonella* infection in Australia was aided by the use of data from the Australian National Burden of Disease study and the previous South Australia and Queensland burden of disease studies (Pike et al., 2002; South Australian Department of Health, 2004). In addition to the assumptions associated with the original methods used in the Global Burden of Diseases (GBD) and the Australian National Burden of Disease studies (Mathers et al., 1999; Murray and Lopez, 1996), such as assumptions on incidence, prevalence and mortality rates, other assumptions need to be addressed in this analysis.

Assumption one: the quantitative associations between climate variation and the target disease were assumed to remain the same in the future, despite potential changes in other factors, such as socio-economic status and the health care system, which have an impact on disease transmission. Such quantitative relationships were then applied to the projective modeling. Assumption two: temperature is the key weather factor influencing the transmission of the target disease. This has been confirmed in previous studies (D'Souza et al., 2004; Kovats et al., 2004; Rose et al., 2001). Other climatic factors, such as rainfall and relative humidity, may also influence disease transmission but with large variations in effect. Thus, the effects of other meteorological variables on *Salmonella* infection have been assumed to be constant. Assumption three: any future change in the vulnerability, both economic and socio-cultural, of the population to climate change, e.g. availability to infrastructure and access to relevant information, was assumed to be unchanged.

The age groups used in this study for both sexes were 0~, 5~, 15~, 25~, 35~, 45~, 55~, 65~ and 75+. Age- and sex-specific incidence rates of *Salmonella* infection were collected from local authorities in each study region. The disability weight for *Salmonella* infection could not be identified from any previous studies because it had been subsumed in the category of "diarrhoeal disease". Therefore, the weights used for the category "diarrhoeal disease" were used in this assessment. Based on the Australian National Burden of Disease study (Mathers et al., 1999), the average disability weight and average duration (years) used in this study was 0.09 and 0.01 for uncomplicated cases and 0.42 and 0.04 for complicated cases, respectively.

Varying discounting and age weightings are used in burden of disease studies. For example, there could be no discounting and uniform age weighting – YLD(0,0) – or 3% discounting and non-uniform age weighting — YLD(3,1). These discounting measures and weights however would not affect the potential trends in the projected burden of disease based on linear regression. Therefore, 3% discounting without age weighting was used for the calculation of the YLD (3,0) in this study, as used in most burden of disease studies (Mathers et al., 1999; Murray and Lopez, 1996). The formula used to calculate the YLDs in this study is presented below (Murray and Lopez, 1996):

$$\mathrm{YLD} = \frac{\mathrm{I} \times \mathrm{DW} \times \left(1 - e^{-r\mathrm{L}}\right)}{\mathrm{r}}$$

Where:

I	incidence rate
DW	disability weight
L	average duration of disability (years)
r	discount rate (0.03)

2.3. Projecting future YLDs for Salmonella infection

The relationship between temperature and *Salmonella* infection in the study areas was quantified in our previously published studies (Zhang et al., 2008, 2010). In these previous studies, based on over 15 years disease surveillance data and metrological data, time series regression models, with consideration of lagged effects, autocorrelation, and seasonality, were applied to quantify the association between temperature, rainfall, relative humidity and the number of cases. Results indicate that a potential 1 °C rise in mean maximum temperature may be related to a 7.6%–10.0% increase in the number of cases in Brisbane. While in South Australia, expected increase in number of cases for 1 °C rise in maximum temperature is 10.6–19.7%. This quantitative association between climatic variables and number of cases is the basis for the projections in this study.

The YLDs for the study disease in 2000 were chosen as the baseline for the projection due to the data availability. Projections for future burden of disease from the baseline were conducted for 2030 and 2050. Climatic and demographic changes were both considered in the projections. The projections for the increase in temperature in the study areas were obtained from the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) report (Preston and Jones, 2006). The ranges of the projections of temperatures in the temperate region are 0.3–1.3 °C by 2030 and 0.6–2.2 °C by 2050. In the subtropical region, the projective ranges are 0.3–2.0 °C and 0.5–3.2 °C by 2030 and 2050, respectively. The scenarios for future population structures were collected from the Australian Bureau of Statistics (ABS). A range of the morbidity burden (YLDs) under various scenarios rather than a point estimation is presented to incorporate the quantifiable uncertainties. The demographic changes in the study areas are summarized in Table 1.

3. Results

3.1. Projected YLDs for Salmonella infection in South Australia, a temperate region

Table 2-1 illustrates the calculated YLDs for *Salmonella* infections in 2000 and projected YLDs in 2030 and 2050 under different scenarios of climatic and population changes in South Australia. It can be seen that the total YLDs for *Salmonella* infections in 2000 in South Australia were 54. There were no differences in the YLDs for *Salmonella* infections between males and females. A clear increasing trend in the YLDs has been projected by different scenarios associated with climatic and demographic changes.

The projected increasing trends in the total YLDs are demonstrated in Fig. 1-1. It can be observed that under the temperature change scenarios alone, the YLDs might increase by up to 33% by 2030 (72 YLDs) and 56% by 2050 (84 YLDs), compared to those in 2000. Considering the effect of both climate and demographic changes, the YLDs for *Salmonella* infections in South Australia may increase up to 48% by 2030 (80 YLDs) and 87% by 2050 (101 YLDs), compared to that 2000, given other factors remain constant. The age-specific YLDs for *Salmonella* infections in South Australia are demonstrated in Fig. 2-1. It indicates that children and young adults are the most vulnerable groups, accounting for a large proportion of the burden of *Salmonella* infections.

3.2. Projected YLDs for Salmonella infection in Brisbane, a sub-tropical region

Table 2-2 shows that the total YLDs for *Salmonella* infections in Brisbane were 53 in 2000. No difference was observed between males and females. An increase in the burden of *Salmonella* infections in 2030 and 2050 has been projected under different climate and demographic change scenarios.

Fig. 1-2 demonstrates the increase in total YLDs for *Salmonella* infections in Brisbane under various scenarios. It suggests that an increase in temperature may result in an up to 57% increase in the YLDs (83) for *Salmonella* infections by 2030 and more than 106% increase by 2050 (109), compared to that in 2000. With consideration of both temperature and population change, the YLDs for *Salmonella* infections in Brisbane may increase by almost 100% by 2030 (106 YLDs) and 143% by 2050 (129 YLDs), if other factors remain unchanged. Fig. 2-2 demonstrates the estimated and projected age-specific YLDs for *Salmonella* infections in Brisbane. Similar to South Australia, the children and young adults account for the largest proportion of the burden of *Salmonella* infections among all age groups.

4. Discussion

This is the first study to examine the future disease burden of *Salmonella* infections associated with climate change in different regions of Australia. This study suggests that while the exact YLDs for *Salmonella* infection are not very high, an increasing trend in the burden of *Salmonella* infections in Australia may occur if there are no effective measures for climate change taken into account. By 2050, the morbidity burden of *Salmonella* infections may nearly double in the temperate region and may increase by almost 1.5 times in the subtropical region of Australia, if other factors remain constant. Given the very low mortality from *Salmonella* infections in Australia, the projected morbidity burden could be considered to approximate the whole burden of the disease.

Table 1
Future demographic change in study regions in Australia.

Australia	South Australia			Brisbane		
	2000	2030	2050	2000	2030	2050
Population (thousands)	1505.0	1648.5	1586.2	1689.1	2723.8	3328.0
Population sex ratio (males per 100 females)	97.7	98.8	99.2	97.8	99.7	99.9
Percentage aged 0–4 (%)	6.2	4.8	4.4	6.7	5.3	4.9
Percentage aged 5–14 (%)	13.3	10.2	9.4	13.8	11.2	10.4
Percentage aged 15–24 (%)	13.1	10.7	10.3	15.6	11.8	11.2
Percentage aged 65 or over (%)	13.5	26.2	29.8	10.9	21.3	25.2

Table 2
The YLDs for *Salmonella* infections in South Australia and Brisbane: 2000, 2030 and 2050.

Scenarios		Total	Male	Female
2-1: South Australia				
2000		54	27	27
2030	Increasing temperature	56 ~ 72	28 ~ 36	28 ~ 36
	Increasing temperature and population change	59 ~ 80	30 ~ 40	29 ~ 40
2050	Increasing temperature	58 ~ 84	29 ~ 43	29 ~ 41
	Increasing temperature & population change	71 ~ 101	36 ~ 52	35 ~ 49
2-2: Brisbane				
2000		53	28	25
2030	Increasing temperature	58 ~ 83	30 ~ 44	28 ~ 39
	Increasing temperature and population change	80 ~ 106	42 ~ 56	38 ~ 50
2050	Increasing temperature	85 ~ 109	44 ~ 56	41 ~ 53
	Increasing temperature and population change	99 ~ 129	51 ~ 68	48 ~ 61

The increasing trend in the morbidity burden from *Salmonella* infection appears similar in temperate and subtropical regions in Australia. Although most studies on climate–health relationship address the potential adverse impacts in tropical or subtropical areas, this study indicates that temperate regions, with relatively mild climate conditions, may suffer a similar magnitude of extra health burden from enteric infections due to future climate change. This is of significance for local and national health policies for enteric infection control and prevention.

Children have been and will be most affected by *Salmonella* infection in Australia. Although children living in developed countries enjoy better health and safer living conditions than those living in developing countries, they are not exempt from both the effects of unsafe and unhealthy environments and from global warming. In Queensland, for example, almost half (47%) of the notifications of *Salmonella* infections occur in children under 5 years (Queensland Health, 2001). Despite the decline in diarrheal mortality, diarrhea remains one of the principal causes of morbidity and mortality among children (Kowek et al., 2003). The burden of disease attributable to selected environmental factors and injury among children and young people has been investigated in Europe (Valent et al., 2004). However, global warming was not included as an environmental risk factor in that analysis. Population growth combined with rising temperature may have an enhanced impact on the future burden of *Salmonella* infection.

Similar to those in other burden of disease studies, this analysis also has uncertainties inherent in the methods and scenarios. The method of calculation of DALYs, including YLLs and YLDs, has been widely adopted by national and global burden of disease studies for both chronic and infectious diseases, although weaknesses and problems still exist (Murray and Acharya, 1997; Mathers et al., 1999; WHO, 2004). The WHO estimated 1,459,000 DALYs of diarrhea attributable to climate change in 2000 (WHO, 2004). It is important to estimate morbidity (YLDs) in burden of infectious disease studies, particularly for those infectious diseases that have few deaths and high incidence or prevalence, such as diarrhea. The estimation of morbidity burden is more complex and difficult, compared to using mortality as the indicator of health status. Rather than simply measuring the number of deaths, there are many ways of measuring the morbidity burden, e.g. incidence, prevalence or number of days with disability (Zhang et al., 2007). In addition to age- and sex-specific morbidity data, it is necessary to obtain incidence, duration and severity of focused diseases to calculate YLDs (Murray and Lopez, 1996). In the field of environmental burden of disease studies, especially in the estimation of the effects of climate change on population health, studies conducted among various populations in diverse

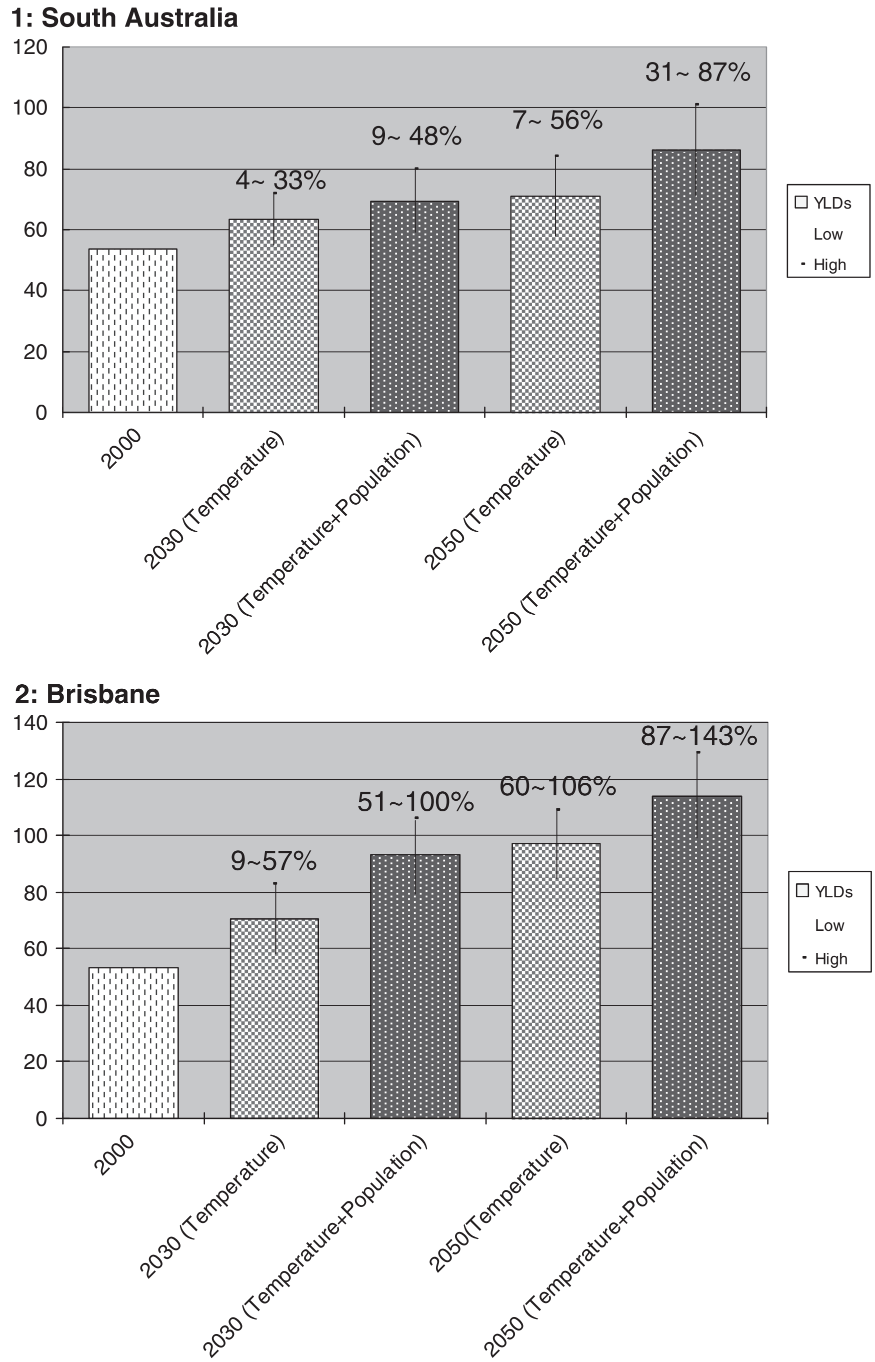

Fig. 1. Projected YLDs for *Salmonella* infections in South Australia and Brisbane.

climatic regions may enhance the validity of the estimation of climate-related burden of disease.

There are some other limitations of this study. Firstly, underreport of food-borne diseases in the communicable disease surveillance system is not uncommon. It is estimated that for every 100 notified cases *Salmonella* infection in the Australian, approximately 695 cases occurred in the community are not reported (Hall et al., 2008). Estimates of the burden of disease would be much higher given that around 85% of Salmonella cases are not reported. However, the undercount of cases would not affect our estimated increasing trend in the projected YLDs with the assumption that the rate of underreport remain unchanged over the projection period. In addition, potential sequelae for *Salmonella* infection, such as irritable bowel disease, or reactive arthritis, have not been analyzed in this study. It is mainly because that these conditions could be from either *Salmonella* infection or other gastroenteritis e.g. *Campylobacter* infection, which would make the results very difficult to interpret. However, we recognized that the projected health burden from *Salmonella* infection would be underestimated without considering its sequelae. Moreover, mortality burden in terms of YLLs due to *Salmonella* infection has been left out, with the consideration of the very low number of deaths attributable to *Salmonella* infection in the study areas. Although excluding of YLLs would not significantly affect our results, particularly the increasing trends in the projected health burden, it is recognized that the underlying cause of death due to *Salmonella* infection or other diarrheal diseases could always be underestimated clinically, which would make the real burden of disease for *Salmonella* infection higher than our estimation.

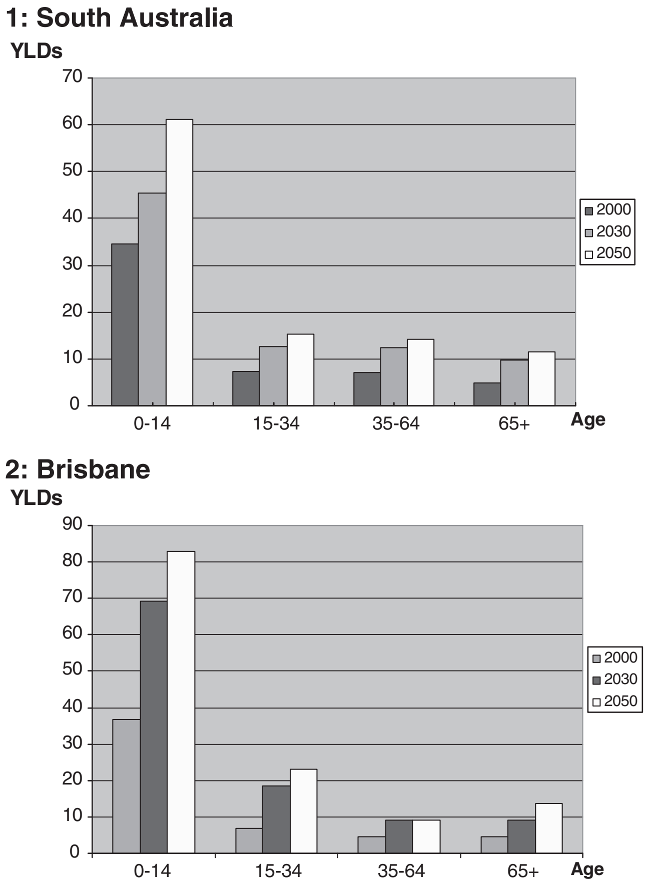

Fig. 2. Projected YLDs for *Salmonella* infections by age in South Australia and Brisbane under scenarios of increasing temperature and changing population.

Regardless of the above discussed limitations, this study has presented evidence for the potential of a consistent increasing trend in the burden of enteric infection caused by future climate and demographic changes in different Australian local regions with various climatic characteristics, which has significant policy implications for governments, health practitioners and local communities. It is not only for current but also for future generations that public health strategies that incorporate preventive measures and responses to extra health burden associated with climate change should be developed.

As an environmental risk factor, climate change seems to make less of a contribution to population burden of disease than other risk factors. For example, tobacco smoking is the risk factor responsible for the greatest burden of disease including chronic diseases in Australia. It was responsible for the loss of about 227,000 Disability Adjusted Life Years (DALYs) in 1996 in Australia (Mathers et al., 1999). However, this could be because that climate change has been emerging risk factors recently and there have been no sufficient studies to identify the health burden attributable to climate change. Furthermore, the aim of this estimate is not to inform priority setting among risk factors but to call for action to moderate any possible increasing burden related to climate change. However, unlike other risk factors that can be controlled or prevented, exposure to climate change is inevitable, accelerated, global, long-term (up to several centuries) and involves complex interactions among climatic, environmental, economic, political, social and technological processes (Kovats and Haines, 2005; Patz et al., 2005). Therefore, necessary adaptation and mitigation strategies should be taken at an early stage.

In conclusion, an increasing trend in the health burden of *Salmonella* infection related to climate change has been projected in different climatic regions in Australia, if other factors remain constant. Indeed, the extra burden of disease caused by future climate change would be much higher than the estimates given in this study if all other climate-related enteric infections are included. This study will be useful for consideration in the development of sustainable health policies for the next decades in a changing environment.

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References

Abelson P, Forbes MP, Hall G. The annual cost of foodborne illness in Australia. Canberra: Australian Government Department of Health and Ageing; 2006.
Checkley W, Epstein LD, Gilman RH, et al. Effects of El Niño and ambient temperature on hospital admissions for diarrhoeal diseases in Peruvian children. Lancet 2000;355(9202):442–50.
D'Souza R, Becker N, Hall G, Moodie K. Does ambient temperature affect foodborne disease? Epidemiol Infect 2004;15:86–92.
Hall G, Yohannes K, Raupach J, Becker N, Kirk M. Estimating community incidence of Salmonella, Campylobacter, and Shiga toxin-producing *Escherichia coli* infections, Australia. Emerg Infect Dis 2008;14(10):1601–9.
Kovats R, Edwards S, Hajat S, et al. The effect of temperature on food poisoning: a time-series analysis of salmonellosis in ten European countries. Epidemiol Infect 2004;132:443–53.
Kovats RS, Haines A. Global climate change and health: recent findings and future steps. CMAJ 2005;172:501–2.
Kowek M, Bern C, Guerrant RL. The global burden of diarrhoeal disease, as estimated from studies published between 1992 and 2000. Bull World Health Organ 2003;81(3):197–204.
Mathers C, Vos T, Stevenson C. The burden of disease and injury in Australia. Canberra: Australian Institute of Health and Welfare; 1999.
Murray C, Acharya AK. Understanding DALYs. J Health Econ 1997;16:703–30.
Murray C, Lopez A. The global burden of disease. Geneva: World Health Organization; 1996.
OzFoodNet Working Group. Reported foodborne illness and gastroenteritis in Australia: annual report of the OzFoodNet network, 2004. Commun Dis Intell 2005;29:164–90.
Patrick M, Christiansen L, Wain M, Ethelberg S, Madsen H, Wegener H. Effects of climate on incidence of Campylobacter spp. in humans and prevalence in broiler flocks in Denmark. Appl Environ Microbiol 2004;70(12):7474–80.
Patz JA, Campbell-Lendrum D, Holloway T, Foley JA. Impact of regional climate change on human health. Nature 2005;438:310–7.
Pike A, Baade P, Harper C, Muller S, Kennedy B. Quantifying the burden of disease and injury in Queensland 1996–1998. Inf Circ Qld Health 2002;61:1-11.
Pittock B, editor. Climate change: an Australian guide to the science and potential impacts. Canberra: Commonwealth of Australia; 2003.
Preston BL, Jones RN. Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions. The Commonwealth Scientific and Industrial Research Organisation (CSIRO); 2006.
Queensland Health. Notifiable diseases report 1997–2001; 2002.
Rose JB, Epstein PR, Lipp EK, Sherman BH, Bernard SM, Patz JA. Climate variability and change in the United States: potential impacts on water- and foodborne diseases caused by microbiologic agents. Environ Health Perspect 2001;109(Suppl. 2):211.
South Australian Department of Health. South Australian burden of disease study. Accessed 6 May 2004. Available from: http://www.health.sa.gov.au/burdenofdisease/DesktopDefault.aspx.
Tam C, Rodrigues L, O'Brien S, Hajat S. Temperature dependence of reported Campylobacter infection in England, 1989–99. Epidemiol Infect 2006;134(1):119–25.
Valent F, Little D, Bertollini R, Nemer L, Barbone F, Tamburlini G. Burden of disease attributable to selected environmental factors and injury among children and adolescents in Europe. Lancet 2004;363:2032–9.
WHO. Comparative quantification of health risks. Volume 2, Chapter 20: Global climate change. 2004. Avalable from http://www.who.int/healthinfo/global_burden_disease/cra/en/index.html.
Zhang Y, Bi P, Hiller JE. Climate change and disability adjusted life years. J Environ Health 2007;70:32–6.
Zhang Y, Bi P, Hiller JE. Climate variations and salmonellosis transmission: a comparison of regression models. Int J Biometeorol 2008;52:179–87.
Zhang Y, Bi P, Hiller JE. Climate variations and Salmonella infection in Australian subtropical and tropical regions. Sci Total Environ 2010;408:524–30.