**Two Decades of Endemic Dengue in Bangladesh (2000-2022): Trends, Seasonality, and Impact of Temperature and Rainfall Patterns on Transmission Dynamics**

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**Abstract:**

**Background:** The objectives of this study were to compare dengue virus (DENV) cases, deaths, case-fatality ratio, and meteorological parameters between the first and the recent decade (2000-2010 vs. 2011-2022) and to understand the trends, seasonality, and impact of change of temperature and rainfall patterns on transmission dynamics of dengue in Bangladesh

**Methods:** For the period 2000-2022, dengue cases and death data from Bangladesh’s Ministry of Health and Family Welfare’s website, and meteorological data from the Bangladesh Meteorological Department were analyzed. A Poisson regression model was performed to identify the impact of meteorological parameters on the monthly dengue cases. A forecast of dengue cases was performed using an autoregressive integrated moving average model.

**Results:** Over the past 22 years, a total of 244,246 dengue cases were reported including 849 deaths (Case fatality ratio [CFR] =0.34%). The mean annual number of dengue cases increased eight times during the second decade, with 2,216 cases during 2000-2010 vs. 18,321 cases during 2011-2022. The mean annual number of deaths doubled (21 vs. 46), but the overall CFR has decreased by one-third (0.69% vs 0.23%). Concurrently, the annual mean temperature increased by 0.49 °C, and rainfall decreased by 314 mm. Monthly mean temperature (Incidence risk ratio [IRR]: 1.26), first-lagged rainfall (IRR: 1.08), and second-lagged rainfall (IRR: 1.17) were significantly associated with monthly dengue cases.

**Conclusions:** The increased local temperature and changes in rainfall seasonality might have contributed to the increased dengue cases in Bangladesh.

**Keywords:** Dengue, Bangladesh, Climate change, Temperature, Rainfall

**Introduction:**

Dengue fever is a mosquito-borne disease (MVD) caused by four distinct serotypes of the dengue virus (DENV) within the family *Flaviviridae* [1]. DENV is transmitted to humans by bites of *Aedes aegypti (L.)* and *Aedes albopictus (*Skuse*)* [2,3]. DENV is endemic in over 125 countries, and the number of cases globally reported to WHO continues to increase yearly [4,5]. Annually, an estimated 390 million dengue infections are estimated worldwide, including 96 million clinical cases making DENV one of the most important vector-borne diseases (VBDs) [6–8]. Most infections (>80%) are self-limiting with no or mild clinical manifestation resulting in lifelong immunity for that serotype [9]. However, reinfection with different serotypes, known as secondary or tertiary dengue infection, may result in severe dengue, including increasing the risk of fatal outcomes[10].

Currently, South and Southeast Asia are ‘hotspots’ of DENV infection, with more than 50% of cases recorded in these regions [11]. The first DENV outbreak in Bangladesh was reported in 2000, and since then, dengue has become endemic in the country posing a significant health challenge [12]. Over the past few years, the number of dengue cases has been steadily increasing, with significant seasonal and regional variations. Analysis of data from 2000 to 2017 revealed that almost half of the dengue cases occurred during the monsoon (May-August) and the post-monsoon (September-December) seasons [13]. However, a shift in seasonal patterns has been observed since 2014, with dengue cases being reported during the pre-and-post monsoon seasons [13]. Historically Monsson has been the primary dengue transmission season in Bangladesh although the number of dengue cases has increased during the post-monsoon season in recent years [14]. [13][15]

Bangladesh’s hot and humid weather favor’s reproduction of a large variety of mosquito species with a record of more than 123 species listed in 2016 [16]. The most detected larvae in the capital city Dhaka were *Culex, Anopheles, Toxorhynchites and Aedes and Mansonia*[17]. The most common vector of dengue virus, *Ae aegypti* and *Ae albopictus* were first recorded in 1952[18] and recent studies showed a higher Breteau index which measures the number of positive containers per 100 households in Dhaka, Bangladesh: 30.8 in 1997, 24.6 in 2000, 55.8 in 2011, 28.7 in 2012 and 22.5 in 2013 [19,20]. In 2022, the maximum Breteau index of >50 was recorded for six wards of the Dhaka South City corporation area [21]. The pupal index (PI) which measures the number of pupae per 100 houses was estimated during the monsoon season in several years in Bangladesh: 62.2 in 2011, 153.5 in 2012, and 75.9 in 2013[18]. However, during the dry period, the PI was estimated as 16.7 in 2012 [18].

Climate change, including changes in precipitation, temperature, and humidity, as well as rapid unplanned urbanization, were identified as strong indicators of an ecological imbalance that has led to an increase in dengue cases in Bangladesh [13]. These changes suggest that the dengue transmission season could eventually extend year-round, with a chance of outbreaks occurring at any time of the year. Identifying trends and seasonality in dengue cases can aid health authorities and relevant public and private administrations in effectively allocating resources to control the spread of the DENV through vector control. The objectives of our current study were to: i) compare the annual and monthly dengue cases between 2000 and 2022, ii) identify the overall trend and seasonality of dengue cases, iii) quantify the impact of weather parameters on the monthly dengue cases, and iv) forecast the annual dengue cases for the next decade.

**Methods:**

**Data sources:**

The current dengue surveillance in Bangladesh is coordinated by the Management Information System (MIS) of the Ministry of Health and Family Welfare of Bangladesh [22]. The surveillance includes the hospitalized patients diagnosed as infected with the dengue virus in the country primarily from government hospitals except in the capital city Dhaka, where more than 57 private hospitals are included in addition to 20 public hospitals. Outside the capital city Dhaka, the central district hospital of each 64 districts and medical college hospitals are also included in the surveillance system. We collected the data on the number of reported dengue cases and deaths from the publicly shared database of MIS for the period of January 2000 to December 2022 [15]. We used the definition of dengue cases used by the Ministry of Health and Family Welfare, Bangladesh. “Dengue cases were identified based on clinical symptoms (including fever and rash) and/or laboratory tests for IgM or IgG antibodies to DENV, and nonstructural 1 protein (NS-1) of DENV [23].

We used three-hourly temperature and daily rainfall data from only Dhaka, as the majority of the cases were reported from Dhaka. We collected those data from the Bangladesh Meteorological Department (BMD) over the period 2000–2022 for the meteorological station located in Mirpur, Dhaka (Lat 23.46, Lon 90.23). However, we acknowledged that the weather data of one station might not be representative of the whole country. Historically, more than 90% of dengue cases in Bangladesh were recorded from Dhaka [17] and thus our analysis will be more relevant to the weather changes of Dhaka city rather than the whole country.

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**Procedures**

The monthly number of dengue cases was used as the primary outcome variable. Two weather variables- temperature and rainfall were used as the covariates for the regression analysis. In addition, two lagged variables monthly rainfall in lag 1 and lag 2 were also used as predictors for the monthly dengue cases to capture the impact of those meteorological parameters. A lagged variable refers to a value from a prior time point. When studying the meteorological impact on dengue cases, it's crucial to consider the time-series effect of lag variables: lag 1 refers to the data from the preceding month, and lag 2 pertains to the data from two months prior.

**Statistical analysis**

We analyzed the monthly dengue cases and meteorological data for the period of 2000-2022. We consider 2010 as a divider of the period 2000-2022 as the year is close to the median year of the duration. Then, we compared the number of dengue cases, deaths, and weather parameters in two decades (2000-2010 and 2011-2022) using a paired sample t-test, aimed at examining and comparing trends, developments, and changes over specific periods. In the first stage, descriptive analyses were conducted to determine the characteristics of confirmed dengue cases and deaths with mean, and interquartile range (IQR) in each year and each month for the entire period. Then, we compared the number of dengue cases, deaths, and weather parameters in two decades (2000-2010 and 2011-2022) using a paired sample t-test, aimed at examining and comparing trends, developments, and changes over specific periods. Next, we calculated the monthly growth factor (GF) of dengue cases by dividing the number of dengue cases reported in each month by the number of dengue cases reported in the previous month and repeating this process for each month from 2000 to 2022 [15]. The formula for the growth factor can be given by

where indicates the number of dengue cases in th month. To avoid the occurrence of zeros in some months, we added 1 to the total number of cases for each month. This allows us to obtain a real-valued measurement of the GF for the above equation. The distribution of GF was skewed; therefore, we used the natural log transformation before the data was further examined. However, we have also performed a reverse transformation of the log (GF) values by back-transforming exponentiating values to the original scale for ease of interpretation [15]. A monthly GF greater than 1 indicates that the number of dengue cases would be more than the number of dengue cases of the previous month while a GF less than 1 means that the number of dengue cases in a new month would be less than the previous month. For example, if there are 100 cases in January, the number of dengue cases in February would be 200 when the value of GF is 2.0 or 50 cases when the value of GF is 0.5 for January [15]

We performed forecasting using the autoregressive integrated moving average (ARIMA) model. The ARIMA model is a data-driven, exploratory strategy that enables us to fit a suitable model and forecast values. The ARIMA model consists of autoregressive (p) terms, differencing (d) terms, and moving average (q) operations, and it is denoted as ARIMA (p, d, q) [24]. To select the appropriate autoregressive and moving average orders, the autocorrelation function (ACF) and partial autocorrelation function (PACF) were examined. Additionally, the differencing parameter, represented by "d," indicated the number of times the time series was different to achieve stationarity. An ARIMA (p, d, q) process refers to an autoregressive moving average (ARMA) model that has been differenced "d" times to obtain stationarity[25]. By removing high-frequency noise from the data, the model discovers local patterns by assuming that the time series values are linearly related. We also conducted a Mann-Kendall (M-K) trend analysis to determine possible upward or downward trends [26]. The null hypothesis posits no monotonic trend, while the alternative hypothesis suggests the presence of a trend, which could be positive, negative, or non-null. We also performed Sen's slope test to assess variations in annual dengue cases and deaths. The slope greater than 0 indicates an upward trend and less than 0 indicates a downward trend of a given period [27].

We, then used a time series count generalized linear model (GLM), more specifically, a time-series Poisson regression model to determine whether the meteorological factors were associated with the change in dengue cases over time [28][29,30]. Monthly dengue cases were utilized as the outcome variable in this model, along with data from the Bangladesh Meteorological Department (BMD) on temperature and rainfall.

We have estimated the degree-hour generated by the additional temperature each year in Bangladesh. To compare this with the extrinsic incubation period of the dengue virus in Aedes mosquito we estimated the degree-hour required to accomplish the EIP at 26° C using the mathematical formula [-0.1393 + 0.008\*Temp] suggested by Fock et al (1995) [31]. We used the statistical program RStudio, version 3.5.2.2 for the analyses [32].

**Results:**

Between 2000 and 2022, DGHS reported a total of 244,246 dengue cases, with an annual mean of 10,619 cases (interquartile range [IQR]: 859.5-5805.5), including 849 fatal outcomes with a case-fatality ratio (CFR) of 0.34%. Between 2000 to 2010, the mean annual number of dengue cases was 2,216 (IQR: 480-3182) which increased by 8 times in the following decade (2011-2022) at 18,321 (IQR: 1405-28429, p=0.22) **(Table 1)**. Between these two periods, the mean number of annual deaths due to DENV cases increased by 2.2 times, from 21.2 to 46.6 cases (p=0.85). However, the CFR of DENV cases decreased from 0.69% to 0.23 (p=0.08) % (**Table 1)**.

The highest monthly average number of cases was recorded in August (n=3,407 cases) and the lowest was in March (n=6.7 cases) **(Fig 1B)**. The highest number of annual cases was reported in 2019 with 101,354. The highest number of deaths was recorded in 2022 with 281 deaths, which was 35% of total deaths recorded in the past 23 years in Bangladesh **(Fig 1)**. Most (65%, n=550) of the dengue-related deaths were recorded after 2018 **(Fig 1)**.

The average annual temperature was 26.35 °C (SD=0.49) during the first decade (2000-2010) and 26.84 °C (SD=0.37) during the recent decade (2011-2022) (**Table 1**). The increase of 0.49 ° C temperature was equivalent to 4292 degree-hours/year of heat (365 days X 24 hours X 0.49 ° C). The annual total rainfall decreased by 314 mm between two decades, from 2078.6 mm to 1764.5 mm (**Table 1**), of which 308 mm decreased during the monsoon (July-October) season and only 6 mm decreased during the non-monsoon period. However, during pre-and-post monsoon season, rainfall (more than 3rd quantile value of monthly rainfall for the decade) increased in the second decade **(Fig 2)**.

The overall mean GF for the number of dengue cases per month was 1.37 (SD=0.86). However, in four months (April-July), the monthly GF was above one (lower 95% confidence interval >1), while for the rest of the months, the monthly GF was less than 1 (95% confidence interval crossed 1). More than 77% (71/92) of months between April and July for the period 2000–2022 had mean monthly GF > 1 compared to only 16% (30/184) of months between August and March of the same period. June had the highest GF with a mean value of 3.47 indicating that cases would be more than three times higher in the next month (July). The lowest GF was recorded in December with a mean of 0.54 (95% CI: 0.40 to 0.69) indicating that cases in January would be halved compared to the number of cases recorded in December (**Fig. 3**). In the M-K trend analysis, we found a positive trend of reported dengue cases (p <0.001 and tau = 0.26). In Sen’s slope test, the slope was 171.67 (95% CI: -46 to 687) with a tau value of 0.26 and p-value of 0.14 indicating an upward trend in upcoming months.

In the GLM, the estimated effect of each variable is presented as the incidence risk ratio (IRR). The model indicates that dengue cases would rise by 26% with a one-degree centigrade (°C) temperature increase. For each additional centimeter (cm) of rainfall in the first lagged month, the number of dengue cases increased by 8% (IRR= 1.08 [95% CI: 1.08-1.09]), and in the second lagged month increases in cases would be by 17% [IRR=1. 17 (95% CI: 1. 17 -1.18)].

In the ARIMA model, we detected an increasing trend for the first few years, which then started to decline. However, a strong rise in cases was observed after 2018 except for 2020 (the first year of the COVID-19 pandemic). The forecasted value showed a continuously increasing trend in the number of DENV cases in Bangladesh **(Fig 4)**. For dengue virus transmission, approximately 349-degree-hours equivalent heat is needed to accomplish the EIP of dengue virus in *Aedes* mosquitoes at 26° C [31].

**Discussion:**

Dengue is currently an important public health challenge for Bangladesh. Our analysis showed that the number of DENV cases has increased eight times and deaths have doubled, and the CFR dropped to one-third between the first and second decades of this century in Bangladesh. Between these periods, the annual temperature increased by 0.49 °C, and annual rainfall decreased by 314 mm, despite changes in seasonality of rainfall with unusually early or late rainfall outside the typical monsoon season (July-October) [33]. The monthly growth factor remained above one for four months (April to July) which overlapped the hot and humid period of the year. Monthly mean temperature, monthly first-lagged rainfall, and second-lagged rainfall played a critical role in monthly dengue cases in Bangladesh.

The increase of 0.49 °C temperature adds approximately 4292-degree-hours of equivalent heat per year. This additional heat would favor VBD transmission. For dengue virus transmission, approximately 349-degree-hours equivalent heat is needed to accomplish the extrinsic incubation period in *Aedes* mosquitoes at 26° C [31]. Therefore the addition of 0.49°C temperature will add the burden of more than 12 generations of infectious mosquitoes in the environment of Bangladesh. An 8-fold increase in dengue cases is an indication of such changes in temperature in the country. Our model identified a significant role of monthly mean temperature with an additional 1 °C temperature increasing the monthly cases by 26%. Earlier studies showed that for every 1 °C increase in temperature, dengue cases increased by 61% in Australia, 12-22% in Cambodia, 5% in Vietnam, and 2.6% in Mexico [34]. Increasing temperatures can accelerate mosquito reproduction and shorten the duration of the EIP of the virus allowing a faster transmission potential, increasing the biting rate but decreasing the daily survival probability of mosquitoes but in the long run expanding the geographic range of mosquitoes, impacting global disease transmission dynamics [35,36]. The draught can increase the risk of dengue with different delays, especially in urbanized areas that have a shortage and intermittent water supply during drought [37].

Rainfall provides oviposition and larval developmental sites and thereby plays an important role in mosquito-borne pathogen transmission. Although we found a 15% reduction in annual rainfall in the recent decade from the immediate past decade, we detected an increase in unusually high rainfall in pre-and-post monsoon seasons, therebyextending the season for mosquitoes and other arthropod vectors. Our model showed that both the first and the second lagged month’s rainfall increased monthly cases by 8% and 17%, respectively. These findings were consistent with earlier studies in Bangladesh that showed that peak dengue cases occurred two months after the peak rainfall[38] or an additional rainy day per month increased dengue cases by 6% in the succeeding month [39]. Similar findings were reported in Vietnam with dengue cases being associated with both first and second-lagged months[40]. In the greater part of the capital city Dhaka, there is a shortage of regular supply of water, and thus people attempt to store water from the daily supply when available as well as from rainwater. This might facilitate the breeding of Aedes mosquitoes [41]. In Timor-Leste, a 47% increase in dengue cases were recorded with an additional 1 mm seasonal rainfall increase [42]. These findings are biologically plausible as altered precipitation during pre- and post-monsoon allows extended vector seasons facilitating additional human cases[43].

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Bangladesh’s dengue season is characterized by hot and wet periods between June to August. This is the period with the highest amount of rainfall facilitating *Aedes* abundance in the country [45]. The monthly mean growth factor above 1 for April – June indicates that for each of these months, the dengue cases will surpass the previous month. Thus, we suggest starting vector control intervention in April in Bangladesh.

Two large dengue outbreaks occurred in Bangladesh during 2019 and 2022, with both characterized by unusual weather patterns and the occurrence of two different DENV serotypes. The 2019 outbreak was characterized by early rainfall of 120 mm in February compared to a monthly mean of 20 mm precipitation, along with the introduction of a new serotype of DENV-3 in the country [23]. The 2022 outbreak was characterized by the late onset of rainfall with 297 mm rainfall in October compared to a monthly mean of 156 mm that may have prolongedthe vector transmission season and by the introduction of a new serotype, DENV-4, in the country [45]. The occurrence of a new serotype exposed a large naïve population in a densely populated country like Bangladesh. A large proportion of the population had already been infected with one or more serotypes of DENV with more than 80% of people living in Dhaka having antibodies against DENV [38]. Another study predicted an estimated 40 million people had been infected with DENV nationally, with 2.4 million annual infections [53]. Thus, any subsequent infections raise the risk of developing severe dengue hemorrhagic fever through antibody-dependent enhancement (ADE) [10]. The deaths of many people in 2022 when DENV-4 was introduced were probably associated with secondary and/or tertiary DENV infection [45].

Controlling vector-borne diseases in tropical countries where temperatures, humidity, and rainfall remain favorable for mosquitoes during most periods of the year is a difficult task[45]. Concerns have been raised over the development of insecticide resistance [23,54] and the failure of developing a successful dengue vaccine [55]. The prospect of *Wolbachia-*related intervention is still far from being applied on a national scale considering the expenses and associated technicalities. In this situation, an integrated and holistic vector management plan while engaging the local communities is key for controlling *Aedes*-borne diseases, especially in resource-limited countries. Regular destruction of mosquito developmental sites and increasing surveillance for detecting active cases are key to controlling dengue virus infection. The development of a municipal water system that would preclude the need to store water is highly essential to prevent *Aedes* mosquito reproduction. Continuous active surveillance for DENV cases will enable early detection of cases and outbreaks. Public health authorities will be able to identify areas where the disease is spreading, take immediate action to control mosquito populations, isolate infected patients, and implement public awareness campaigns to educate people about preventive measures. Early detection and response can help prevent the further spread of the disease and reduce its impact on individuals and communities.

[45].

Several weaknesses may have impacted our study. We relied on the reported number of cases from the Ministry of Health and Family Welfare’s website, which mainly relies on passive reporting systems from the selected health facilities in the country[23]. The hospitals included in the surveillance system are only a small fraction of total health care facilities in Bangladesh (~5%) where dengue patients can seek health care [22]. These numbers seem to underestimate the actual number of infections and fever cases. A modeling study based on the national seroprevalence of DENV antibodies predicted an annual infection of 2.4 million people [53]. Dengue cases is underestimated globally as it is difficult to detect asymptomatic or mild cases that never reach healthcare settings. Although mild cases are missed more frequently, the severe and fatal cases would likely visit the hospital and thus be counted as numerators in our estimation. Thus, our estimation did not overlook the worst-case scenario, but may have estimated a higher CFR because of the underestimation of the denominators. Another limitation pertains to our exclusive utilization of weather data from the Dhaka station. Given Bangladesh's relatively small size and the moderate climate variation across the country, we focused our data collection solely on the Dhaka station. Furthermore, a substantial proportion of historical dengue data originates from Dhaka city. We could not use herd immunity data in our model as their data are not available for different serotypes of DENV in Bangladesh. However, earlier studies show that people living in the capital city and larger cities like Chittagong have higher seroprevalence whereas in the rural areas as low as 3% antibodies for DENV [53]. This illustrates a high risk of antibody-dependent enhancement (ADE) through secondary and tertiary infection in large cities. We also acknowledged that the increase in dengue cases in the recent decade could be a result of multiple factors that we could not include in the analysis. These factors include the improvement of the healthcare system which now detects a greater proportion of clinical cases than in the past, the arrival of new serotypes ode DENV, and the increased size of the urban population.

**Conclusions:**

Between the first (2000-2010) and the second decade (2011-2022), dengue cases have increased by 8.3 times, and annual deaths have increased by 2.2 times in Bangladesh. This growth of cases may partly be explained by global warming, with an increase of 0.49°C annual temperature as well as changes in duration and length of the rainy season. Unusual rain including early or late rain in and beyond the monsoon season likely contributed to extending the length of the dengue transmission season in Bangladesh. The monthly mean temperature and monthly total rainfall of the first-lagged month and second-lagged months showed a large influence on the monthly DENV cases in Bangladesh. The mean monthly growth factor remained significantly above one during April-July, which coincided with the hot and rainy season of the country indicating an earlier vector control would benefit the country. The ARIMA model forecasted a continuously increasing trend of DENV cases for the next decade in Bangladesh. We recommend an integrated and holistic vector management plan while engaging the local communities in the elimination of mosquito larval habitats and increasing surveillance for detecting active dengue cases. Proactive surveillance, vector control, and vaccine rollout remain essential public health interventions. In the context of climate change, urbanization, trade, and the movement of infected people, there is a need to operationalize the One Health approach to address dengue fever and other vector-borne diseases in Bangladesh and beyond.

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**Author contribution statement:** NH ideated the study and all authors helped develop the study outline and protocol. MNH and IK collected the data. NH, MNH, MA and AZ analyzed the data. NH, IK and MNH prepared the first draft manuscript and all authors contributed to several drafts and finalization of the manuscript. All authors approved the final draft and submission of the manuscript.

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**Conflict of interest:** The authors declare that they have no conflict of interest.

**Ethics statement:** This study does not include individual-level data and thus does not require ethical approval. We used publicly available data on Dengue cases and deaths.

**Data availability statement:** All the dengue data presented in this manuscript are publicly available on Bangladesh’s Ministry of Health and Family Welfare’s Directorate General of Health Services website (<https://dghs.gov.bd/> ). The meteorological data were purchased from Bangladesh Meteorological Department and are restricted to use for research purposes only and anyone interested in these data can request Bangladesh Meteorological Department (<https://live3.bmd.gov.bd/> ).

**References**

1. Simmonds P, Becher P, Bukh J, Gould EA, Meyers G, Monath T, et al. ICTV Virus Taxonomy Profile: Flaviviridae. J Gen Virol. 2017;98: 2–3. doi:10.1099/jgv.0.000672

2. CDC. Transmission through mosquito bites. 2019 [cited 15 May 2023]. Available: https://www.cdc.gov/dengue/transmission/index.html

3. WHO. DENGUE: GUIDELINES FOR DIAGNOSIS, TREATMENT, PREVENTION AND CONTROL. Geneva, Switzerland; 2009.

4. WHO. Dengue and severe dengue. https://www.who.int/news-room/fact-sheets/detail/dengue-and-severe-dengue. In: WHO. 16 Jul 2023 pp. 1–3.

5. Bhatt S, Gething PW, Brady OJ, Messina JP, Farlow AW, Moyes CL, et al. The global distribution and burden of dengue. Nature. 2013;496: 504–7. doi:10.1038/nature12060

6. WHO. Dengue and severe dengue. 2023 [cited 15 May 2023]. Available: https://www.who.int/news-room/fact-sheets/detail/dengue-and-severe-dengue

7. Murray NEA, Quam MB, Wilder-Smith A. Epidemiology of dengue: past, present and future prospects. Clin Epidemiol. 2013;5: 299–309. doi:10.2147/CLEP.S34440

8. Messina JP, Brady OJ, Golding N, Kraemer MUG, Wint GRW, Ray SE, et al. The current and future global distribution and population at risk of dengue. Nat Microbiol. 2019;4: 1508–1515. doi:10.1038/s41564-019-0476-8

9. WHO-Bangladesh. Dengue - Bangladesh. In: https://www.who.int/emergencies/disease-outbreak-news/item/2022-DON424. 28 Nov 2022.

10. Teo A, Tan HD, Loy T, Chia PY, Chua CLL. Understanding antibody-dependent enhancement in dengue: Are afucosylated IgG1s a concern? Evans MJ, editor. PLoS Pathog. 2023;19: e1011223. doi:10.1371/journal.ppat.1011223

11. WHO South-East Asia. Dengue in the South-East Asia. In: WHO Regional office for South-East Asia. May 2023 pp. 1–6.

12. Sharmin S, Viennet E, Glass K, Harley D. The emergence of dengue in Bangladesh: epidemiology, challenges and future disease risk. Trans R Soc Trop Med Hyg. 2015;109: 619–627. doi:10.1093/TRSTMH/TRV067

13. Mutsuddy P, Tahmina Jhora S, Shamsuzzaman AKM, Kaisar SMG, Khan MNA, Dhiman S. Dengue Situation in Bangladesh: An Epidemiological Shift in terms of Morbidity and Mortality. Can J Infect Dis Med Microbiol. 2019;2019. doi:10.1155/2019/3516284

14. Hossain MS, Noman A Al, Mamun SA Al, Mosabbir A Al. Twenty-two years of dengue outbreaks in Bangladesh: epidemiology, clinical spectrum, serotypes, and future disease risks. Trop Med Health. 2023;51: 37. doi:10.1186/s41182-023-00528-6

15. Haider N, Chang Y-M, Rahman M, Zumla A, Kock RA. Dengue outbreaks in Bangladesh: Historic epidemic patterns suggest earlier mosquito control intervention in the transmission season could reduce the monthly growth factor and extent of epidemics. Current Research in Parasitology & Vector-Borne Diseases. 2021;1: 100063. doi:10.1016/j.crpvbd.2021.100063

16. Irish SR, Al-Amin HM, Alam MS, Harbach RE. A review of the mosquito species (Diptera: Culicidae) of Bangladesh. Parasit Vectors. 2016;9: 559. doi:10.1186/s13071-016-1848-z

17. Bashar K, Rahman MdS, Nodi IJ, Howlader AJ. Species composition and habitat characterization of mosquito (Diptera: Culicidae) larvae in semi-urban areas of Dhaka, Bangladesh. Pathog Glob Health. 2016;110: 48–61. doi:10.1080/20477724.2016.1179862

18. Asir-Ud-Din M. Mosquitoes breeding in tree-holes and bamboo stumps in Dacca (East Pakistan). 2: 110–112. Pakistan Journal of Health . 1952;2: 110–112.

19. Ferdousi F, Yoshimatsu S, Ma E, Sohel N, Wagatsuma Y. Identification of Essential Containers for Aedes Larval Breeding to Control Dengue in Dhaka, Bangladesh. Trop Med Health. 2015;43: 253–64. doi:10.2149/tmh.2015-16

20. Paul KK, Dhar-Chowdhury P, Haque CE, Al-Amin HM, Goswami DR, Kafi MAH, et al. Risk factors for the presence of dengue vector mosquitoes, and determinants of their prevalence and larval site selection in Dhaka, Bangladesh. PLoS One. 2018;13: e0199457. doi:10.1371/journal.pone.0199457

21. Tawsia Tajmim. Aedes larva density high in Gulshan, Banani, Motijheel, Gopibagh . The Business Standard. 20 Sep 2022: 1–2.

22. Haider N, Asaduzzaman M, Hassan MN, Rahman M, Sharif AR, Ashrafi SAA, et al. Bangladesh’s 2023 Dengue outbreak – age/gender-related disparity in morbidity and mortality and geographic variability of epidemic burdens. International Journal of Infectious Diseases. 2023. doi:10.1016/j.ijid.2023.08.026

23. Ahsan A, Haider N, Kock R, Benfield C. Possible Drivers of the 2019 Dengue Outbreak in Bangladesh: The Need for a Robust Community-Level Surveillance System. Reisen W, editor. J Med Entomol. 2021;58: 37–39. doi:10.1093/jme/tjaa150

24. Kumar N, Susan S. COVID-19 Pandemic Prediction using Time Series Forecasting Models. 2020 11th International Conference on Computing, Communication and Networking Technologies (ICCCNT). IEEE; 2020. pp. 1–7. doi:10.1109/ICCCNT49239.2020.9225319

25. Hasan MN, Haider N, Stigler FL, Khan RA, McCoy D, Zumla A, et al. The Global Case-Fatality Rate of COVID-19 Has Been Declining Since May 2020. Am J Trop Med Hyg. 2021;104: 2176–2184. doi:10.4269/ajtmh.20-1496

26. Yue S, Pilon P. A comparison of the power of the t test, Mann-Kendall and bootstrap tests for trend detection / Une comparaison de la puissance des tests t de Student, de Mann-Kendall et du bootstrap pour la détection de tendance. Hydrological Sciences Journal. 2004;49: 21–37. doi:10.1623/hysj.49.1.21.53996

27. Sen PK. Estimates of the Regression Coefficient Based on Kendall’s Tau. J Am Stat Assoc. 1968;63: 1379–1389. doi:10.1080/01621459.1968.10480934

28. Sumi SN, Sinha NC, Islam MA. Generalized linear models for analyzing count data of rainfall occurrences. SN Appl Sci. 2021;3: 481. doi:10.1007/s42452-021-04467-x

29. Fokianos K. Count Time Series Models. 2012. pp. 315–347. doi:10.1016/B978-0-444-53858-1.00012-0

30. Quddus MA. Time series count data models: An empirical application to traffic accidents. Accid Anal Prev. 2008;40: 1732–1741. doi:10.1016/j.aap.2008.06.011

31. Focks DA, Daniels E, Haile DG, Keesling JE. A simulation model of the epidemiology of urban dengue fever: Literature analysis, model development, preliminary validation, and samples of simulation results. American Journal of Tropical Medicine and Hygiene. 1995. doi:10.4269/ajtmh.1995.53.489

32. R Core Team. R: A language and environment for statistical computing. Vienna, Austria. URL https://www.R-project.org/. Austria; 2022.

33. Haider N, Rahman MS, Khan SU, Mikolon A, Gurley ES, Osmani MG, et al. Identification and Epidemiology of a Rare HoBi-Like Pestivirus Strain in Bangladesh. Transbound Emerg Dis. 2014;61: 193–198. doi:10.1111/tbed.12218

34. Soneja S, Tsarouchi G, Lumbroso D, Tung DK. A Review of Dengue’s Historical and Future Health Risk from a Changing Climate. Curr Environ Health Rep. 2021;8: 245–265. doi:10.1007/s40572-021-00322-8

35. Najmul Haider. Modeling the vector-borne disease transmission potential in northern Europe with a special emphasis on microclimatic temperature: PhD Thesis. Technical University of Denmark. 2018. Available: https://orbit.dtu.dk/en/publications/modeling-the-vector-borne-disease-transmission-potential-in-north

36. Couper LI, Farner JE, Caldwell JM, Childs ML, Harris MJ, Kirk DG, et al. How will mosquitoes adapt to climate warming? Elife. 2021;10. doi:10.7554/eLife.69630

37. Lowe R, Lee SA, O’Reilly KM, Brady OJ, Bastos L, Carrasco-Escobar G, et al. Combined effects of hydrometeorological hazards and urbanisation on dengue risk in Brazil: a spatiotemporal modelling study. Lancet Planet Health. 2021;5: e209–e219. doi:10.1016/S2542-5196(20)30292-8

38. Salje H, Morales I, Gurley ES, Saha S. Seasonal Distribution and Climatic Correlates of Dengue Disease in Dhaka, Bangladesh. Am J Trop Med Hyg. 2016;94: 1359–1361. doi:10.4269/ajtmh.15-0846

39. Rahman KM, Sharker Y, Rumi RA, Khan M-UI, Shomik MS, Rahman MW, et al. An Association between Rainy Days with Clinical Dengue Fever in Dhaka, Bangladesh: Findings from a Hospital Based Study. Int J Environ Res Public Health. 2020;17: 9506. doi:10.3390/ijerph17249506

40. Cuong HQ, Hien NT, Duong TN, Phong TV, Cam NN, Farrar J, et al. Quantifying the Emergence of Dengue in Hanoi, Vietnam: 1998–2009. PLoS Negl Trop Dis. 2011;5: e1322. doi:10.1371/journal.pntd.0001322

41. Akanda AS, Johnson K, Ginsberg HS, Couret J. Prioritizing Water Security in the Management of Vector‐Borne Diseases: Lessons From Oaxaca, Mexico. Geohealth. 2020;4. doi:10.1029/2019GH000201

42. Wangdi K, Clements ACA, Du T, Nery SV. Spatial and temporal patterns of dengue infections in Timor-Leste, 2005–2013. Parasit Vectors. 2018;11: 9. doi:10.1186/s13071-017-2588-4

43. Yuan H-Y, Liang J, Lin P-S, Sucipto K, Tsegaye MM, Wen T-H, et al. The effects of seasonal climate variability on dengue annual incidence in Hong Kong: A modelling study. Sci Rep. 2020;10: 4297. doi:10.1038/s41598-020-60309-7

44. Siraj AS, Oidtman RJ, Huber JH, Kraemer MUG, Brady OJ, Johansson MA, et al. Temperature modulates dengue virus epidemic growth rates through its effects on reproduction numbers and generation intervals. PLoS Negl Trop Dis. 2017. doi:10.1371/journal.pntd.0005797

45. Haider N, Hasan MN, Khalil I, Tonge D, Hegde S, Chowdhury MAB, et al. The 2022 dengue outbreak in Bangladesh: hypotheses for the late resurgence of cases and fatalities. J Med Entomol. 2023. doi:10.1093/jme/tjad057

46. European CDC. Dengue worldwide overview. In: ECDC. 1 Jun 2023 pp. 1–10.

47. Huits R, Schwartz E. Fatal outcomes of imported dengue fever in adult travelers from non-endemic areas are associated with primary infections. J Travel Med. 2021;28. doi:10.1093/jtm/taab020

48. Liu Y, Lillepold K, Semenza JC, Tozan Y, Quam MBM, Rocklöv J. Reviewing estimates of the basic reproduction number for dengue, Zika and chikungunya across global climate zones. Environmental Research. 2020. doi:10.1016/j.envres.2020.109114

49. Rahim R, Hasan A, Hasan N, Nakayama EE, Shioda T, Rahman M. Diversity of Dengue Virus Serotypes in Dhaka City: From 2017 to 2021. Bangladesh Journal of Medical Microbiology. 2021;15: 23–29. doi:10.3329/bjmm.v15i2.57817

50. Diseases Control Division (DGHS). National guidelines for clinical management of Dengue syndrome. Dhaka; 2013.

51. WHO. Improving the quality of care in the public health system in Bangladesh: building on new evidence and current policy levers: Bangladesh Health Systems in Transition, Policy Notes. Dhaka ; 2017 Jan.

52. Albis MLF, Bhadra SK, Chin B. Impact evaluation of contracting primary health care services in urban Bangladesh. BMC Health Serv Res. 2019;19: 854. doi:10.1186/s12913-019-4406-5

53. Salje H, Paul KK, Paul R, Rodriguez-Barraquer I, Rahman Z, Alam MS, et al. Nationally-representative serostudy of dengue in Bangladesh allows generalizable disease burden estimates. Elife. 2019;8. doi:10.7554/eLife.42869

54. Al-Amin HM, Johora FT, Irish SR, Hossainey MRH, Vizcaino L, Paul KK, et al. Insecticide resistance status of Aedes aegypti in Bangladesh. Parasit Vectors. 2020;13: 622. doi:10.1186/s13071-020-04503-6

55. Wang TT, Sewatanon J, Memoli MJ, Wrammert J, Bournazos S, Bhaumik SK, et al. IgG antibodies to dengue enhanced for FcγRIIIA binding determine disease severity. Science (1979). 2017;355: 395–398. doi:10.1126/science.aai8128

56. BMD. Climate and Weather Data Portal | Bangladesh Meteorological Department. 2023 [cited 15 May 2023]. Available: http://www.bmddataportal.com/#/

**Tables and Figure Legends:**

**Tables:**

**Table 1: Comparison of dengue cases, deaths, and weather parameters between the first (2000-20210) and the recent decade (2011-2022) in Bangladesh**

**Figures:**

**Fig 1A:**: Number of dengue cases and deaths over the period 2000-2022, Bangladesh. 1B: Number of monthly dengue cases and deaths recorded in Bangladesh, 2000-2022.

**Fig 2:** The boxplot compares monthly rainfall in Dhaka city, Bangladesh between two decades (2000-2010 vs 2011-2022). The bottom and top of the box indicate the first and third quantiles, the band inside the box is the median. The dots outside the box are individual outliers. Most of the months in the second decade had outlier rainfall whereas in the first decade, only the cooler months (Nov-Jan) had some extreme rainfall.

**Fig 3: Top:** Mean monthly growth factor for the period of 2000-2022. **Bottom:** The Monthly growth factor for the individual year 2000-2022. The horizontal dashed line indicates monthly growth factor 1 (the same number of dengue cases in two subsequent months).

**Fig 4:** The observed and forecasted number of dengue cases in Bangladesh using the autoregressive moving average (ARIMA) model including a 95% confidence interval.