

Association between climate variability and hospital visits for non-cholera diarrhoea in Bangladesh: effects and vulnerable groups

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Background We estimated the effects of rainfall and temperature on the number of non-cholera diarrhoea cases and identified population factors potentially affecting vulnerability to the effect of the climate factors in Dhaka, Bangladesh.

Methods Weekly rainfall, temperature and number of hospital visits for non-cholera diarrhoea were analysed by time-series regression. A Poisson regression model was used to model the relationships controlling for seasonally varying factors other than the weather variables. Modifications of weather effects were investigated by fitting the models separately to incidence series according to their characteristics (sex, age, socio-economic, hygiene and sanitation status).

Results The number of non-cholera diarrhoea cases per week increased by 5.1% (95% CI: 3.3–6.8) for every 10 mm increase above the threshold of 52 mm of average rainfall over lags 0–8 weeks. The number of cases also increased by 3.9% (95% CI: 0.6–7.2) for every 10 mm decrease below the same threshold of rainfall. Ambient temperature was also positively associated with the number of non-cholera diarrhoea cases. There was no evidence for the modification of both ‘high and low rainfall’ effects by individual characteristics, while the effect of temperature was higher amongst those individuals at a lower educational attainment and unsanitary toilet users.

Conclusions The number of non-cholera diarrhoea cases increased both above and below a threshold level with high and low rainfall in the preceding weeks. The number of cases also increased with higher temperature, particularly in those individuals at a lower socio-economic and sanitation status.

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Diarrhoea is one of the principal causes of mortality and morbidity especially in developing countries. Some data suggest that 4 billion episodes of diarrhoea occurred each year, of which more than 90% occurred in developing countries.¹ Many investigations have reported seasonal coincidence of the peak of diarrhoea incidence with the rainy season in tropical regions.² However, these studies did not address the direct association between rainfall and diarrhoea allowing for the potential confounding by seasonally varying factors other than rainfall. Ambient temperature could also contribute to the incidence of diarrhoea.³ Clarifying the potential role of weather on the transmission of diarrhoeal diseases could help by bringing a deeper insight into the mechanisms of the seasonality of the disease. This study quantifies the impacts of rainfall and temperature on the number of non-cholera diarrhoea cases. Overall relationships of non-cholera diarrhoea are particularly focused on here because cholera has been known to have a strong link to weather factors,⁴ while that of the rest of diarrhoeal diseases is less clear.⁵ Population factors potentially affecting vulnerability to the effect of the climate factors are also examined. To have some insight into the causal pathways between rainfall and diarrhoea, the association with river levels was also investigated.

Methods

Hospital surveillance

The primary outcome in this study is the weekly number of patients visiting the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR,B) Dhaka Hospital due to non-cholera diarrhoea. The hospital serves an urban population of approximately 10 million individuals⁶ and provides free treatment to more than 100 000 cases of diarrhoea each year. Every 50th patient visiting the hospital has been enrolled in a surveillance system since 1996. For all patients enrolled in the surveillance, microbiological examination of stool or a rectal swab sample was conducted to identify enteric pathogens. The patient or family members were interviewed by health workers who collect socio-demographic data at the time of the hospital visits. We abstracted individual information on the date of the hospital visit, age, sex, socio-economic status (educational level and roof structure of the house), hygiene and sanitation practices (drinking water source, distance to the water source and type of toilet) and pathogens identified from stool specimen during a 7-year period (January 1996–December 2002). A patient was classified as non-cholera diarrhoea when *Vibrio cholerae* was not identified from the stool specimen. The cause of non-cholera diarrhoea was categorized as rotavirus, *Shigella*, *Salmonella*, *Campylobacter*, *Escherichia coli*, *Aeromonas* or other diarrhoea to show the components of non-cholera diarrhoea. *Salmonella* includes all *Salmonella* species except for *S. typhi*. *E. coli* consists of enterotoxigenic and enteropathogenic *E. coli*. Other diarrhoea

includes diarrhoea with none of pathogens identified. When two or more pathogens amongst these non-cholera pathogens were identified from the same stool specimen, the patient was classified in each category of pathogen-specific diarrhoea for pathogen-specific descriptive analysis. Parasites were also routinely examined during the study period including *Cryptosporidium parvum*, *Entamoeba histolytica* and *Giardia lamblia* of which the number of cases was small.

Meteorological and river-level data

We obtained daily rainfall and maximum and minimum temperature in Dhaka from the Bangladesh Meteorological Department. The daily river-level of the Brigonga River at Mill Barrack in Dhaka was recorded by the Bangladesh Water Development Board. The weekly means for maximum temperature and maximum river-level and the total weekly rainfall were calculated from the daily records.

Statistical analysis

Statistical methods are summarized here and described in detail in the supplementary online appendix. We examined the relationship of the number of weekly non-cholera cases with rainfall and temperature using generalized linear Poisson regression models allowing for overdispersion.⁷ To account for the seasonality of non-cholera counts not directly due to the weather, Fourier terms up to the sixth harmonic were introduced into the model. Indicator variables for the years of the study were incorporated into the model to allow for long-term trends and other variations between years. An indicator variable for public holidays was incorporated into the model to control bias in the event that holidays affected access to the hospital, as was suggested in a previous time-series study in the UK.⁸ To allow for the autocorrelations an autoregressive term at order one was incorporated into the models.⁹

Models for rainfall

From exploratory analyses, existing literature and considerations of interpretational difficulty with very long lags, we considered lags (delays in effect) of up to 16 weeks for rainfall. In the initial analyses designed to identify the broad shape of any association, we fitted natural cubic splines (3 df)¹⁰ to (i) the average rainfall over lags 0–16 and (ii) the average over 0–8 weeks and 9–16 weeks, as separate splines simultaneously included in the model. We also included temperature as a natural cubic spline (3 df) in all models to control confounding, with lag 0–4 weeks, following expectation from published work.^{3,8,11} Because initial analyses suggested a broad ‘U’ shape, we then fitted a double-thresholds model, comprising linear terms for rainfall above and below ‘high’ and ‘low’ thresholds, respectively, with no association (i.e. flat) in between.¹² Guided by the spline analysis the low and high rainfall terms were based on the 0–16 and 0–8 week average, respectively. The thresholds were estimated by maximum likelihood. An increase

or decrease in the number of cases that were associated with a 10 mm increase or decrease in a given measure of rainfall, estimated as coefficients from the regression model, was reported as percentage change.

With the simple thresholds model we then examined lag effects in more detail, by fitting linear unconstrained distributed lag models, comprising terms for low and high rainfall at each lag up to the previous 16 weeks.¹² The simple linear-thresholds model also allowed investigation of the modification of rainfall effects by patient characteristics (e.g. socio-economic status), by fitting the models separately to incidence series according to their characteristics.

Models for temperature

Delayed effects of temperature on diarrhoea due to some pathogens, have been known to be approximately 1 month,^{3,8,11} so we considered lags of up to 4 weeks for temperature. Rainfall terms with natural cubic spline (3 df) were included in all models to control confounding of rainfall over lags 0–8 and 9–16 weeks. Because a smooth relationship using natural cubic splines (3 df) suggested a log-linear association through the whole range of temperature, we fitted simple linear models. Detailed lag effects were examined by fitting linear unconstrained distributed lag models comprising terms for temperature at each lag up to previous 4 weeks.¹² We also investigated the modification of temperature effects by patient characteristics, by the same methods with models for rainfall.

The same analyses were conducted for non-cholera diarrhoea without the inclusion of rotavirus because its seasonality differs from the rest of the pathogens. Sensitivity of estimates to the degree of seasonal control (3 and 12 harmonics) was also examined. All statistical analyses were carried out using Stata 9.0 (Stata Corporation, College Station, TX, USA).

Results

There were 12 182 hospital visits (2% sample) due to all non-cholera diarrhoea from 1996 to 2002, in which 41% were under one year olds and 31% were aged between 1 and 14 years. Descriptive statistics for the number of patients and weather variables are displayed in Table 1. A wide variety of pathogens were found in the diarrhoea patients, most common were rotavirus and *E. coli*, each found in about a quarter of the cases. Total non-cholera diarrhoea had a bimodal seasonality of which timing of the first peak was before the monsoon (high rainfall period) and the second peak was at the end of the monsoon (Figure 1). Seasonality was varied between pathogen-specific diarrhoea, for example, rotavirus was common in winter in addition to a lower peak in the middle of the monsoon. *E. coli* had a single peak before the monsoon.

Relationship with rainfall

The relationships between the number of non-cholera diarrhoea and rainfall adjusted for season, between-year variations, holidays and temperature are shown in Figure 2. An increase in non-cholera diarrhoea can be seen with high rainfall at lag 0–8 weeks, while increase in the cases with both high and low rainfall is observed at lag 0–16 weeks. The maximum

Table 1 Distribution of the weekly average of meteorological and river-level data in Dhaka, and the number of patients with non-cholera diarrhoea in ICDDR,B hospital, 1996–2002

Variable (unit)	Minimum	Median	Maximum
Rainfall (mm)	0	13	360
Temperature (°C)			
Maximum	19.9	31.3	37.1
Minimum	9.4	23.5	28.9
Mean	15.7	27.8	32.4
River level (m)	1.2	2.7	7
All non-cholera	17	32	66
Rotavirus	1	9	27
Shigella	0	2	8
Salmonella	0	0	4
Campylobacter	0	3	15
E.coli	0	8	29
Aeromonas	0	4	15
Other diarrhoea	3	11	37

Counts for *Campylobacter*, *E. coli*, *Aeromonas* and other diarrhoea are cases for 1996–2000.

likelihood estimates of the threshold for high rainfall and low rainfall coincided at 52 mm (95% CI: 30–70) for average rainfall over lags 0–8 and 0–16 weeks by using double thresholds model. For a 10 mm increase above the threshold, the number of non-cholera diarrhoea cases increased by 5.1% (95% CI: 3.3–6.8). For a 10 mm decrease below 52 mm of average rainfall over lags 0–16 weeks, the number of cases increased by 3.9% (95% CI: 0.6–7.2).

The ‘high rainfall’ effect was observed at shorter lags with statistical significance at lags 1–5 weeks (Figure 3a). In contrast, the positive effect of low rainfall was observed throughout the longer lags around 10–16 weeks in addition to lag 0 (Figure 3b). Investigations of the modification of the rainfall effects by sex, age, socio-economic status and hygiene and sanitation practices found no differences approaching statistical significance (details are provided in Supplementary Table S1 on the web.).

Relationship with river level

The relationships between the number of non-cholera diarrhoea cases and the river level adjusted for season, between-year variations, holidays and temperature are shown in Figure 4. The pattern shows a positive slope with high river levels and there seems to be a threshold at around 4–5 m. The estimated threshold was 4.8 m (95% CI: 4.5–5.1). For a 1 m increase above the threshold, the number of cases increased by 53.9% (95% CI: 43.2–65.5).

Relationship with rainfall adjusted for river level

The positive slope of the number of cases with high and low rainfall observed at lags 0–8 and 0–16 weeks almost disappeared after adjustment for river level. In the double-thresholds model the estimate of the effect of high rainfall decreased on adjustment for river level to 0.6% (95% CI: –1.6, 2.7), using the same threshold with that for unadjusted

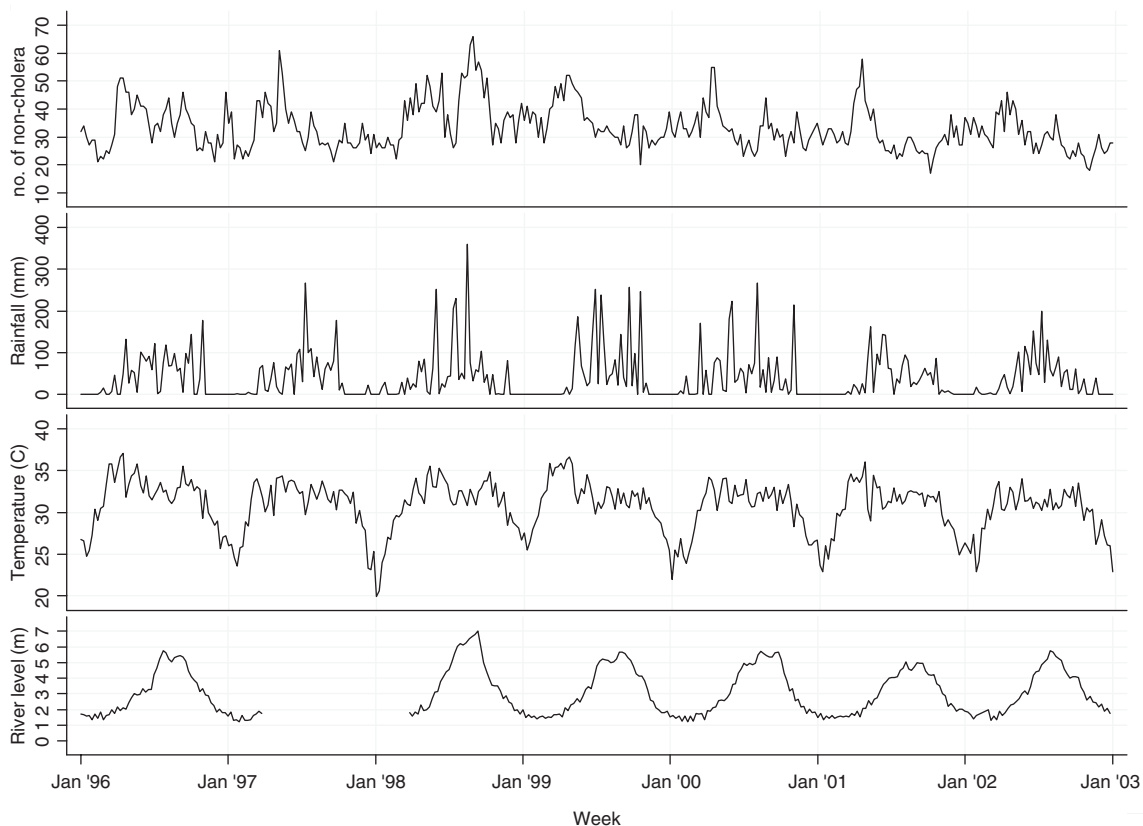


Figure 1 Seasonal variations in the number of all non-cholera diarrhoea cases per week and meteorological and river-level data in Dhaka, 1996–2002. The river-level data are missing from April 1997 to March 1998

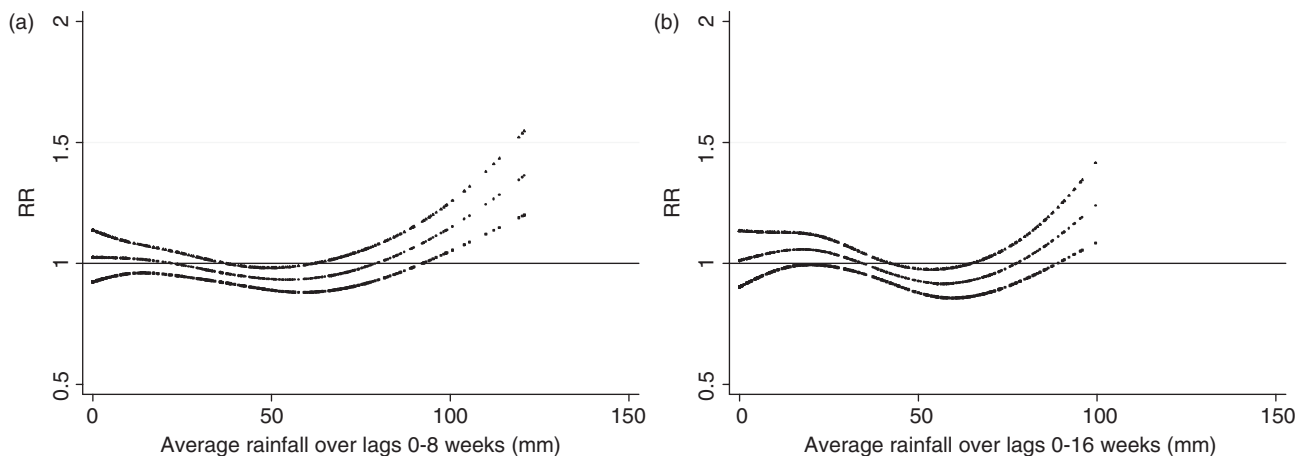


Figure 2 Relationship between the number of non-cholera diarrhoea cases and average rainfall over lags of (a) 0–8 and (b) 0–16 weeks (shown as a 3 df natural cubic spline) adjusted for seasonal variation, between-year variations, public holidays and temperature. RR represents the relative risk of non-cholera diarrhoea (scaled against the mean weekly number of cases). The centre line in each graph shows the estimated spline curve and the upper and lower lines represent the 95% confidence limits

for river level. The ‘low rainfall’ effect also decreased to 0.3% (95% CI: –2.9, 3.6).

Relationship with temperature

The relationships between the number of non-cholera diarrhoea cases and temperature adjusted for season, between-year

variations, holidays and rainfall are shown in Figure 5. There is linear increase in the number of cases with high temperature. For a one degree increase in average temperature over lags 0–4 weeks, the number of cases increased by 5.6% (95% CI: 3.4–7.8) by using a model that assumes a log-linear increase in risk. The independent effects of

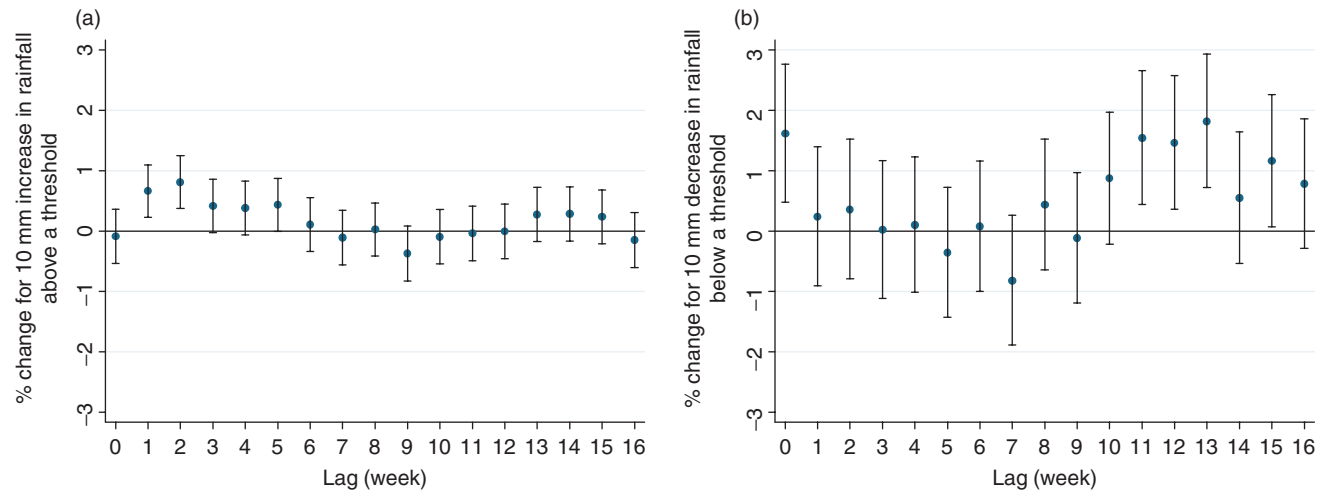


Figure 3 Percentage change (and 95% CIs) in the number of non-cholera diarrhoea cases for 'high' (a; per 10 mm increase above threshold) and 'low' rainfall (b; per 10 mm decrease below threshold) at each lag (unconstrained distributed lag models)

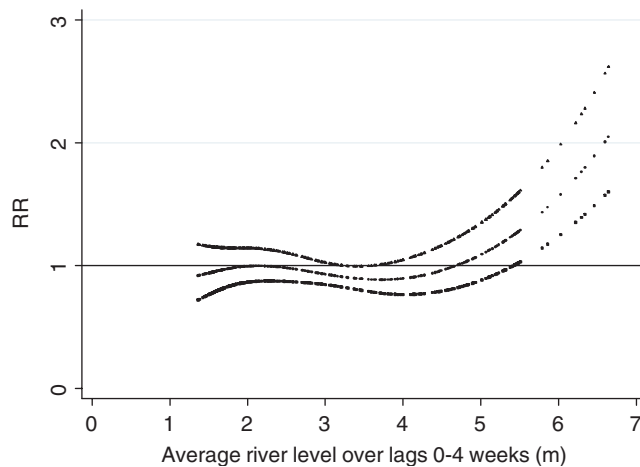


Figure 4 Relationship between the number of non-cholera diarrhoea and the average river level over a lag of 0–4 weeks (shown as a 3 df natural cubic spline), adjusted for seasonal variation, between-year variation, public holiday and temperature. RR is the relative risk of non-cholera diarrhoea (scaled against the mean weekly number of cases). The centre line in each graph shows the estimated spline curve and the upper and lower lines represent the 95% CI

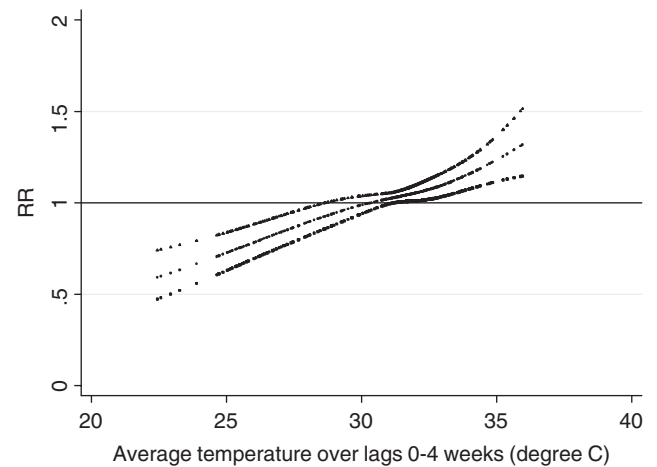


Figure 5 Relationship between the number of non-cholera diarrhoea and the average temperature over a lag of 0–4 weeks (shown as a 3 df natural cubic spline) adjusted for seasonal variation, between-year variation, public holidays and rainfall. RR represents the relative risk of non-cholera diarrhoea (scaled against the mean weekly number of cases). The centre line in each graph shows the estimated spline curve and the upper and lower lines represent the 95% CI

temperature at different lags showed that the positive association was observed in the same week and decreased to null at lags 2 and afterwards (Figure 6).

There was evidence for differences in temperature effects between sub-groups examined; the risks for non-cholera diarrhoea were higher for those individuals at a lower educational attainment, those living in the household with non-concrete roof and unsanitary toilet users (Table 2). There was weak evidence for higher risk of non-cholera diarrhoea for those individuals whose drinking water source was more than 5 m distant from the household. No modification of temperature effects were observed by sex or age.

Repeating analyses excluding rotavirus diarrhoea left patterns of the effects of high and low rainfall and of temperature largely unchanged. However, the high rainfall slope was slightly

increased from 5.1% to 7.4% (95% CI: 5.0–9.8) and that of low rainfall was increased from 3.9% to 5.7% (95% CI: 0.5–11.1). The effect of temperature also slightly increased from 5.6% to 6.5% (95% CI: 3.5–9.5).

When in sensitivity analyses the degree of seasonal control was halved (3 harmonics) or doubled (12 harmonics), the estimates of the effect of high and low rainfall and of the temperature changed little.

Discussion

This study shows that there was significant association of hospital visits due to non-cholera diarrhoea with high and low rainfall and with high temperature in Dhaka, Bangladesh.

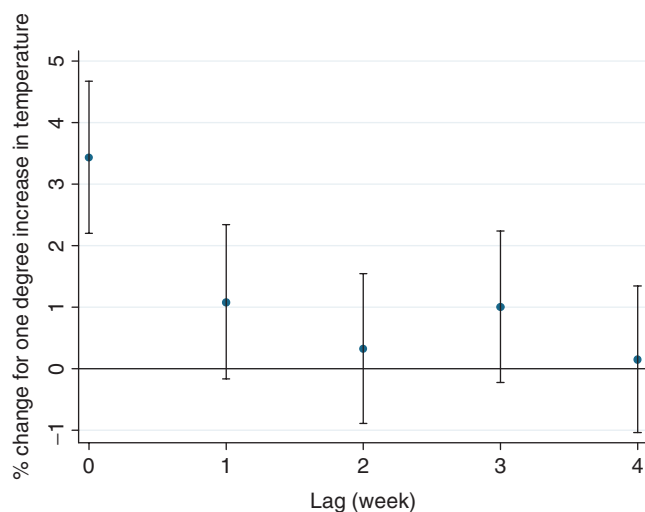


Figure 6 Percentage change (and 95% CIs) in the number of non-cholera diarrhoea cases for a 1°C increase in temperature at each lag (unconstrained distributed lag models)

The effect of temperature on the incidence of non-cholera diarrhoea was higher for people with lower educational attainment, those living in the household with non-concrete roof and unsanitary toilet users. The effects of rainfall were not differential by any socio-economic status or hygiene and sanitation practices.

The high rainfall association is broadly consistent with a study in Fiji reporting that monthly diarrhoea incidence in infants increased with increased rainfall after allowing for the effects of long-term trends and seasonal patterns.¹³ In that study, high rainfall was associated with significant increases in diarrhoea in the same month but decreased in the following month suggesting that initially high rainfall flushes faecal contaminants from pastures and dwellings into water supplies, but continued rain leads to a subsequent improvement in water quality. In the present study, however, no consistent protective effect of high rainfall was observed in any lag periods by detailed analysis of lag structure. The current study is also broadly in accordance with a US study reporting that waterborne disease outbreaks were preceded by heavy rainfall within a 2-month lag.¹⁴ However, these studies were conducted in regions which are climatologically and geographically very different from Dhaka, and careful interpretation is needed. Causative agents of diarrhoea are also likely to be different in Dhaka as compared with these regions.

This study found that the river level explained nearly all the associations between high rainfall and the incidence of diarrhoea, suggesting that factors associated with the river level are on the causal pathway between high rainfall and diarrhoea. Another study in Dhaka indicated adverse effects of flood on the number of non-cholera diarrhoea cases that was higher for tube well users, those using distant water sources and unsanitary toilet users as compared with tap-water users, those using a close water source and sanitary toilet practices (unpublished data). These findings suggest that heavy rains leading to excessive flooding break down water and sanitation

Table 2 Percentage change in the number of non-cholera diarrhoea cases per week for 1°C increase in temperature at lag 0–4 weeks (1996–2002: ICDDR,B Dhaka Hospital)

	Mean ^a	SD	% change	95% CI	P-value ^b
Total	33.5 (8.3)		5.6	(3.4, 7.8)	
Characteristics					
Sex					0.77
Female	13.2 (4.4)		5.4	(1.3, 9.6)	
Male	19.9 (5.8)		6.2	(3.1, 9.4)	
Age (years)					1.00
≤ 14	23.8 (6.7)		5.7	(2.9, 8.6)	
15–29	4.1 (2.3)		5.6	(–1.7, 13.6)	
30+	5.2 (2.6)		5.9	(–0.5, 12.8)	
Socio-economic status					
Education ^c					0.04
No education	15.0 (5.1)		8.9	(5.2, 12.6)	
Informal or <6 years	5.9 (2.8)		7.3	(1.0, 14.0)	
6 years +	12.2 (3.9)		2.0	(–1.9, 6.0)	
Roof structure					0.02
Non-concrete	25.5 (7.1)		6.7	(4.1, 9.4)	
Concrete	7.1 (2.8)		–0.3	(–5.3, 5.0)	
Water and sanitation					
Drinking water source ^d					0.16
Tube well	13.7 (4.5)		7.9	(4.1, 11.8)	
Tap water	19.3 (5.9)		4.3	(1.0, 7.6)	
Distance to water source ^d					0.09
More than 5 m	20.2 (6.0)		7.5	(4.5, 10.6)	
5 m or less	12.9 (4.0)		3.2	(–0.7, 7.2)	
Type of toilet ^e					0.01
Non-sanitary	14.2 (4.5)		9.6	(6.0, 13.4)	
Sanitary	18.9 (5.8)		3.1	(–0.1, 6.5)	

^aMean weekly count of cases due to non-cholera ($n = 364$ weeks).

^bP-value for test for heterogeneity between subgroups.

^cEducational level which combined mother's educational level for children under 15 years and self-educational level for those 15 years or older.

^dDistance to drinking water source from the kitchen.

^eNon-sanitary includes dug hole, open pit, hanging and no fixed place. Sanitary includes sanitary and semi-sanitary toilets.

systems and promote the intake of contaminated drinking water, although this study did not find any evidence for the modification of the rainfall effect by water source. Investigations on detailed pathways of the rainfall–diarrhoea relationship, particularly the role of drinking water quality are warranted.

The low rainfall effect found in this study was also broadly consistent with results of the time-series study in Fiji, which found that low rainfall was significantly associated with increases in diarrhoea in the same month and the following month.¹³ A possible explanation is the lack of dilution of sewage effluent and increased contamination of pond and lake water scattered amongst the communities in Dhaka and water

used for washing and bathing, through stagnation during low rainfall. Transmission of enteric pathogens through the faecal-oral route could increase in overcrowded areas with relatively unsanitary practices due to low rainfall.

The positive linear relationship between non-cholera diarrhoea and temperature in this study is broadly consistent with previous studies in Peru and Fiji.^{3,13} This finding is also biologically plausible through higher temperatures promoting the growth of bacteria, although some enteric viruses have been suggested to increase survival and transmission under lower temperatures.^{15,16} Consistent with this is the finding in our analysis without the inclusion of rotavirus diarrhoea of a slightly larger effect of temperature.

A new finding of this study is that the effect of temperature on non-cholera diarrhoea incidence is higher for people with lower educational attainment, those living in the household with non-concrete roof and unsanitary toilet users. Weak evidence for modification of the temperature effect by distance to drinking water source from the kitchen was observed. Educational attainment and household construction material can be robust indicators of socio-economic status in Bangladesh, and people in lower socio-economic status are, in general, at a higher risk of suffering from diarrhoea.¹⁷

We have reported results for all non-cholera diarrhoea, though associations between rainfall or temperature would not necessarily be the same for different pathogens, as indicated by their different seasonal patterns. Separate analyses proved problematic for two main reasons. Firstly, the number of cases for any specific pathogen was small, so patterns were unclear. Secondly, a high proportion (29.5%) of cases had more than one pathogen identified, making classification of the underlying cause of the visit difficult. Therefore, the results of this study should be interpreted with caution in this regard, although the analyses without the inclusion of rotavirus diarrhoea, which is most likely to differ from the rest of the pathogens in its relationship with climate, provided the results largely unchanged. Further studies for the effect of climate on pathogen-specific diarrhoea are warranted.

Less severe cases would be less likely to be included, but this does not pose a threat to validity of the comparisons over time, which is the subject of this study. More problematic would be cases missing because of limitations in the capacity of the hospital to receive the patients, in particular during epidemics of diarrhoeal diseases. However, in principle, the hospital accepts all patients visiting the hospital and

has never refused patients due to over capacity. Thus, the capacity of the hospital should not be an important threat to this study. If a bias remained, it would act to 'blunten' peaks, and thus most likely bias associations towards the null.

In this study, rainfall and temperature were found to explain departure of the number of diarrhoea cases from the usual seasonal pattern. This does not mean that these factors can explain the usual seasonal patterns themselves. Further work could clarify the role of weather in the seasonality of diarrhoea in Bangladesh and would be of interest.

The results of this study can contribute to development of early warning systems to predict epidemics of diarrhoea. The vulnerable groups identified in this study should have particular focus in the use of such a warning system. Expected increases in temperature, changes in precipitation patterns and increased flooding in Bangladesh¹⁸ also give particular relevance to the results, though the short-term associations reported here should not be directly extrapolated to changes in climate over decades.

In conclusion, this study found evidence that the number of non-cholera diarrhoea cases increases both above and below a threshold level with high and low rainfall in the preceding weeks. Most of the effects of high rainfall can be explained by the effect of high rainfall on river levels. Ambient temperature was also positively associated with the number of non-cholera diarrhoea cases, particularly in those individuals at a lower socio-economic and sanitation status.

Supplementary material

Supplementary material and table can be found at *IJE* Online (<http://ije.oxfordjournals.org>).

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Conflict of Interest: None declared.

KEY MESSAGES

- Clarifying the potential role of weather on the transmission of diarrhoeal diseases could help by bringing a deeper insight into the mechanisms of the seasonality of the disease.
- The number of hospital visits due to non-cholera diarrhoea increases both above and below a threshold level with high and low rainfall in the preceding weeks.
- Factors associated with river level are suggested on the causal pathway between high rainfall and incidence of cholera.
- Ambient temperature was also positively associated with the number of non-cholera diarrhoea cases, particularly in those individuals at a lower socio-economic and sanitation status.

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