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Assessing the effect of climate factors on childhood diarrhoea burden in Kathmandu, Nepal

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ABSTRACT

Introduction: This study was undertaken to assess the effect of climate variability on diarrhoeal disease burden among children under 5 years of age living in Kathmandu, Nepal. The researchers sought to predict future risk of childhood diarrhoea under different climate change scenarios to advance the evidence base available to public health decision-makers, and the Nepalese infection control division, in planning for climate impacts.
Methods: A time series study was conducted using the monthly case count of diarrhoeal disease (2003–2013) among children under 5 years of age living in Kathmandu, Nepal. A quasi Poisson generalised linear equation with distributed lag linear model was fitted to estimate the lagged effect of monthly maximum temperature and rainfall on childhood diarrhoea. The environmental framework of comparative risk assessment was used to assess the environmental burden of diarrhoea within this population.
Results: A total of 219,774 cases of diarrhoeal disease were recorded during the study period with a median value of 1286 cases per month. The results of a regression model revealed that the monthly count of diarrhoea cases increased by 8.1% (RR: 1.081; 95% CI: 1.02–1.14) per 1 °C increase in maximum temperature above the monthly average recorded within that month. Similarly, rainfall was found to have significant effect on the monthly diarrhoea count, with a 0.9% (RR; 1.009; 95% CI: 1.004–1.015) increase in cases for every 10 mm increase in rainfall above the monthly cumulative value recorded within that month. It was estimated that 7.5% (95% CI: 2.2%–12.5%) of the current burden of diarrhoea among children under 5 years of age could be attributed to climatic factors (maximum temperature), and projected that 1357 (UI: 410–2274) additional cases of childhood diarrhoea could be climate attributable by the year 2050 under low-risk scenario (0.9 °C increase in maximum temperature).
Conclusion: It is estimated that there exists a significant association ($p < 0.05$) between childhood diarrhoea and an increase in maximum temperature and rainfall in Kathmandu, Nepal. The findings of this study may inform the conceptualization and design of early warning systems for the prediction and control of childhood diarrhoea, based upon the observed pattern of climate change in Kathmandu.

1. Introduction

Diarrhoea remains a leading cause of death among children under 5 years of age. In 2015, 1.31 million diarrhoea-related deaths were reported globally, and diarrhoeal disease represents the second major cause of death among children under 5 years in low and middle-income countries (Troeger et al., 2017; Walker et al., 2013). The average total societal cost of diarrheal disease treatment in low and middle-income countries has been estimated to be as high as US$101 per episode in Rwanda, and US$ 67.81 in Bangladesh (Ngabo et al., 2016; Sarker et al., 2018). In the context of Nepal, the financial burden borne by a family due to childhood diarrhoea is undetermined but can be speculated to be calamitous.

Evidence suggests that the onset and transmission of diarrhoeal disease can be influenced by many factors including climatic parameters such as rainfall and temperature (Checkley et al., 2000; Hashizume et al., 2007; Lama et al., 2004; Onozuka et al., 2010; Singh et al., 2001). During extreme weather events such as floods and hurricanes, water sources can become contaminated with micro-organisms including bacteria (e.g.: Salmonella, *Shigella, Escherichia coli, Campylobacter, Vibrio cholerae),*

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viruses (e.g.: Rotavirus, Norovirus, Adenovirus) and protozoa (e.g.: *Giardia*, *Cryptosporidium*, *Cyclospora*) that are capable of causing gastrointestinal infections (Bronstert, 2003; Reacher et al., 2004). An increase in temperature is likely to have a direct effect on the spread of diarrhoeal diseases by altering their geographical distribution and encouraging bacterial growth (Patz et al., 2003).

A national report on climate change vulnerability in Nepal projects that the mean annual temperature of Nepal will increase by 0.5 °C to 2.0 °C with a multi-model mean of 1.4 °C by the 2030s, and 1.7–4.1 °C with a multi-model mean of 2.8 °C by the 2060s, under a high emission scenario (the 'A2 scenario' used in the third assessment report by the Intergovernmental Panel on Climate Change (IPCC) (NCVST, 2009). Indeed, the 5th assessment report of the IPCC has predicted an increase in the magnitude of extreme weather events (including flood, drought and heat waves) due to the effect of anthropogenic and natural climate change, which in turn is likely to result in an increased prevalence of diarrhoeal disease (Hartmann et al., 2013).

Kathmandu city has a high population density (4416 people per square kilometre) (Central Bureau of Statistics, 2012) and faces an acute shortage of potable water during hot and dry summer months owing to the water demands of the increasingly populated Kathmandu valley (Thapa et al., 2017). According to Nepalese Government estimates, in 2014, 83.59% of the total population in Nepal had access to basic water supply services, and 70.28% had access to basic sanitation facilities (National Management Information Project (NMIP), 2014), although data specific to Kathmandu city were not available. Under such conditions, people are compelled to consume unsafe water leading to an increased susceptibility to diarrhoeal diseases (Boithias et al., 2016). Rutkowski et al. (2007) have reported a widespread use of pathogen-contaminated wastewater for irrigation purposes in Kathmandu city and its outskirts during dry seasons of low rainfall. Residents' consumption of vegetables and crops irrigated with waste water can pose a potential risk factor for infective gastroenteritis (Shrestha et al., 2017). Moreover, for developing countries like Nepal, climatic variations and employment opportunities are likely to drive migration of people into urban centres (Bohra-Mishra et al., 2014). Internal migration can lead to an increase in urban density, exacerbating already poor living conditions and the risk of transmission of diarrhoeal diseases among vulnerable populations (Boithias et al., 2016).

Compared to the adult population, children are more vulnerable to the effect of adverse environmental challenges caused, or aggravated by, climate change (Stanberry et al., 2018). During the aftermath of hurricane Maria in Puerto Rico in 2017, for instance, an upsurge of infective gastroenteritis was reported among children (Stanberry et al., 2018). Musengimana et al. (2016), reported a 32% increase in diarrhoea among children under five years of age in Cape Town, South Africa for every 5 °C increase in maximum temperature. Given the higher vulnerability of children to the effects of global climate change, and susceptibility to diarrhoeal diseases (Xu et al., 2012), there remains an increasing concern over the endemicity of diarrhoeal diseases in low income countries like Nepal.

In light of these concerns, the current study was undertaken to assess the effect of climate variability on diarrheal diseases among children under 5 years of age living in Kathmandu Nepal and to predict future climate-attributable diarrhoea burden. The study seeks to advance the evidence for health policy decision-makers by assessing the risk of childhood diarrhoea under current and future climate change scenarios in Kathmandu.

2. Methods

2.1. Data source

Kathmandu district is situated at an average elevation of 1400 m (4600 ft) above sea level and lies in a warm, temperate zone characterised by a subtropical highland climate (Fig. 1). According to the 2011 national census, the total population of Kathmandu district was 1,744,240 with a population density of 4416 persons per square kilometre (Central Bureau of Statistics, 2012), which was 30 times higher than the total population density of the country at that time. Based upon the National Census of 2011, and data from the 2011 National Living Standard Survey, the Human Development Index (HDI) for Kathmandu district was estimated to be 0.632, which is below the average value of living standards of South Asian countries (Government of Nepal National Planning Commission, 2014).

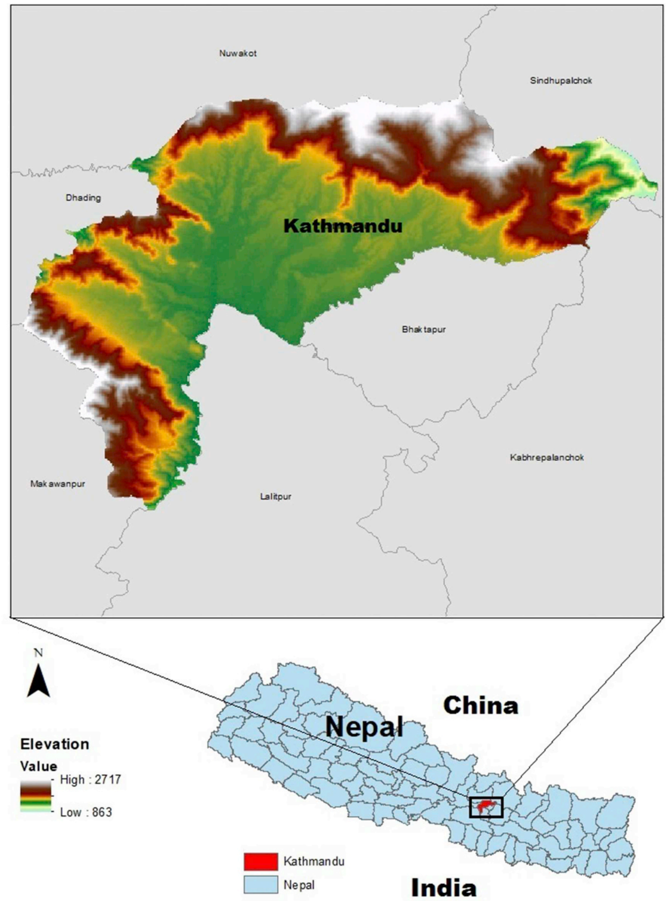


Fig. 1. Map of Nepal showing the study site, Kathmandu district.

This study included monthly reported infectious diarrhoea cases among the children under 5 years of age living within Kathmandu district, the capital city of Nepal, over a 10 year period (2003–2013). Data on the monthly count of diarrhoeal disease were obtained from the Health Management Information System (HMIS), Department of Health Services (DoHS), Ministry of Health and Population, Nepal. HMIS was established in 2000 and has been effectively managing health service information from all levels of health service delivery, including services provided by Female Community Health Volunteers and community level health workers to the tertiary care hospitals in Nepal.

Clinical facilities in Nepal adhere to the operational definition of diarrhoea as the passage of three or more liquid stools per day (or more frequent passage than is normal for the individual), as a result of an infection in the intestinal tract caused by bacterial, parasitic or viral organisms (Department of Health Services, 2014). The HMIS dataset does not record details of the specific diarrheagenic pathogens by which population members (children under 5 years of age) have been infected. As such, our analysis included the aggregated monthly diarrhoea count as the outcome variable in our regression model during the data analysis.

Daily climate data from Kathmandu district were obtained from the Department of Hydrology and Meteorology, Nepal and monthly means for maximum and minimum temperature, relative humidity and rainfall were calculated from the daily records. We used data from Kathmandu Airport station for completeness and to obtain a wider range of coverage for the study location. Demographic data for Kathmandu district were obtained from the central Bureau of Statistics, Nepal. Data from the last census (2011) were used for the purpose of the study.

2.2. Statistical analysis

2.2.1. Modelling the relationship between maximum temperature, rainfall and childhood diarrhoea

Pearson's correlation analysis was carried out to assess the association between monthly diarrhoeal count and climate variables including monthly minimum temperature, maximum temperature, mean temperature, relative humidity and rainfall. Monthly maximum temperature and rainfall were used to estimate the relationship between temperature variability and diarrhoea count due to the positive correlation of these factors with diarrhoea. We conducted a time series analysis to examine the relationship between monthly diarrhoeal count, monthly average maximum temperature and total monthly rainfall using a generalised linear Poisson regression model, allowing for overdispersion. Seasonality and long term effects not directly related to weather were adjusted in the model using natural cubic splines with four knots per year (degree of freedom (df) = 40) (Supplementary Fig. S1). A linear relation was assumed between the maximum temperature and diarrhoeal disease above its monthly average temperature, and the lag effect was modelled using unconstrained distributed lag linear model using the DLNM package in software R (Gasparrini, 2011). Guided by the prior research on the effect of climate variability on diarrhoeal diseases, and based upon the result of correlation analysis at different lag periods (Table 1), we set a lag period up to 1 month to assess the delayed effect of maximum temperature and rainfall (Checkley et al., 2000; Hashizume et al., 2007; Singh et al., 2001). The confounding effect of relative humidity was adjusted in the model by including a natural cubic spline (df = 3). In summary, the final model took the following form:

$$\text{Log}\ [E(y)] = \alpha + \beta_1\ (\text{cbo\_max\_temp}) + \beta_2\ (\text{cbo\_rainfall}) + \text{NS}\ (\text{mean\_rh}, df = 3) + \text{NS}\ (\text{time}, df = 40)$$

where [E(y)] is the expected monthly case count, cbo_max_temp is the cross basis matrix for mean monthly maximum temperature, cbo_rainfall is the cross basis matrix for mean monthly rainfall, $\beta 1$ & β_2 are their respective regression coefficients, NS (mean_rh) is the monthly mean relative humidity with natural cubic spline of 3 degree of freedom, and NS (time) is the natural cubic spline of time with 4 degree of freedom per year.

2.2.2. Calculating climate-attributable risk for diarrhoea and projecting the future attributable burden

Firstly, we calculated the potential impact fraction (PIF) to assess the proportional reduction in childhood diarrhoea burden, assuming a counterfactual situation in which the study population experience the least exposure to increased temperature under the current climate scenario. We used the environmental framework of comparative risk assessment developed by World Health Organization (WHO) for assessing the environmental burden of diseases to compute PIF(Prüss-Üstün et al., 2003).

$$\text{PIF} = (\Sigma\ P_i\ RR_i - \Sigma P_i{}^* RR_i)/\Sigma P_i RR_i$$

where P_i is the proportion of the population in exposure group i, P_i* is the proportion of the population in the exposure group under a counterfactual situation, RR_i is the relative risk for the exposure group.

Assuming the counterfactual situation of least exposure, the above PIF can be calculated using a simplified formula,

$$\text{PIF} = \Sigma\ P_i\ RR_i\text{-}1/\Sigma P_i RR_i$$

We then estimated the future climate change-attributable increase in diarrhoea burden for Kathmandu district using the formulae adapted by the WHO for their climate-related quantitative risk assessment of disease morbidity study (Kovats and Lloyd, 2014).

$$n = N\ (\exp^{(\beta * \Delta\ T)} - 1)\ /\ \exp^{(\beta * \Delta\ T)}$$

where n is the number of climate change-attributable average annual cases of diarrhoea, N is the total average annual baseline (current) diarrhoeal count, Δ T is the future change in temperature for various climate change scenarios, and β is the log linear increase in diarrhoea per 1 °C rise in temperature.

2.2.3. Sensitivity analysis

Sensitivity of the model was analysed by changing the degree of smoothing (knots per year), in time splines and lag periods (0, 1 and 2 months) for both rainfall and maximum temperature. The model with lowest qAIC value was selected as the robust model (Supplementary Table S1) and used to project the climate-attributable increase in diarrhoea under future climate change scenarios. Further, the robustness of the model was tested by checking the residual autocorrelation plot and distribution of the residuals (Supplementary Figs. S2 and S3).

Table 1
Pearson's correlation coefficient of the diarrhoea and maximum temperature at different lag periods.

Climate variables	Pearson's correlation coefficient (r)	p-value
Maximum temperature (Lag 0)	0.7591	< 0.001
Maximum temperature (Lag 1)	0.5465	< 0.001
Maximum temperature (Lag 2)	0.2795	< 0.001
Rainfall (Lag 0)	0.6832	< 0.001
Rainfall (Lag1)	0.3169	< 0.001
Rainfall (Lag 2)	−0.1124	0.199

3. Results

A total of 219,774 cases of diarrhoea were recorded among the children under 5 years of age living in Kathmandu district during the study period from 2003 to 2013. The monthly average diarrhoeal case-count for this population reported during the study period was 1665 (Table 2). Seasonal distribution of the diarrhoeal cases showed a higher burden between the months of June–August (Fig. 2).

3.1. Relationship with maximum temperature

We estimated an 8.1% (RR: 1.081; 95% CI: 1.02–1.14) increase in risk of diarrhoea cases among children under 5 years of age per 1 °C increase in maximum temperature above the monthly average recorded within that month. (Fig. 3). The effect of maximum temperature on diarrhoea was not significant at the lag period of 1 month (refer to Supplementary Fig. S4 for the estimated relationship between mean temperature and diarrhoea).

3.2. Relation with rainfall

We estimated a 0.9% (RR; 1.009; 95% CI: 1.004–1.015) increase in risk of diarrhoea cases among children under 5 years of age per 10 mm increase in rainfall above the monthly cumulative value recorded within that month (Fig. 3). Similar to the effect of maximum temperature, the effect of rainfall was not significant at the lag period of 1 month.

3.2.1. Estimation of current potential impact fraction (PIF) and climate attributable diarrhoea burden

According to the National Census carried out in the year 2011, the total population of Kathmandu district was 1,744,240 and the

Table 2
Distribution of meterological data (monthy average) and diarrhoeal count in children under 5 years in Kathmandu district 2003–2013.

Study variables	Lowest	1st quartile	Median	Mean	3rd quartile	Highest
Maximum temperature (° C)	17.46	23.28	28.08	26.33	29.25	31.91
Rainfall (mm)	0	15.45	73.05	149.94	261.52	735.70
Relative humidity (%)	58.03	72.75	78.72	76.73	82.40	90.21
Under 5 Diarrhoeal count	100	621	1286	1665	2676	4232

population of children under five years of age was 111,600 (Central Bureau of Statistics, 2012). We assumed all children under 5 years of age were exposed to the risk factor (maximum temperature), and estimated the potential impact fraction to be 0.075. We estimated, 7.5% (95% CI: 2.2%–12.5%) of the current burden of diarrhoea among children under 5 years of age to be attributable to the climatic factor (maximum temperature).

3.3. *Projection of climate-attributable diarrhoea count in future climate change scenarios*

We conducted a literature search to identify studies that have projected future increases in maximum temperature for Kathmandu district under different climate change scenarios (Supplementary Table S2), and used the estimated increase in temperature range (0.5 °C to 3.7 °C) for different time slices under future climate change scenarios (Table 3). We calculated the mean annual count of diarrhoea in children under 5, taking the summation of monthly diarrhoea counts for each year (2003–2013), and estimated the baseline diarrhoeal count to be 20,019. Due to the unavailability of data on the projected population of children under 5 years of age in the Kathmandu district, we assume no significant change in study population when projecting the future burden. Under the low risk scenario and the most conservative estimate, we projected 766 (228–1297) (refer to Supplementary Table S3 for calculation details) additional annual diarrhoea cases attributable to climate change by the year 2020 (Fig. 4).

4. Discussion

This study is one of the few epidemiological studies conducted in Kathmandu, Nepal that uses the national disease surveillance dataset to comprehensively quantify the association between childhood diarrhoea and climate variability after adjusting for the long-term effects and seasonal pattern of the disease. The findings of our study showed that the onset and distribution of diarrhoea among children under 5 years of age in Kathmandu, Nepal is highly associated with climate variability. We estimated that an increase in both maximum temperature and rainfall intensity is likely to increase the burden of climate change-attributable childhood diarrhoea in Kathmandu for different projected time slices in future.

The positive association between diarrhoea incidence and temperature observed in our study mirrors the findings of similar studies conducted in Asia, Pacific islands and Latin America, which have reported a 5%–13% increase in diarrhoea cases per 1 °C increase in ambient temperature (Checkley et al., 2000; Hashizume et al., 2007; Kolstad and Johansson, 2011; Onozuka et al., 2010; Singh et al., 2001; Zhang et al., 2008b). These studies, however, used weekly or daily mean temperature as a predictor variable, compared to maximum temperature as used in our study. We used daily maximum and minimum temperature data to compile monthly average temperature measures, which may fail to capture the discrete effect of extreme short-term variability in temperature, and may harmonize the effect of diurnal or weekly variability in the maximum temperature measure. Despite the use of a different temperature index, the significant association observed between maximum temperature and diarrhoea count in our study resonates with findings of studies from Pacific islands, Latin America and other Asian countries (Checkley et al., 2000; Hashizume et al., 2007; Onozuka et al., 2010; Singh et al., 2001). Along with mean temperature, maximum temperature is also considered a suitable index of temperature exposure, and has been increasingly used as the index of choice by epidemiologists in recent years (Milazzo et al.,

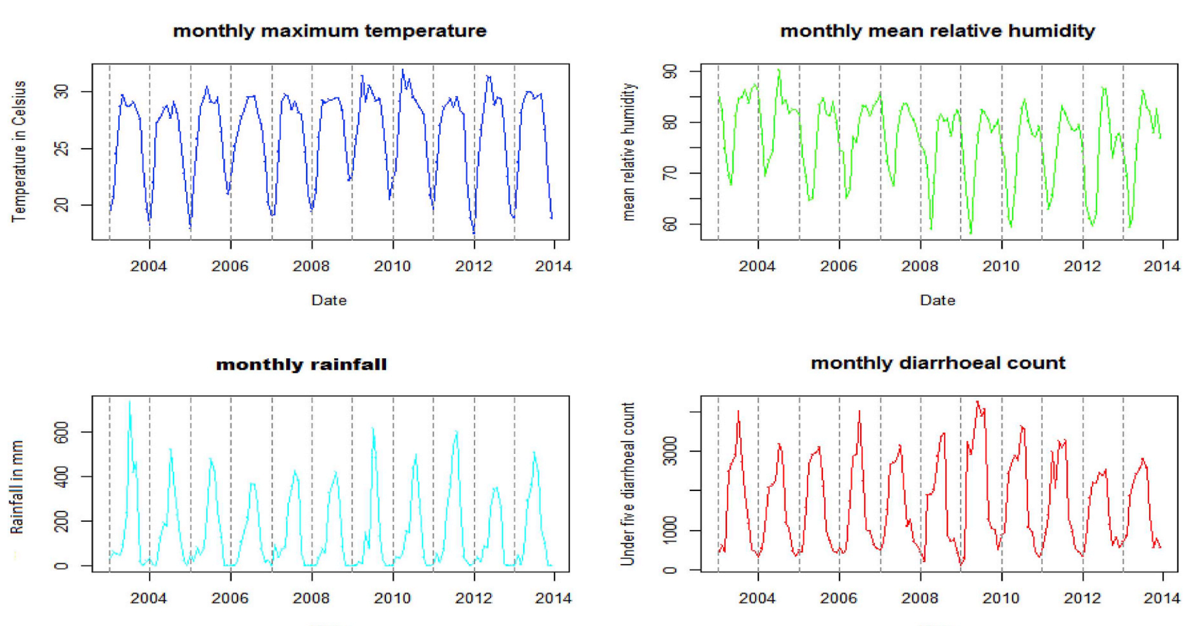
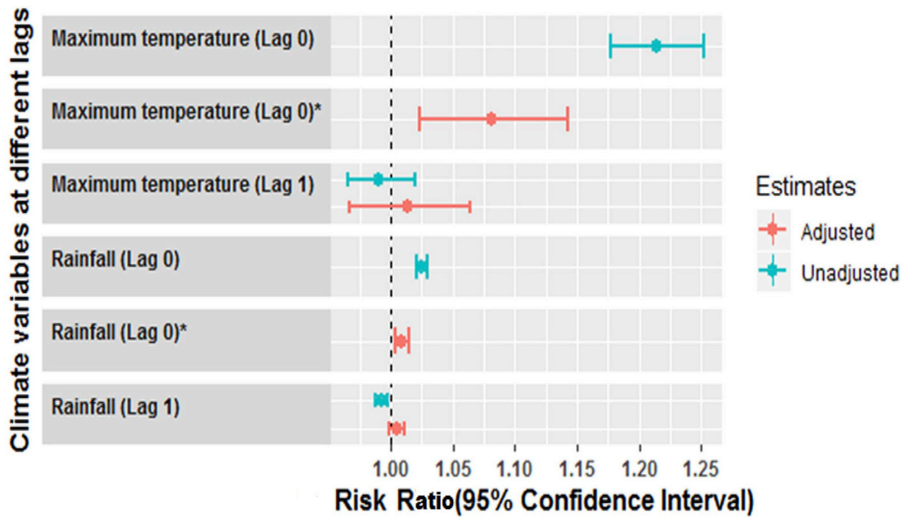


Fig. 2. Trend of meteorological data and monthly diarrhoeal count in children under 5 in Kathmandu district 2003-2013
*Note:Adjusted relation indicates all the climate variables that were included in the model and adjusted for seasonality, long term variation and the effect of relative humidity; CI: confidence interval; *p value significant at < 0.05.*



*Note:Adjusted relation indicates all the climate variables that were included in the model and adjusted for seasonality, long term variation and the effect of relative humidity; CI: confidence interval; *p value siginificant at <0.05.*

Fig. 3. Effect estimates of maximum temperature and rainfall on monthly diarrhoea cases at different lag periods showing crude and adjusted relationship.

2015; Xiang et al., 2014). Barnett et al. (2010), in their seminal paper entitled "What measure of temperature is the best predictor of mortality?" have concluded that the choice of temperature measure between mean and maximum temperature can be made on the basis of practical concern as these indices have the same predictive ability in terms of exposure risk estimation. We observed an immediate effect of temperature increase on childhood diarrhoea in our study, which can be explained by the fact that the incubation period for most of the entero-pathogens is under a few weeks (Shane et al., 2017). Our findings indicate a low risk effect of maximum temperature on diarrhoea incidence beyond the lag period of 1 month, which is consistent with the findings of previous works from Bangladesh, Japan and Australia (Hashizume et al., 2007; Onozuka and Hashizume, 2011; Zhang et al., 2008a). Our study did not include the adult population, however a study from Bangladesh has reported a lack of evidence on the differential effects of temperature on diarrhoea incidence by individual characteristics such as age and gender (Hashizume et al., 2007). Although an overall nonsignificant effect of diarrhoea risk and age was reported in the study, their age-stratified analysis did show a significant increment in risk of diarrhoea among children in the age group < 14 years compared to the age group > 30 years. Compared to the adult population, children can be assumed to be more vulnerable to diarrhoeal risk under climate change owing to their comparatively weaker immune system and lack of control over their exposure to contaminants, potential pathogens and other risk factors (Stanberry et al., 2018).

Several plausible explanations have been proposed to elucidate the underlying mechanisms affecting the association between an increase in temperature and higher onset and transmission of diarrhoea (Levy et al., 2016). Diarrheagenic pathogens such as *Shigella,* spp. have been reported to express virulent gene coding for toxin-causing inflammation of intestinal linings resulting in fluid loss in response to the increase in temperature from 30 °C to 37 °C (Konkel and Tilly, 2000). Likewise, an increase in temperature may result in higher survival and increased load of diarrhoeagenic pathogens (especially, bacteria and protozoa) in their zoonotic host, facilitating the prolonged transmission of the pathogens (Lal et al., 2012). In addition, scarcity of water during dry summer months has been reported to facilitate transmission of waterborne diarrheagenic pathogens due to the compromised hygiene and altered feeding behaviours of the human host (Levy et al., 2016). Chronic scarcity of water in Kathmandu district during the dry summer seasons (Thapa et al., 2017) could be therefore be one factor contributing to the higher risk of diarrhoea during the period of increased maximum temperatures (Boithias et al., 2016). Likewise, compromised hygienic practice among the parents and care-givers during Kathmandu's dry and hot conditions might have favoured the increased transmission of pathogens to the children in our study. Although data on specific pathogens causing diarrhoea among children were not available, children below the age of 5 years have been reported to be more prone to infection with foodborne bacterial pathogens such as *Salmonella* spp., *Escherichia coli, Norovirus* genogroup I (GI) and II (GII) and *Campylobacter* when the ambient temperature is high (Bentham and Langford, 2001; Randazzo et al., 2018; Sockett and Rodgers, 2001), leading to increased hospitalization due to diarrhoea. In the context of Nepal, the diagnostic laboratories at public hospitals and community health care centres are generally not funded financially to test the viral aetiology of diarrhoea on a routine basis. Nor are pathology labs at community health care centres well equipped to carry out routine analysis of stool samples for the viral aetiology of diarrhoea. As such, cases of Rotavirus, Norovirus and other viruses causing childhood diarrhoea are under reported, which might have resulted in the distinct summer peak (Fig. 1) of diarrhoea in our study compared to the bimodal distribution (summer and winter peak) of diarrhoea reported in some other studies analysing the effect of climate variation on paediatric diarrhoea (Onozuka and Hashizume, 2011).

In addition to maximum temperature, our findings also revealed a significant association between monthly average rainfall and diarrhoea burden among the children in Kathmandu district, Nepal with an estimated, 0.9% increase in diarrhoea burden for every 10 mm increase in rainfall within the same month. This result is in concordance with studies conducted in Bangladesh and Mozambique which have reported 5.1%, and 1.04% increases in diarrhoea within four weeks of a heavy rainfall (Hashizume et al., 2007; Horn et al., 2018). Our estimate of a 0.9% increase with each 10 mm increase in rainfall is slightly lower than the findings of a study in Bangladesh (Hashizume et al., 2007). This may be explained by the fact that Dhaka has been reported to have experienced several diarrhoeal epidemics during flooding episodes caused by excessive rainfall in the context of a monsoon (Schwartz et al., 2006). Regular flooding in Dhaka plays an important role in the contamination of water sources with pathogenic bacteria, giving rise to a higher incidence of diarrhoea during heavy rainfall events when compared to Kathmandu district, which has not recorded severe

Table 3
Estimates of predicted temperature increase for Kathmandu valley informing projection of future increase in climate-attributable childhood diarrhoea under different climate change scenarios.

Study	Projection coverage	Climate model used	Scenarios	Baseline data used (years)	Projection years	Projected increase in temperature (ΔT in °C)		Remarks	Risk category
Babel et al. (2014).	Kathmandu district (Baghmati river Basin)	5 GCM tested and HadCM3 was selected because of best fit	A2 based on SRES	1970-1999	2020s	0.5		Projection made for maximum temperature and GCM was downscaled	Low risk
				1970-1999	2050s	1.1			
				1970-1999	2080s	2.1			
			B2 based on SRES	1970-1999	2020s	0.5			
				1970-1999	2050s	0.9			
				1970-1999	2080s	1.5			
NCVST (2009).	Nepal (central Nepal, which includes Kathmandu district)	15 GCMs with details of name of all the models used in projection and 2 RCM models (PRECIS and RegCM3)	A2 based on SRES, due to closest match to observe emission for region since 2000.			Nepal	Central Nepal	RCM model used to make projection for central Nepal, which includes Kathmandu district.	Medium risk
				1970-1999	2030s	1.4 (0.5-2)	1.4 (0.9-2)		
				1970-1999	2060s	2.8 (1.7-4.1)	3.0 (1.7-4.1)		
				1970-1999	2090	4.7 (3-6.3)	4.9 (3.0-6.3)		
Jha (2012).	Kathmandu valley	21 GCMS available in SimCLIM software and IPSL-CM40 used for projection	A1F1 based on SRES	1980-2009	2030s	1.8 – 1.9		Temperature type not mentioned	High risk
				1980-2009	2050	3.7 – 3.8			
				1980-2009	2100	9.3 – 9.7			

flooding for over 30 years. Rainfall can cause a flushing action, sending pathogens into surface and ground water sources through the infiltration of bacteria and protozoan oocysts deposited in soil by their zoonotic hosts and flushing out bacteria from fertilizers, leading to the contamination of water sources (Levy et al., 2016). This phenomenon has been previously reported for Kathmandu where, in addition to zoonotic sources, the seepage of waste water and the leakage of sewers from improperly constructed septic tanks have resulted in increased microbial contamination of water sources following the events of heavy rainfall (Shrestha et al., 2013).

We sought to quantify the burden of climate-attributable childhood diarrhoea in Nepal under future climate change scenarios for various time slices in the near (2030) and far future (2050). The outcomes of this study will serve to inform mitigation and adaptation policy in the management of the projected additional burden of childhood diarrhoea in Kathmandu under future climate change scenarios, as well as to inform strategies for resilience against the impacts of climate change. For the purposes of projecting climate change-attributable diarrhoea, we selected 3 different studies that have predicted the future increase in maximum temperature, under different climate change scenarios (Table 3), for Kathmandu district (Babel et al., 2014; Jha, 2012; NCVST, 2009). These studies were classified as low, medium and high risk based upon the results of the future climate projections for the study site. We also included the 50th percentile of the climate projection for the South Asian region (1.5 °C; 0.5–2 °C) under the Representative Concentration Pathway 2.6 (RCP), reported in the IPCC 5th assessment report (Hartmann et al., 2013), as a standard reference for the study region. To the best of our knowledge this is the first study that has attempted to project the future burden of climate-attributable diarrhoea among children. Our study estimated a substantial increase of 700–5000 cases of climate-attributable diarrhoea among children in the Kathmandu district in the near (2030) and longer-term (2050) future. This finding highlights the imperative that the infection control and prevention division in Nepal prepare and enhance their capacity to respond to the increased prevalence of diarrhoea, whilst underscoring the risk of future climate change-related health impacts on children (Xu et al., 2012). The United States Centre for Disease Control and Prevention (CDC) has developed the Building Resilience Against Climate Effect (BRACE) framework to assist health officials in the development of strategies and programs to protect public health against the adverse effects of climate change (Marinucci et al., 2014). Out of the five sequential steps advocated by the BRACE framework (vulnerability assessment, projection of disease burden, assessment of public health interventions, development and implementation of adaptation plans, and evaluation of the impact of interventions), 'projection of the disease burden' is key. We anticipate that our childhood diarrhoea burden projection estimates will facilitate health officials in Nepal to design the subsequent phases of BRACE framework for the control of climate-attributable childhood diarrhoea.

Our findings can be utilized to inform the conceptualization and design of early warning systems for the prediction and control of childhood diarrhoea in Kathmandu based upon the observed variation in climate patterns in this area. These results can support evidence-based decision-making around the existing childhood diarrhoea control program via the inclusion of climate change adaptation perspective. The inclusion of climate change adaptation measures can further improve the efficacy of the Control of Diarrheal Disease (CDD) program, implemented under the Integrated Management of Childhood Illness (IMCI) by the Child Health Division of Ministry of Health and Population, Nepal.

At the same time, these findings should be interpreted with caution given the caveats associated with the study. Firstly, data used in this study was monthly-aggregated data on diarrhoea among children under 5 years of age, which limits the possibility of estimating the precise short-term effect of the exposure-response relationship that may vary within the span of a day or a week. Secondly, weak surveillance systems

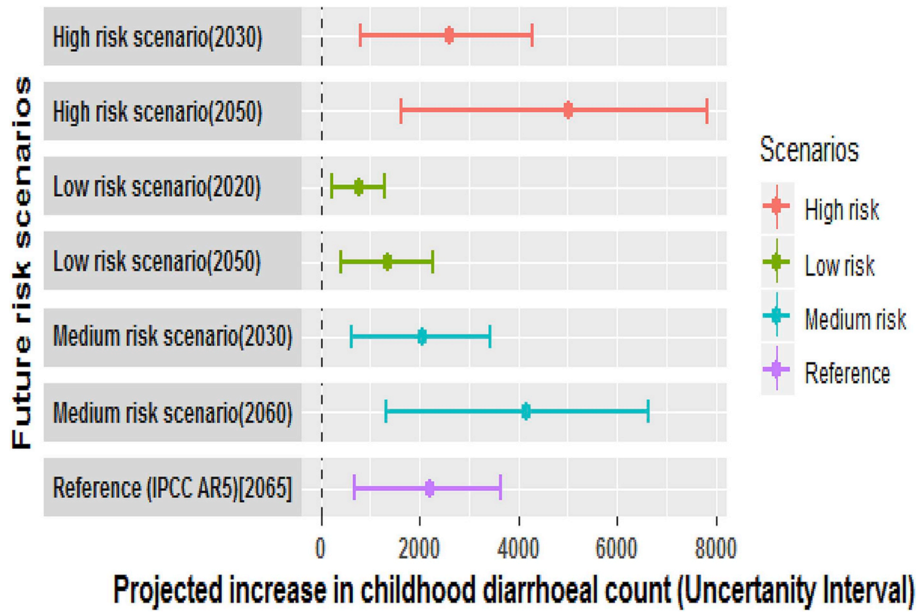


Fig. 4. Projected increase in diarrhoeal count attributable to cliamte change in children below 5 years of age. * Baseline annual count of diarrhoea used for prediction was 20,019 [calculated by summation of monthly diarrhoea count for each year (2003–2013.

in low and middle-income countries like Nepal can lead to an underestimation of the burden of disease due to under-reporting of cases, as well as a lack of the resources required to diagnose the precise aetiology of diarrhoea at the community level. Finally, the projection of diarrhoea counts was based on data published in peer reviewed studies that have made predictions with regard to future temperature changes, which might limit our ability to endorse their findings. In addition, these studies have used obsolete scenarios (SERS) in projecting future temperature increases, instead of the RCP-based scenarios endorsed by IPCC's 5th assessment report. Also, our assumption of no significant change in the study population during the estimation of disease projection may fail to reflect the role of change in population size, especially considering the massive demographic changes and mobility of people due to climate change.

In conclusion, our analysis demonstrated a strong association between diarrhoeal disease among children under 5 years of age and increases in maximum temperature and rainfall in Kathmandu, Nepal. Although these findings highlight the effect of regional climate impacts on childhood diarrhoea in Kathmandu, the precision of future predictions can be improved by analysing the short-term association between climate and disease data collected on a daily or weekly basis. Future research in environmental and infectious disease epidemiology in Nepal will produce impactful outcomes if disease morbidity and mortality data are reported on time, and systematically centralized in an electronic database and shared among researchers and policy makers.

Ethical consideration

The study was granted ethical approval by the Human Research Ethics Committee (HREC) of the University of Adelaide (H-2018-236), and the Nepal Health Research Council (Reg. no. 560/2018). Data related to human participants used in the study were non-identifiable and were analysed anonymously.

Conflicts of interest

We declare no conflict of interest.

Author's contribution

D.B: Research design, data curation, data analysis and manuscript preparation, P.B, J.B.S and S.H.E: Conceptualization, overall supervision and manuscript preparation; M.D: Data curation, conceptualization, manuscript preparation and overall supervision.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijheh.2019.09.002.

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