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### Is heat wave a predictor of diarrhoea in Dhaka, Bangladesh? A time-series analysis in a South Asian tropical monsoon climate

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| Abstract: | While numerous studies have assessed the association between temperature and diarrhoea in various locations, evidence of relationship between heat wave and diarrhoea is scarce. We defined elevated daily mean and maximum temperature over the 95th and 99th percentiles lasting for at least one day between March to October 1981 – 2010 as TAV95 and TAV99 and D95 and D99 heat wave, respectively. We investigated the association between heat wave and daily counts of hospitalisations for all-cause diarrhoea in Dhaka, Bangladesh using time series regression analysis employing constrained distributed lag-linear models. Effects were assessed for all ages and children aged under 5 years of age. Diarrhoea hospitalisation increased by 6.7% (95% CI: 4.6% – 8.9%), 8.3% (3.7 – 13.1), 7.0 (4.8 – 9.3) and 7.4 (3.1 –11.9) in all  ages on a TAV95, TAV99, D95 and D99 heat wave day, respectively. These effects were more pronounced for under-5 children with an increase of 13.9% (95% CI: 8.3 – 19.9), 24.2% (11.3 – 38.7), 17.0 (11.0 – 23.5) and 19.5 (7.7 – 32.6) in diarrhoea  hospitalisations on a TAV95, TAV99, D95 and D99 heat wave day, respectively. At lags of 3 days, we noticed a negative association indicating a ‘harvesting’ effect. Given that no heat wave definitions exist, and no heat warnings are issued at present, these results may help to define heat waves for Dhaka and trigger public health interventions including heat alerts to prevent heat-related morbidity in Dhaka, Bangladesh. |
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| 1 | **Is heat wave a predictor of diarrhoea in Dhaka,** |
| 2 | **Bangladesh? A time-series analysis in a South** |
| 3 | **Asian tropical monsoon climate** |
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# Abstract

1. While numerous studies have assessed the association between temperature
2. and diarrhoea in various locations, evidence of relationship between heat wave and
3. diarrhoea is scarce. We defined elevated daily mean and maximum temperature
4. over the 95th and 99th percentiles lasting for at least one day between March to
5. October 1981ꟷ2010 as TAV95 and TAV99 and D95 and D99 heat wave,
6. respectively. We investigated the association between heat wave and daily counts of
7. hospitalisations for all-cause diarrhoea in Dhaka, Bangladesh using time series
8. regression analysis employing constrained distributed lag-linear models. Effects
9. were assessed for all ages and children aged under 5 years of age. Diarrhoea
10. hospitalisation increased by 6.7% (95% CI: 4.6% – 8.9%), 8.3% (3.7 – 13.1), 7.0 (4.8
11. – 9.3) and 7.4 (3.1 – 11.9) in all ages on a TAV95, TAV99, D95 and D99 heat wave
12. day, respectively. These effects were more pronounced for under-5 children with an
13. increase of 13.9% (95% CI: 8.3 – 19.9), 24.2% (11.3 – 38.7), 17.0 (11.0 – 23.5) and
14. 19.5 (7.7 – 32.6) in diarrhoea hospitalisations on a TAV95, TAV99, D95 and D99
15. heat wave day, respectively. At lags of 3 days, we noticed a negative association
16. indicating a ‘harvesting’ effect. Given that no heat wave definitions exist, and no heat
17. warnings are issued at present, these results may help to define heat waves for
18. Dhaka and trigger public health interventions including heat alerts to prevent heat-
19. related morbidity in Dhaka, Bangladesh.

# Keywords

1. heat wave, diarrhoea, heat effects, extreme heat, temperature extreme, Bangladesh

# Introduction

1. It is now evident that anthropogenic climate change is increasing the intensity
2. and frequency as well as duration of heat waves in addition to raising the average
3. ambient temperature across the globe (1, 2). The observed increasing trend of heat
4. waves and warm spells due to global climate change are projected to continue in the
5. future (3, 4). Heat waves can exert serious and potentially life-threatening impacts on
6. human health including heat stroke, heat exhaustion, heat syncope, and heat
7. cramps (5). Heat extremes have been associated with excess all-cause mortality,
8. increased emergency room visits and hospital admissions, increased mortality from
9. cardiovascular and other diseases, mental health issues, adverse pregnancy and
10. birth outcomes and increased healthcare costs (5-12).
11. Health effects of heat wave tend to be governed by a variety of complex,
12. interacting biological, medical, environmental, social and geographical factors
13. including locations, individual susceptibility, prevalence of certain diseases,
14. healthcare infrastructure and health system status (2, 5, 7, 13). In addition, the
15. mechanisms by which extreme temperatures influence disease causation may vary
16. widely according to different morbidities. For example, heat extremes in countries
17. with less than optimum water and sanitation infrastructure may significantly increase
18. the risk of waterborne diseases including diarrhoea by increasing exposure to
19. contaminated drinking water needed to replace the volume lost through excessive
20. sweat in addition to increasing host susceptibility to infection (5).
21. Although there have been several reports of increased mortality, limited
22. information exists on the impact of heat waves on morbidity across the globe and
23. particularly in the South Asian context (14, 15). The perceived risk of health hazards
24. from heat waves or warm spells is low in the developing countries of the tropical and
25. sub-tropical regions in South Asia where comfortable warm temperature is the norm
26. (15). Although temperature-related deaths and diseases may be largely preventable
27. and heat warning systems (HWSs) as well as heat early warning systems (HEWS)
28. are existent in many high-income cities globally, such warning systems rarely exists
29. in the South Asian setting (11). One important gap that hampered the development
30. of a warning system in South Asian countries is the lack of consensus about the
31. definition of heat waves. Furthermore, there is dearth of knowledge regarding the
32. nature of heat-health risk, climate hazard, societal exposure and population
33. vulnerability (15).
34. Bangladesh, a South Asian country with a tropical monsoon climate, is highly
35. vulnerable to the adverse impacts of climate change (16) and heat waves in the
36. future (15). With more than an estimated 76 million people affected with diarrhoeal
37. disease episodes in all age groups in Bangladesh annually (17), the potential impact
38. of heat wave on the incidence of diarrhoeal disease in the future could be concerning
39. for Bangladesh. Given that the capital city of Dhaka is struggling to ensure water
40. quality and facing a number of challenges to ensure the quality of urban life and
41. sustainable urban growth including rising surface temperature in the context of
42. urbanisation and global climate change, insufficient infrastructure, inadequate
43. sanitation and poor hygiene brought about by poverty (18, 19), the impacts of heat
44. waves on diarrhoea are likely to be considerably higher in Dhaka.

94

1. This paper aims to evaluate the influence of heat waves on hospitalisations
2. due to diarrhoea in Dhaka. Although it is acknowledged that correlations uncovered
3. do not necessarily imply direct causation, such indicators support understanding of
4. the effects of heat waves on diarrhoeal disease morbidity thereby aiding further
5. research to elicit linkages between climate change and gastrointestinal health. Given
6. that many of the South Asian cities including Dhaka do not currently have a clearly
7. agreed heat wave definition, this paper additionally aimed to identify pragmatic
8. definitions of heat waves for Dhaka, which is a necessary first step to inform the
9. development of a HWS for Dhaka.

# Data and methodology

## Diarrhoea data

1. Daily diarrhoea hospitalisation data between 1 January 1981 to 31 December
2. 2010 were collected from the Dhaka Hospital of the International Centre for
3. Diarrhoeal Diseases Research, Bangladesh (icddr,b) on 7 October 2020. The
4. hospital served an urban population of approximately 3.5 million in 1981, 6.6 million
5. in 1990 and 14.6 million in 2010 and provided free treatment to more than 140,000
6. patients with diarrhoea in 2010 (20). Given that reliable records of the total number
7. of patients with admitted with diarrhoea per day or their disease onset dates were
8. not available for the study period (1981–2010), information from the robust
9. Diarrhoeal Disease Surveillance System (DDSS) was obtained instead to estimate
10. the total number of patients hospitalised with diarrhoea per day. We did not access
11. any information that could identify individual participants during or after data
12. collection. The DDSS platform recorded the information of all-cause diarrhoea
13. patients who were enrolled into the surveillance system (21). It is likely that
14. predominantly infectious gastroenteritis (IG) cases were included in this study.
15. However, a limited number of people who had chronic or persistent diarrhoea at their
16. first presentation and people with inflammatory bowel disease (IBD) who presented
17. with similar symptoms were also likely included. Since ambient temperature
18. including heat wave affect both IG and IBD (14), and because it was logistically
19. impossible to test all stool samples for all possible pathogens, a syndromic approach
20. was regarded appropriate for this study (S1: Additional information on health data).

## Meteorological data

1. We collected data on daily climate parameters including the ambient,
2. maximum, minimum temperature, cumulative rainfall, and relative humidity for Dhaka
3. City from the Bangladesh Meteorological Department (BMD) from 1981 – 2010. The
4. BMD recorded 3-hourly data from three validated weather stations for Dhaka
5. (https://bmd.gov.bd/external-link/https://dataportal.bmd.gov.bd/).

## Defining heat wave for Dhaka

1. In the absence of an acceptable and agreed definition of heat wave for
2. Dhaka, Bangladesh, 16 indices of heat wave were calculated for Dhaka by
3. incorporating the conditions known to affect thermal stress including day and night
4. time temperature and duration and based on available data and resources (11).
5. These are summarised in Table 1. Analyses of heat extremes were restricted to the
6. warm seasons (pre-monsoon summers and rainy monsoons – March – October) to
7. avoid confounding by cold temperature (15).
8. **Table 1: Definitions of the 16 proposed heat wave indicators tested. Max and**
9. **min represent the daily maximum and minimum temperature, respectively. All**
10. **indices calculated from March to October during 1981 – 2010**

|  |  |  |
| --- | --- | --- |
| **Index name** | **Conditions** | **Minimum duration**  **(day)** |
| **TAV95** | Daily mean temperature > 95th percentile | 1 |
| **TAV99** | Daily mean temperature > 99th percentile | 1 |
| **D95** | Daily max temperature > 95th percentile | 1 |
| **D99** | Daily max temperature > 99th percentile | 1 |
| **MIN95** | Daily min temperature >95th percentile | 1 |
| **D&N** | Daily max and min temperature >95th percentile | 1 |
| **TAV952** | Daily mean temperature > 95th percentile | 2 |
| **TAV953** | Daily mean temperature > 95th percentile | 3 |
| **TAV992** | Daily mean temperature > 99th percentile | 2 |
| **TAV993** | Daily mean temperature > 99th percentile | 3 |
| **D952** | Daily max temperature > 95th percentile | 2 |
| **D953** | Daily max temperature > 95th percentile | 3 |
| **D992** | Daily max temperature > 99th percentile | 2 |
| **D993** | Daily max temperature > 99th percentile | 3 |
| **MIN952** | Daily min temperature >95th percentile | 2 |
| **D&N2** | Daily max and min temperature >95th percentile | 2 |

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| 144 | **Exploratory analysis** |
| 145 | Any missing data on the climate or health parameters were replaced by the by |
| 146 | the respective month’s average value for the parameter. Using established methods, |
| 147 | each data series were checked for stationarity, autocorrelation, long-term trends, |
| 148 | seasonality, possible outliers, normality, homoscedasticity and volatility (22-24). |

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## Regression modelling

1. Negative binomial time series regression models were employed to compute
2. the incidence rate ratio (IRR) estimates for the effect of heat waves on daily
3. diarrhoea hospitalisations. The Wald-type 95% confidence intervals for the incidence
4. rate ratios and associated *P*-values based on a reference distribution were also
5. computed. The simple heat wave indicators defined above were used as predictor
6. variables, and the regression models were used to determine the percentage
7. increase or decrease in diarrhoea morbidity associated with each indicator. The risk
8. estimates were adjusted for day of the week effects (with 7 categories, treating
9. public holidays as Fridays), long-term time trend and seasonality (using natural cubic
10. splines) and autocorrelation. Given that the optimum degree of freedom per year to
11. account for the long-term trend and seasonality was unknown, the analysis was
12. repeated with 3–7 degrees of freedom per year. The model with the lowest BIC value

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was the preferred model.

1. Past studies have shown significant effects of heavy rainfall and inconsistent
2. effects of relative humidity on diarrhoea (25-34). As a result, the heat wave models
3. were adjusted for heavy rainfall and humidity was not included in the models. Heavy
4. rainfall (defined as the rainfall above the 95th percentile for the study period) was
5. included as a categorical variable. Past studies have also highlighted potential lag
6. effects of heavy rainfall on diarrhoea. Since individual and distributed lagged models
7. allowed investigation of potential harvesting effects, correlation analysis was
8. performed with relevant lag values of temperature extremes. As statistically
9. significant relationship between heat wave at lags of 0 and 3 days and diarrhoea
10. were found, lag effects were considered in the final model. Lagged effects of heavy
11. rainfall (0-8 days) were also included into the model. Ultimately, a constrained
12. distributed lag linear model (DLLM) was used to investigate the effects of heat waves
13. on diarrhoea after adjusting for the potential confounding effects of other
14. meteorological factors, long-term trend, seasonality, day-of-the-week effect and

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autocorrelation.

181 The model took the following form:

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*Yt ~ Negative Binomial (µt, θ)*



1. Where, Yt denotes daily all-cause diarrhoea count, ETt and HeavyRaint denote
2. heat extreme and heavy rainfall indicator at time t. To control for long-term trends
3. and seasonality, a natural cubic spline with 7 degrees of freedom per year was
4. incorporated into the model. Dowt was the categorical day of the week with a

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reference day of Friday.

1. The relative risk of hospitalisation for all-cause diarrhoea during a heat wave
2. day was calculated from equation (1) as incidence rate ratio (IRR) and the
3. associated percentage increase in hospitalisation during heat wave days were

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derived from the model parameters through Eq. (2)



1. Multiple sensitivity analyses by changing the amount of control for seasonality
2. and long-term trend, including relative humidity as a linear term and heavy rainfall as

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| 199 | a categorical variable without any lagged effects were carried out to check if the |
| 200 | main findings were robust to changes in key assumptions. In addition, the analyses |
| 201 | were rerun using the total number of diarrhoea patients enrolled into the icddr,b |
| 202 | DDSS as the outcome instead of the total estimated diarrhoea hospitalisations per |
| 203 | day. |
| 204 |  |
| 205 | **Results** |
| 206 | Between March to October 1981–2010, a total of 61,054 diarrhoea cases |
| 207 | were enrolled into the DDSS platform and an estimated total of 2,171,500 patients of |
| 208 | all ages and 1,103,325 children <5 years of age with all-cause diarrhoea sought |
| 209 | hospital care from the icddr,b Dhaka Hospital. The average seasonal cycles of |
| 210 | diarrhoea hospitalisation, temperature, rainfall and relative humidity in Bangladesh |
| 211 | are shown in Fig 1. Diarrhoea hospitalisation in all ages and <5 children reached an |
| 212 | annual maximum in April. Mean temperature remained high from April to June |
| 213 | peaking during May before lowering down in October. Maximum temperature |
| 214 | reached an annual maximum in April and May (close to 35⁰C) and decreased |
| 215 | markedly during the rainy monsoon (June/July through to October) when the relative |
| 216 | humidity was also high. However, night time temperatures (daily minimum) did not |
| 217 | show similar pattern as day time temperatures (daily maximum). Relative humidity |
| 218 | reached an annual maximum at approximately 90% during July and decreased |
| 219 | towards the end of the rainy season in October. |

1. **Fig 1. Monthly distributions of all-cause diarrhoea hospitalisations in all ages**
2. **(upper left) and <5 children (upper right), mean (upper middle left), maximum**
3. **(upper middle right), minimum temperatures (lower middle left), relative**
4. **humidity (lower middle right), cumulative rainfall (lower left) and heavy rainfall**
5. **(lower right) in Dhaka, Bangladesh between 1 January 1981 and 31 December**
6. **2010**
7. Fig 2 shows the temporal distribution of the heat wave day indicators by
8. months. Most heat wave days were concentrated during the summer months. TAV95
9. and TAV99 heat wave categories peaked in May. D95 and D99 heat waves peaked
10. during April. The MIN95 heat wave days were more widely distributed between April
11. through October with the highest number found in June. The combined minimum and
12. maximum temperature category (D&N) heat wave days were concentrated during
13. April through June with the highest number in May.
14. **Fig 2. Monthly distribution of heat wave days in Dhaka, Bangladesh, March–**
15. **October 1981–2010**
16. Table 2 displays the temporal distribution of the heat wave day indicators by
17. decades. While the TAV95, TAV 99, MIN95 and D&N heat waves appeared to be
18. increasing, the D95 and D99 heat wave days showed a decreasing trend across the
19. decades. Table 3 shows the persistence of the heat wave day indicators lasting for
20. 1–13 days. In all categories, most of the heat waves lasted for one day only with very
21. few events lasting for more than four days. Two episodes of TAV95 heat wave and
22. one episode of D95 heat wave lasting for a maximum of 13 consecutive days were
23. identified during the study period.
24. **Table 2. Distribution of the 16 proposed heat wave indicators tested by decades.**
25. **Max and min represent the daily maximum and minimum temperature,**

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| 247 | **Table 3 Duration of persistence of heat wave days in Dhaka, Bangladesh,** |
| 248 | **1981–2010** |

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**respectively. All indices calculated from March to October during 1981 - 2010**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Index** | **Number of heat-wave events** | | | |
| **1981-1990** | **1991-2000** | **2001-2010** | **1981-2010** |
| **TAV95** | 112 | 130 | 167 | 409 |
| **TAV99** | 20 | 26 | 28 | 74 |
| **D95** | 141 | 144 | 106 | 391 |
| **D99** | 45 | 34 | 11 | 90 |
| **MIN95** | 100 | 127 | 158 | 385 |
| **D&N** | 17 | 18 | 28 | 63 |
| **TAV952** | 24 | 29 | 31 | 84 |
| **TAV953** | 14 | 17 | 18 | 49 |
| **TAV992** | 6 | 5 | 6 | 17 |
| **TAV993** | 0 | 3 | 4 | 7 |
| **D952** | 28 | 30 | 23 | 81 |
| **D953** | 18 | 20 | 14 | 52 |
| **D992** | 10 | 6 | 1 | 17 |
| **D993** | 5 | 3 | 1 | 9 |
| **MIN952** | 17 | 23 | 31 | 71 |
| **D&N2** | 4 | 3 | 5 | 12 |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Duration of persistenc e of heat**  **wave (Days)** | **Heat wave category** | | | | | |
| **TAV9 5** | **TAV99** | **D95** | **D99** | **MIN95** | **D&N** |
| **1** | 92 | 30 | 68 | 35 | 145 | 28 |
| **2** | 35 | 10 | 29 | 8 | 36 | 5 |
| **3** | 19 | 4 | 17 | 1 | 12 | 4 |
| **4** | 9 | 3 | 8 | 5 | 10 | 2 |
| **5** | 7 | - | 10 | 2 | 5 | 1 |
| **6** | 5 | - | 7 | 1 | 4 | - |
| **7** | 1 | - | 3 | - | 3 | - |
| **8** | 2 | - | 3 | - | - | - |
| **9** | 3 | - | 2 | - | - | - |
| **10** | - | - | - | - | 1 | - |
| **11** | 1 | - | - | - | - | - |
| **12** | - | - | 1 | - | 1 | - |
| **13** | 2 | - | 1 | - | - | - |

1. Table 4 displays the percentage increase in diarrhoea hospitalisation during
2. heat wave events. We found significant increase in diarrhoea hospitalisation in all
3. ages for only 5 out of the 16 proposed heat wave indicators. For <5 children
4. significant results were obtained for 6 out of the 16 proposed indices. Compared to a
5. non-heat wave day, all-cause diarrhoea hospitalisation increased by 7% and 8% in
6. all ages and by 14% and 24% in children under 5 years on a TAV95 and TAV99 heat
7. wave day, respectively. Increases in diarrhoea hospitalisations were strongest when
8. defining heat waves using 99th percentile of daily maximum temperature.
9. **Table 4. Percentage increase in diarrhoea hospitalisation in all ages and <5**
10. **children during heat wave days compared to non-heat wave days in Dhaka,**
11. **1981–2010**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **All ages** | | **<5 Children** | |
| **Indicator** | **Percentage increase in diarrhoea hospitalisations on heat wave days**  **(95% CI)** | ***P*-value** | **Percentage increase in diarrhoea hospitalisations on heat wave days**  **(95% CI)** | ***P*-value** |
| **TAV95** | **6.7 (4.6 – 8.9)** | <0.001 | **13.9 (8.3 – 19.9)** | <0.001 |
| **TAV99** | **8.3 (3.7 – 13.1)** | <0.001 | **24.2 (11.3 – 38.7)** | <0.001 |
| **D95** | **7.0 (4.8 – 9.3)** | <0.001 | **17.0 (11.0 – 23.5)** | <0.001 |
| **D99** | **7.4 (3.1 – 11.9)** | 0.001 | **19.5 (7.7 – 32.6)** | 0.001 |
| **MIN95** | 0.05 (-0.2 – 2.1) | 0.964 | 4.4 (-0.8 – 9.9) | 0.098 |
| **D&N** | 4.0 (-0.8 – 9.1) | 0.107 | **14.0 (0.9 – 28.7)** | 0.035 |
| **TAV952** | **4.6 (0.4 – 9.0)** | 0.031 | **21.0 (3.2 – 41.9)** | 0.019 |
| **TAV953** | -1.3 (-9.3 – 7.5) | 0.770 | 17.0 (-5.7 – 45.2) | 0.153 |
| **TAV992** | 1.9 (-0.50 – 9.2) | 0.599 | 29.4 (-3.9 – 74.3) | 0.089 |
| **TAV993** | 5.2 (-3.8 – 15.1) | 0.269 | 16.7 (-27.0 – 86.5) | 0.519 |
| **D952** | 1.9 (-5.0 – 9.2) | 0.599 | 13.4 (-4.91 – 35.1) | 0.162 |
| **D953** | 5.2 (-3.8 – 15.1) | 0.269 | 22.3 (-2.7 – 53.6) | 0.084 |
| **D992** | 11.5 (-2.3 – 27.2) | 0.755 | 22.77 (-12.1 – 71.3 | 0.230 |
| **D993** | -34.1 (-5.2 – 36.5) | 0.776 | -11.8 (-65.4 – 25.2) | 0.793 |
| **MIN952** | -5.8 (-11.6 – 0.2) | 0.058 | -2.3 (-16.5 – 14.4) | 0.755 |
| **D&N2** | -4.8 (-19.4 – 12.5) | 0.562 | 19.4 (-21.6 – 81.9) | 0.409 |

1. \*Bold values indicate significant results

262

1. Although lower than the same day effect, heat waves persisting for two days
2. (TAV952) was significantly associated with diarrhoea among all ages. This effect
3. was four times stronger in <5 children compared to all ages (4.6% Vs 21%).
4. Significant effects were also observed for maximum temperature categories (D95
5. and D99). For all ages, neither the minimum temperature nor the days when both
6. minimum and maximum temperature exceeded the 95th percentile (D&N) were
7. found to be significantly associated with diarrhoea hospitalisation. However,
8. significant effects of D&N were observed among <5 children. No significant effects of
9. heat wave that lasted for three or more days were observed in these models.
10. Lagged effects of heat wave days were evaluated for 0–14 days initially in
11. individual lag distributed models and later using constrained distributed lag linear
12. models. Diarrhoea hospitalisation decreased by 3.5% (95% CI: 1.5% – 5.4%) three
13. days following a TAV95 heat wave day. Significant negative effects of heavy rainfall
14. were observed at lags 0-1 whereas significant positive effects of heavy rainfall were
15. observed at the lags of 2–8 days. Compared to the holiday of week (Friday), diarrhoea
16. hospitalisations were significantly higher in all weekdays with the highest effect
17. observed on Sunday, when diarrhoea hospital increased by 10.3% (Table 5). Similarly,
18. diarrhoea hospitalisation decreased by 4.9% (95% CI: 0.7% – 9.0%) three days
19. following a TAV99 heat wave day.

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1. **Table 5 Adjusted associations among TAV95 heat wave (defined as the days**
2. **with elevated mean temperature above the 95th percentile) and diarrhoea**
3. **hospitalisations in Dhaka, March to October 1981 to 2010a**

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **IRR** | **95% CI** | **P-value** |
| **TAV95 Heat wave (Daily mean temperature >95th percentile)** | | | |
| **Lag 0** | 1.0672 | 1.0460 – 1.0889 | 0.000 |
| **Lag 1** | 1.0011 | 0.9765 – 1.0263 | 0.930 |
| **Lag 2** | 0.9783 | 0.9542 – 1.0030 | 0.084 |
| **Lag 3** | 0.9650 | 0.9457 – 0.9847 | 0.001 |
| **Heavy rainfall (>95th percentile)** | | | |
| **Lag 0** | 0.9098 | 0.8945 – 0.9253 | 0.000 |
| **Lag 1** | 0.9383 | 0.9221 – 0.9548 | 0.000 |
| **Lag 2** | 1.0201 | 1.0027 – 1.0378 | 0.023 |
| **Lag 3** | 1.0553 | 1.0373 – 1.0736 | 0.000 |
| **Lag 4** | 1.0544 | 1.0365 – 1.0727 | 0.000 |
| **Lag 5** | 1.0447 | 1.0270 – 1.0627 | 0.000 |
| **Lag 6** | 1.0243 | 1.0124 – 1.0478 | 0.001 |
| **Lag 7** | 1.0268 | 1.0076 – 1.0429 | 0.005 |
| **Lag 8** | 1.0222 | 1.0046 – 1.0394 | 0.013 |
| **Day of the week** | | | |
| **Friday** | Referent |  |  |
| **Saturday** | 1.0759 | 1.0580 – 1.0941 | 0.000 |
| **Sunday** | 1.1033 | 1.0849 – 1.1221 | 0.000 |
| **Monday** | 1.0668 | 1.0491 – 1.0848 | 0.000 |
| **Tuesday** | 1.0368 | 1.0197 – 1.0543 | 0.000 |
| **Wednesday** | 1.0558 | 1.0383 – 1.0735 | 0.000 |
| **Thursday** | 1.0646 | 1.0470 – 1.0824 | 0.000 |

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a Constrained distributed lag linear model developed using equation 1 after controlling for long term trend and seasonality, autocorrelation, and lagged effects of heavy rainfall (0-8).

AIC=75800; BIC=75964; Dispersion statistic=0.9577; Mean deviance residual=-0.0573

1. Each model was evaluated to check model fit in addition to evaluating the
2. dispersion statistic, and AIC and BIC values. Fig 3 displays the partial
3. autocorrelation plot of deviance residuals from the final regression model depicting
4. the relationship between TAV95 heat wave day and diarrhoea hospitalisation
5. showing minimal residual autocorrelations.

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1. **Fig 3. Partial autocorrelation function plot of deviance residuals of the final**
2. **regression model adjusted for autocorrelation where heat wave was defined by**
3. **the exceedance of 95th percentile of the mean temperature**

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# Discussion

1. This study found a statistically significant relationship between heat waves
2. and diarrhoea hospitalisations in Dhaka, Bangladesh. This is one of the few studies
3. to investigate the effects of heat waves on diarrhoeal disease morbidity and
4. therefore provides essential information for analysing the potential impact of climate
5. change on diarrhoea (14, 35). Diarrhoea hospitalisation increased by 6.7% (95% CI:
6. 4.6% – 8.9%) and 8.3% (95% CI: 3.1% – 13.1%) on a TAV95 and TAV99 heat wave
7. day.
8. On the other hand, diarrhoea hospitalisation decreased by 3.5% and 4.9%
9. three days following a TAV95 and TAV99 heat wave day, respectively. The apparent
10. protective incidence rate ratio obtained at the lag of 3 days suggested some degree
11. of short-term morbidity displacement i.e. ‘harvesting’ effect. During heat waves,
12. excess hospitalisation due to recent heat wave day (lag 3) may be offset by deficits
13. due to diarrhoea hospitalisation accelerated a couple of days by previous heat wave
14. days. A study in Vietnam has reported short-term displacement effect of diarrhoeal
15. diseases due to rainfall (36). While a few previous studies have reported short-term
16. displacement of deaths due to heat (37-39), the present study was the first to detect
17. any harvesting effect due to extreme heat on diarrhoea hospitalisation. A previous
18. study investigating the effect of heat waves on infectious diarrhoea in Zurich reported
19. a more pronounced effect of heat wave when a 7-day delayed effect of heat waves
20. was considered. The same study reported an immediate effect of heat wave on
21. diarrhoea due to inflammatory bowel disease (IBD). However, no harvesting effect of
22. heat waves was identified in that study (31). In contrast, this study identified an both
23. immediate and harvesting effect of heat waves on diarrhoea hospitalisation in
24. Bangladesh.
25. Environmental temperature is known to play a vital role in the growth and
26. replication of pathogenic bacteria including enterohaemorrhagic *Escherichia Coli*
27. (EHEC) and influence bacterial composition on food, water and skin (14, 40, 41).
28. Heat waves can promote environmental expansion of diarrhoeal pathogens, increase
29. consumption of contaminated drinking water and/or increase food spoilage leading to
30. excess diarrhoea. Given that a few previous studies have reported lags of days
31. between dates of onset of diarrhoea and healthcare seeking in affected individuals,
32. heat wave driven diarrhoea hospitalisation may be expected to take a few days to
33. occur. However, the effects of extreme temperature on diarrhoea hospitalisation
34. were mostly immediate in this study. One previous study using data from the same
35. hospital in Dhaka reported that most of the severely dehydrated patients presented
36. to the hospital within a narrow window of only 4–12 hours after symptom onset (42).
37. This suggested that the hospitalised patients in this study likely presented to the
38. hospital on the same day of the symptom onset. This may partly explain the
39. observed immediate effect of heat waves on diarrhoea hospitalisation in Dhaka. In
40. addition, heat waves may aggravate infectious diarrhoea among already affected
41. individuals leading to the excess hospitalisation for diarrhoea on the same day.
42. While most of the patients enrolled in this study are likely to be infectious in origin, a
43. few IBD diarrhoea cases may have been enrolled. Given that physical and mental
44. stress can lead to flares of IBD and because heat stress are known to increase the
45. frequencies of stress-dependent events including heart attacks and heat strokes
46. (43), heat waves may trigger the flares of IBD or worsen a clinically non-apparent
47. flare leading to excess diarrhoea (44).
48. In general, the effects of heat waves were most intense for children under 5
49. years of age compared to all ages. While the exact mechanism by which extreme
50. temperature affect children’s vulnerability to diarrhoea has never been investigated
51. in much detail, children may be generally more susceptible to infections owing to
52. their immature immune systems and low self-care capacity (45-48).
53. In this study, heat wave days defined by the exceedance of both 95th and 99th
54. percentile of both daily mean temperature and daily maximum temperature
55. performed as significant predictors of diarrhoea hospitalisation. A previous study
56. investigating the effects of heat waves on mortality proposed the heat wave indicator
57. combining day and night time temperatures as a suitable catchall indicator for heat
58. waves in Bangladesh (15). However, D&N heat wave day was only significantly
59. associated with childhood diarrhoea in the present study. The findings of the present
60. study therefore suggest that D&N heat wave may not serve as a suitable indicator for
61. heat wave in Dhaka, Bangladesh in relation to diarrhoeal disease morbidity.
62. Although high nighttime temperatures (i.e. daily minimum temperature) are known to
63. precipitate heat-related mortality by providing no cooling-down period at night (11),
64. such effects may not be relevant to diarrhoeal disease context and expectedly high
65. minimum temperature was not found to be significantly associated with diarrhoea
66. hospitalisation in this study. In addition, duration of heat waves was found to be less
67. important when considering the effect of heat waves on diarrhoeal disease morbidity.
68. While the robust surveillance system, 30-year duration and the relative
69. completeness of coverage of Dhaka’s population constitute key strengths of the data
70. set used in this study, there are several limitations. The estimated total number of all-
71. cause diarrhoea cases hospitalised per day may not represent the exact number of
72. cases admitted in the icddr,b Dhaka Hospital. Furthermore, the less severe cases
73. would be less likely to be included. However, these issues do not pose a threat to
74. the validity of the analysis of trends and comparisons over time, which is the theme
75. of this study. In addition, numerous models were evaluated in this study during the
76. sensitivity analysis to check the robustness of the results. Although the robustness of
77. the results to varying degrees of control for long-term trend and seasonality was
78. reassuring, yet there remains some possibility of residual confounding. Furthermore,
79. there are uncertainties related to the extrapolation of the relationships revealed in
80. this study to other locations with different climate and geography. In particular, the
81. observed association may also be greatly dependent on the degree of water and
82. sanitation infrastructure and hygiene practices in an area. Future studies from
83. different geographic locations and socio-economic settings may provide additional
84. information if the findings would pertain to other places.
85. Heat wave effects may vary depending on their intensity, duration, timing
86. during the season and other traits as previous studies investigating heat wave
87. effects on mortality suggested that heat waves occurring earlier in the summer can
88. have higher effects on mortality. While the effects of intensity and duration of heat
89. waves on diarrhoea has been examined in this study, the role of timing of heat
90. waves during the season was not investigated. While it is unlikely to change the
91. results of this study significantly, future studies could benefit from defining heat
92. waves using month-specific percentiles to examine the effect of timing of heat wave
93. on diarrhoea.

# Conclusion

1. This study identified heat wave as a risk factor for diarrhoea hospitalisation in
2. Dhaka, Bangladesh by proposing several heat wave indices. TAV95 is the preferred
3. heat wave indicator, which defines a heat wave as the elevated daily mean
4. temperature above the 95th percentile persisting for at least one day. This definition
5. results in 409 heat wave days and 176 separate heat waves in 30 years from 1981
6. to 2010. Almost all the heat waves occurred during the pre-monsoon summer
7. season, between April and June, with the highest number of heat waves in May.
8. Diarrhoea hospitalisations increased by 7% in all ages and 14% among children
9. under 5 years of age during a TAV95 heat wave day compared to a non-heat wave
10. day. These results can be used to define heat waves for Dhaka and motivate public
11. health interventions including generation of heat alerts to prevent heat-related
12. morbidity in Dhaka.

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| 557 | **Supporting information** |
| 558 | S1: Additional information on health data |
| 559 |  |

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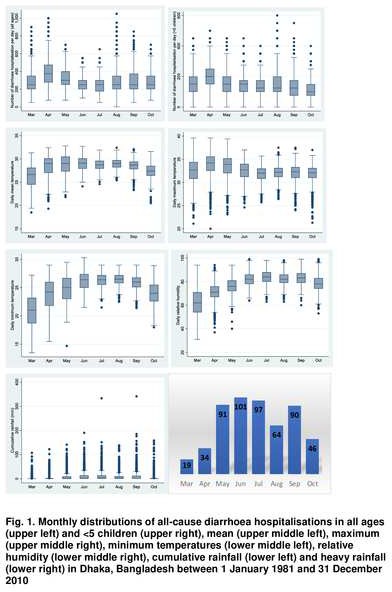


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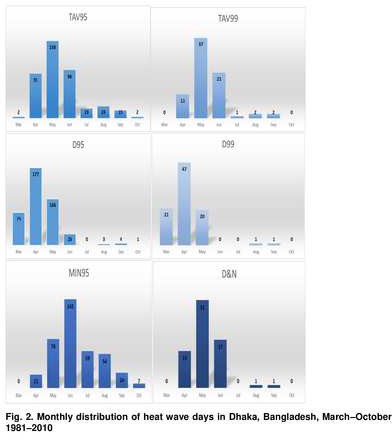
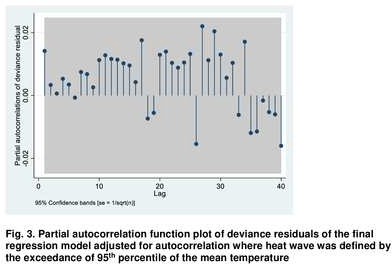


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