**Impact of climate change on hospital visits for diarrhoea in urban Dhaka, Bangladesh: A time-series analysis**

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**Abstract**

**Background**

Measurements of impact of climate change or long-term variations in climate parameters over decadal scales due to anthropogenic forcing on incidence of diarrhoea in Bangladesh are limited. We estimated the relationship of long-term changes in daily ambient temperature with the number of hospital visits for all-cause diarrhoea in urban Dhaka. To inform the decision-makers, we used that relationship to predict the likely effect of climate change on incidence of diarrhoea in 2030 and the associated cost of reactive measures.

**Methods**

We collected the number of hospital visits for all-cause diarrhoea per day from icddr,b Dhaka Hospital and the meteorological data for Dhaka from the Bangladesh Meteorological Department. Daily ambient temperature and number of hospital visits for diarrhoea were analyzed by time-series regression. A negative binomial model was used to model the relationships controlling for seasonality and potential population-level modifying factors (socio-economic, safe water supply, literacy rate and sanitation coverage). We generated the baseline incidence using estimates from 1990, when the impact of human-induced climate change was assumed to be minimal. Based on these results, we estimated the additional number and costs of reactive measures for diarrhoea cases attributable to climate change by 2030 in Dhaka.

**Results**

The number of diarrhoea cases increased by 28.3 % (95% CI: 12.6-44.0) for 1oC rise in daily ambient temperature over lags of 0-1 days. We projected a maximum of 97,552 additional diarrhoea episodes attributable to climate change in Dhaka with an additional cost of US $ 1.5 million for treatment cost only by the year 2030.

**Conclusions**

Climate change, likely to increase the ambient temperature by 1 oC during 2030 can significantly increase hospital visits for diarrhoea. Adaptation measures to increase hospital capacity for additional case management and to improve water and sanitation infrastructure could reduce the impact of climate change on diarrhoea in Dhaka, Bangladesh.

(300 words)

**Introduction**

* Diarrhoeal diseases remain a leading cause of morbidity and mortality among children >5 years worldwide [1-5].
* Rigorous reactive and preventive measures have significantly reduced the morbidity and mortality associated with diarrhoea during the past decade, yet the total estimated episodes of childhood diarrhoea in 139 countries was 1.7 billion during 2010 [4].
* Several studies have found strong association between climate variability and incidence of diarrhoeal diseases [6-10].
* Climate change or long term variations in the climate could lead to changes in the frequency and intensity of natural disasters, quality of water, and sanitation infrastructure, which in turn might increase incidence of diarrhoeal diseases [11].
* In Bangladesh with > 5 million annual reported diarrhoeal episodes in all age groups requiring hospital care during 2009, the potential impact of long term climate variability on human health is particularly concerning [12, 13].
* Several studies in Bangladesh have examined the effects of climate variability on cholera [10, 14-17].
* Hashizume et al (2007) has detected that the number of non-cholera diarrhoea cases in Dhaka increased with higher temperature, particularly among the lower socioeconomic group and those living under poor sanitary conditions [18].
* However, measurements of potential impacts of gradual climate change occurring over decadal time-scales due to human actions (anthropogenic forcing) on diarrhoeal diseases are lacking.
* Since the human health vulnerability to climate change, in terms of exposure (environmental variables) and capacity to cope (socioeconomic variables), may vary considerably between time and place, it is vital to quantify the burden of diarrhoea attributable to climate change at national and local levels [19].
* Improved projections of future risks are necessary for local decision making in addition to further efforts to refine national costs of preventive and reactive adaptation measures in the health sector.
* Also to rationalize allocation of constrained resources and to prioritize policies to mitigate climate change impacts, decision makers require estimation of the disease burden attributable to climate change and its potential impact in the future.
* Given the complex causal webs, absence of appropriate long-term surveillance data, natural climate variability and the role of societal and individual factors on potential effects of climate change, quantification of burden of diarrhoea attributable to climate change is difficult and often associated with uncertainty [20, 21].
* Despite the methodological challenges, we aimed to measure the association between long term climate variability and change on hospital visits for all-cause diarrhoea using hospital-based data over a 30-year period against a baseline.
* Using the association, we attempted to predict the potential impact of climate change on diarrhoea incidence in Dhaka Bangladesh in 2030.

**Methods**

*Site and source of data*

* We collected the total number of patients visiting the Dhaka Hospital for diarrhoeal diseases daily from the Diarrhoeal Disease Surveillance System of the Dhaka Hospital [22].
* The hospital served an urban population of approximately 13 million in 2010 [23].
* The Dhaka Hospital of the icddr,b, treated more than 110,000 patients annually and a systematic 2% sample of the patients were enrolled into the surveillance programme [22].
* Trained research assistants interviewed patients and/or their attendants using structured questionnaires to collect relevant information including socio-economic and demographic characteristics [22].
* As daily hospital visits for diarrhoea were reliably recorded in the Dhaka Hospital, we estimated the association between unit change in ambient temperature and diarrhoea hospital visits based on the data from the Dhaka Hospital only.
* We collected the data on daily climate parameters including the ambient temperature from the Bangladesh Meteorological Department.
* We collected data on potential covariates including population growth and literacy rates from the 10-year Census, the annual GDP growth rate in Bangladesh from the Nationmaster website [24] and the data on safe water and improved sanitation coverage from the UN coverage estimates on access to drinking water and sanitation [25].

***Methods for estimating the exposure (climate change) and response (hospital visits for diarrhoea) relationship***

* According to the World Meteorological Organization and IPCC, the climate property was not strongly affected by anthropogenic forcing before 1990 [20].
* We calculated the risk ratio of hospital visits for diarrhoea in the baseline s*cenario CB* using the data from 1990.
* The climate change s*cenario CCC* (the period assumed to be affected by human-induced factors owing to industrialization and greenhouse gas emission) builds on the baseline s*cenario CB.*
* We generated the relationships between rates of daily hospital visits for diarrhoea and daily ambient temperature based on the results of time series regression using the 30 years data from 1981-2010.
* We generated the risk ratio for the climate change s*cenario CCC*(for 1oC rise in daily ambient temperature) by adding the risk ratio generated from the time-series regression to the risk ratio in the baseline s*cenario CB* [19].
* We considered the potential covariates including the population growth in the catchment area of the Dhaka Hospital, annual GDP growth rate, safe water supply, sanitation coverage, and literacy rate into the model.
* A time variable was incorporated into the model as a proxy to other socioeconomic variables that were absent in this dataset.
* We did not include rainfall and humidity in our model as the impacts of climate change on rainfall and humidity are still not clear. Instead, we only included the two climate parameters (daily ambient and sea surface temperature) showing clear evidence of change since the late-twentieth century [10, 26].

*Statistical methods for estimating hospital visits for diarrhoea due to climate change*

* We checked each data series for trend, seasonality, autocorrelation and possible outliers.
* We pre-whitened the data series for checking cross-correlation between diarrhoea and climate variables at different lags.
* For each data series, we tested several different models with specifications combining the regressors. The preferred models were chosen according to the level of significance of regressors including the ACF and PACF values in each model and the results of a previous correlation analysis of all variables in our datasets.
* To investigate the potential effects of daily climate variability on daily hospital visits for diarrhoea, we initially used the generalized linear Poisson regression model.
* To account for constant over-dispersion in our data, we used the log-linked negative binomial regression model to derive the increase in daily hospital visits for diarrhoea per unit increase in ambient temperature or sea surface temperature using STATA.

***Estimation of the total diarrhoea episodes attributable to climate change in Dhaka in 2030***

* The predicted exposure to climate change in Dhaka, Bangladesh by year 2030 was carried out for ~1oC increase in ambient temperature based on the IPCC Third Assessment Report using the B2 emission scenario [27].
* We assumed that the urban population projections for year 2030 for Dhaka would in line with the UN projected population, which is projected to increase from 13 million during the year 2010 to 26 million people by year 2030 [23].
* We first estimated the projected number of diarrhoea episodes in urban Dhaka in 2030 by multiplying the projected urban population with the risk ratio in the baseline scenario (*Scenario CB*).
* The number of diarrhoea episodes in the climate change scenario was estimated by multiplying the projected urban population with the upper and lower bounds of the risk ratio in the climate change S*cenario CCC*.
* We then estimated the additional hospital visits for diarrhoeal diseases in Dhaka attributable to climate change by year 2030 as the difference between the number of diarrhoea episodes in S*cenario CCC*and *Scenario CB.*
* According to the statistics of the Dhaka Hospital, the approximate cost of hospital-based treatment per diarrhoea case is approximately US $ 15. This included the cost of treatment, bed, personnel and surveillance. We calculated of reactive adaptation measures as costs of treatment only using the constant 2010 US $. We did not include the cost of mortality from diarrhoea. We also did not calculate the cost incurred by diarrhoea affected households.

**Results**

* There were 2,975,150 of hospital visits in 10,950 days from January 1981 to December 2010. Among these, 58% were males. 54% were aged <5 years, 10% were <15 years and 36% were >15 years.
* The descriptive statistics for the climate variables and hospital visits for diarrhoea are displayed in the Table 1.
* The results using the dataset per day showed a positive and significant association between hospital visits for diarrhoea and ambient temperature.
* The risk ratio, which represented the relative change in the risk of the dependent variable (daily hospital visits for diarrhoea) given a one-unit change in the explanatory variable (daily ambient temperature), was estimated to be equal to 0.01094 for s*cenario CCC* (Table 2). In other words, an increase in temperature equal to 1 degree Celsius would increase the risk of daily hospital visits for diarrhoea episodes in Dhaka by 1.1% in the climate change scenario.
* The number of diarrhoea episodes in 2030 for the baseline scenario was estimated to be 221,780, which would consequently increase to 319,332 with an additional number of 97,552 hospital visits for diarrhoea in the upper bound scenario requiring an additional treatment cost of approximately 1.5 million US dollars (Table 3).

**Discussion**

* Our study found significant positive association of hospital visits for all-cause diarrhoea with ambient temperature in Dhaka, Bangladesh.
* The association remained significant after controlling for the socio-economic factors.
* The estimates presented in this study predicted an increase of hospital visits for diarrhoea by 28% for a 1 degree Celsius increase in ambient temperature in Dhaka.
* Our estimate was higher than the 1-17% increase in the initial risk of diarrheal diseases by year 2030 under unmitigated conditions, as predicted by Campbell-Lendrum for Southeast Asia region [20]. However, those estimates were based on studies from Peru [26] and Fiji [10].
* Our estimates were consistent with findings from previous studies on short-term climate variability in Bangladesh which had reported a 40.2% increase in rotavirus diarrhoea in Dhaka for each 1°C increase of temperature above 29°C and 5.6% increase in non-cholera diarrhoea cases for 1°C increase in average temperature [18, 28].
* Our finding of 28% increase in daily diarrhoeal incidence per degree Celsius rise in mean temperature is likely to be an underestimate. Since we determined the association from hospital visits for diarrhoea, the less severe cases were less likely to be included. The covariates were based on aggregate monthly and annual measures. More time-specific data available on socioeconomic modifiers could show stronger impacts. Moreover, the diarrhoeal diseases attributable to increased frequency of natural disasters including floods owing to climate change were not included in this calculation. In addition, the cost of reactive measures based on 2010 rates would be
* The cost of treating additional diarrhoea cases attributable to climate change based on rates of 2010 would be much lower than actual cost incurred in 2030.
* Nevertheless, the results provided robust evidence on the implications of climate change on diarrhoea and to the health sector in terms of hospital capacity to receive patients particularly during epidemics and the associated costs of additional cases.
* Our study suggests that climate change is likely to cause large additional economic burdens to societies and to households.
* The magnitude of the hospital visits and the cost estimates of additional cases of diarrhoea resulting from climate change are substantial, and considerably higher than the current hospital capacity and budgets allocated for diarrheal diseases in Dhaka, Bangladesh.
* To provide treatments to the additional diarrhoea cases, hospital capacity should be increased along with adequate budgetary allocation.
* Though rate of diarrhoea incidence in Bangladesh is expected to decrease in the future with socio-economic development and improvement of the water and sanitation infrastructure, the additional cases for climate change are still substantial.
* This highlights the importance of continued investment for strengthening water quality and sanitation infrastructure to mitigate the climate change impact in Bangladesh.

**(1,983 words excluding the abstract)**

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Table 1: Distribution of the daily average meteorological parameters in Dhaka, and the number of hospital visits in icddr,b Dhaka Hospital, 1981-2010

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Period | **1981-1990** | | **1991-2010** | |
| Variable (unit) | 25th -75th percentile | Median | 25th -75th percentile | Median |
| Temperature (oC) |  |  |  |  |
| Ambient | 22.8-29.0 | 27.1 | 22.9-29.1 | 27.4 |
| Maximum | 28.6-33.0 | 31.2 | 28.5-33.3 | 31.5 |
| Minimum | 17.4-26.1 | 23.4 | 17.8-26.0 | 23.6 |
| Sea surface | 26.5-28.8 | 28.1 | 26.7-29.0 | 28.3 |
| Dew point | 16.3-25.5 | 22.7 | 16.1-25.1 | 22.6 |
| Relative humidity (%) | 70-83 | 77 | 69-82 | 75 |
| Cumulative rainfall (mm) | 0-3 | 0 | 0-3 | 0 |
| Sunshine hour | 5.3-9.2 | 8.1 | 3.5-8.7 | 6.9 |
| Pressure | 1003-1013 | 1008 | 1003-1012 | 1008 |
| Total all-cause diarrhoea | 150-225 | 175 | 250-350 | 300 |

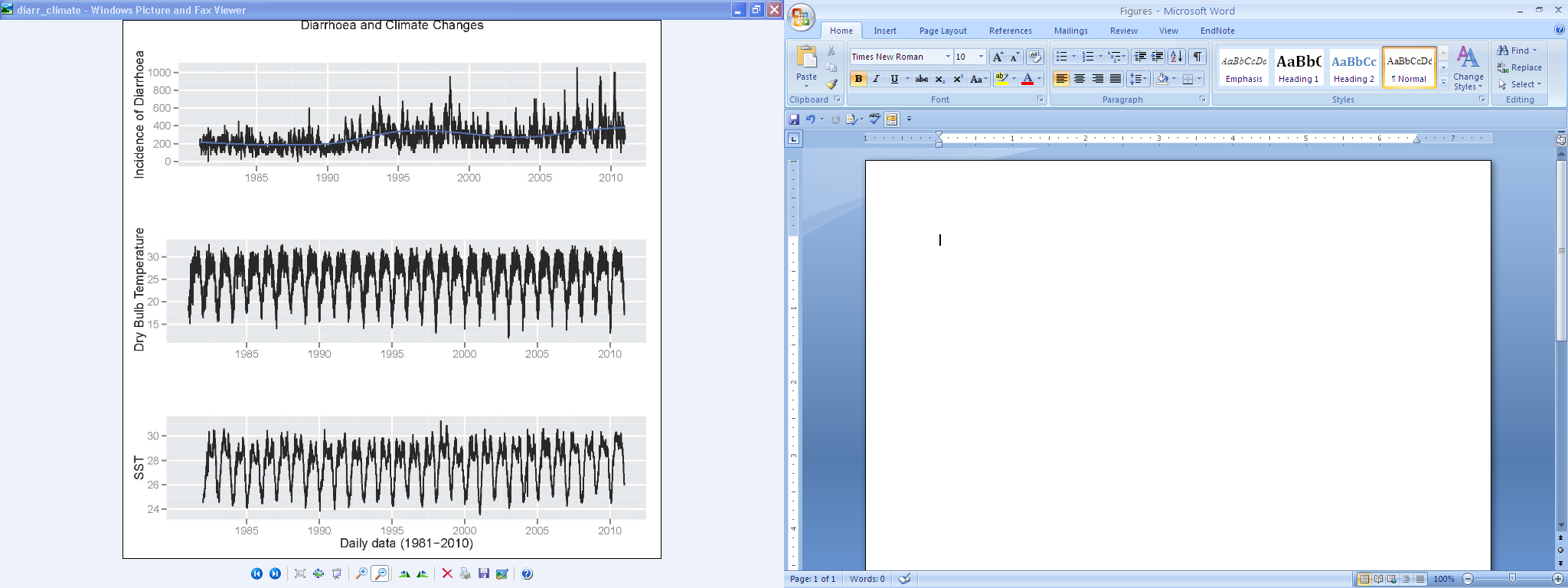
Figure 1: Seasonal variations in the number of all-cause diarrhoea cases per day and daily ambient temperature in Dhaka, Bangladesh, 1981-2010

Figure 2: Cross-correlations between hospital visits for all-cause diarrhoea and 1oC increase in ambient temperature at each lag



Table 2: The table presents the risk ratios for both the baseline and climate change scenarios for 1oC change in daily ambient temperature in 2030

|  |  |  |  |
| --- | --- | --- | --- |
| Scenario | Risk ratio  RR | 95% CI | *P*-value |
| *Scenario CB* (Baseline scenario using estimates from 1990) | 0.00853 |  |  |
| *Scenario CCC*(Climate change 1oC mean temperature rise) | 0.01094 | 0.00961-0.01228 | 0.000 |

* 95% CI: 95% Confidence Interval
* *P*-value: for test of heterogeneity between sub-groups
* RR for climate change *Scenario CCC*= RR *Scenario CB* + Additional risk for climate change (From time-series analysis using data from 1981-2010)= 0.00853 + (0.00241) = 0.01094

Table 3: Projected number of hospital visits for diarrhoea episodes and the associated cost of reactive response for the baseline and climate change scenario in Dhaka during 2030

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Baseline *Scenario CB* (2030)  Using incidence of 1990 | | | | *Scenario CCC*(1 oC rise in ambient temperature 2030) | | | |
|  | |  | |  | | **Lower Upper** | | |
| Diarrhoea cases | | | 221,780 | | | 249,782 | | 319,332 |
| Additional cases | | |  | | | 28,002 | | 97,552 |
| Percentage increase in cases % | | |  | | | 12.6 | | 44.0 |
| Cost of hospital treatment ($15/diarrhoea episode/in 2010) | | | US $ 3,326,700 | | | US $ 3,746,730 | US $ 4,789,980 | |
| Additional cost of treatment | | |  | | | US $ 420,030 | US $ 1,463,280 | |

* The approximate cost of managing each diarrhoea patient in Dhaka Hospital=$ 15 in 2010. This included cost of treatment, bed and other hospital facilities, personnel, and diarrhoea surveillance
* The cost would be increased by approximately 50% assuming a 2% inflation rate per year by the year 2030