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Complete List of Authors:	Hasan, Mohammad Nayeem; Shahjalal University of Science and Technology, Department of Statistics Khalil, Ibrahim; Government of the People's Republic of Bangladesh Ministry of Fisheries and Livestock, Department of Livestock Services Chowdhury, Muhammad Abdul Baker; University of Florida College of Medicine, Department of Neurosurgery Rahman, Mahbubur; University of London, Institute of Epidemiology; Ministry of Health and Family Welfare, Institute of Epidemiology Asaduzzaman, Md; Staffordshire University, Technologies, and Arts Billah, Masum; Staffordshire University, Technologies, and Arts Banu, Laila Arjuman; Bangabandhu Sheikh Mujib Medical University, Department of Anatomy Alam, Mahbub-Ul; International Centre for Diarrhoeal Disease Research Bangladesh, Environmental Intervention Unit Ahsan, Atik; International Centre for Diarrhoeal Disease Research Bangladesh, Environmental Intervention Unit Traore, Tieble; WHO, Emergency Preparedness and Response Programme Uddin, Md. Jamal; Shahjalal University of Science and Technology, Department of Statistics; Daffodil International University, Department of General Educational and Development Galizi, Roberto; Keele University, School of Life Sciences Russo, Ilaria; Keele University, School of Medicine Zumla, Alimuddin; University College London, Division of Infection and Immunity; University College London Hospitals NHS Foundation Trust, Division of Infection and Immunity Haider, Najmul; Keele University, School of Life Sciences
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Two Decades of Endemic Dengue in Bangladesh (2000-2022): Trends, Seasonality, and Impact of Temperature and Rainfall Patterns on Transmission Dynamics

Mohammad Nayeem Hasan[1], Ibrahim Khalil [2], Muhammad Abdul Baker Chowdhury [3], Mahbubur Rahman [4,5], Md Asaduzzaman [6], Masum Billah [6], Laila Arjuman Banu [7], Mahbub-ul Alam[8], Atik Ahsan [8], Tieble Traore [9], Md. Jamal Uddin[1,10] Roberto Galizi [11], Ilaria Russo[12], Alimuddin Zumla[13], Najmul Haider[11*]

[1] Department of Statistics, Shahjalal University of Science and Technology, Sylhet 3114, Bangladesh (MNH: nayeem5847@gmail.com, MJU: jamal-sta@sust.edu)

[2] Department of Livestock Services, Ministry of Fisheries and Livestock, Bangladesh, Dhaka, Bangladesh (IK: dribrahim.dls@gmail.com)

[3] Department of Neurosurgery, University of Florida College of Medicine, Gainesville, Florida FL 32610, USA (MABC: baker.chowdhury@neurosurgery.ufl.edu)

[4] The Royal Veterinary College, University of London, Hawkshead Lane, North Mymms, Hatfield, Hertfordshire, United Kingdom (Email: MR: dr_mahbub@yahoo.com)

[5] Institute of Epidemiology, Disease Control and Research (IEDCR), Ministry of Health and Family Welfare, Mohakhali, Dhaka, Bangladesh (MR: dr_mahbub@yahoo.com)

[6] School of Digital, Technologies, and Arts, Staffordshire University, Staffordshire, UK (MB: masum.billah@staffs.ac.uk , MA: Md.Asaduzzaman@staffs.ac.uk)

[7] Department of Anatomy, Bangabandhu Sheik Mujib Medical University, Dhaka, Bangladesh (dr.lailabanu@gmail.com)

[8] Environmental Intervention Unit, International Centre for Diarrhoeal Diseases Research, Bangladesh (ICDDR,B), Dhaka-1212, Bangladesh (MUA: mahbubalam@icddrb.org, AA: atik.ahsan@icddrb.org)

[9] Emergency Preparedness and Response Programme, WHO Regional Office for Africa, Dakar Hub, Daker, Senegal (TT: traoret@who.int)

[10] Department of General Educational and Development, Daffodil International University, Dhaka, Bangladesh (MJU: jamal-sta@sust.edu)

[11] School of Life Sciences, Faculty of Natural Sciences, Keele University, Keele, Staffordshire, United Kingdom, ST5 5BG (NH: n.haider@keele.ac.uk, RG: r.galizi@keele.ac.uk).

[12] School of Medicine, Faculty of Medicine and Health Sciences, Keele University, Staffordshire, ST5 5BG, United Kingdom (IR: i.russo@keele.ac.uk)

[13] Division of Infection and Immunity, Centre for Clinical Microbiology, University College London and NIHR-BRC, University College London Hospitals, London, United Kingdom (AZ: a.zumla@ucl.ac.uk).

***Corresponding author (NH):** Dr Najmul Haider, School of Life Sciences, Keele University, Huxley Building, Room 122, Keele, Staffordshire, ST5 5BG, United Kingdom, Email: n.haider@keele.ac.uk , Phone : **(+44) 01782 734414**

Abstract:

Background: The objectives of this study were to compare the dengue virus (DENV) infection, 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 pattern 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 incidence. 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-fold during the second decade, with 2216 cases during 2000-2010 vs. 18,321 cases during 2011-2022. The mean annual deaths have doubled (21 vs. 46), but the overall CFR has decreased to one-third (0.69% vs 0.23%). The annual 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 incidence.

Conclusions: The increased local temperature and unusual rainfall might have contributed to the increased incidence of DENV infection in Bangladesh. Community engagement, vector control, and destruction of mosquito habitats are key to controlling dengue.

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) of the Flaviviridae family (WHO 2009). DENV is transmitted to humans by mosquito bites of the female Aedes species, including *Aedes aegypti (L.)* and *Aedes albopictus (*Skuse*)* (WHO 2009, CDC 2019). DENV is endemic in over 125 countries, and the number of cases globally reported to WHO continues to increase yearly (WHO 2023a). Annually, an estimated 390 million dengue infections are recorded worldwide, including 96 million clinical cases making DENV one of the most important vector-borne diseases (VBDs) (Murray et al. 2013, WHO 2023b). Most infections (>80%) are self-limiting with no or mild clinical manifestation resulting in lifelong immunity for that serotype (WHO-Bangladesh 2022). However, infections with different serotypes, known as secondary or tertiary dengue infection, may result in severe dengue with a higher case-fatality ratio(Teo et al. 2023).

Currently, South and Southeast Asia are the hotspots of DENV infection with more than 50% of cases recorded in the regions (WHO South-East Asia 2023). The first official DENV outbreak in Bangladesh was reported in 2000, and since then, dengue has become endemic in the country posing a significant health challenge (Sharmin et al. 2015). 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 season (May-August) and the post-monsoon season (September-December) (Mutsuddy et al. 2019). However, a shift in seasonal patterns has been observed since 2014, with dengue cases being reported during the pre-and-post monsoon season (Mutsuddy et al. 2019). During 2015-2017, the number of dengue cases during the pre-monsoon season was more than seven times higher compared to the previous 14 years (Mutsuddy et al. 2019). The annual incidence of DENV infection started to increase sharply after the introduction of the serotype DENV-3 in 2019 in Bangladesh (Haider et al. 2021).

Climate change, including changes in precipitation, temperature, and humidity, as well as rapid unplanned urbanization, were identified as strong predictors of an ecological imbalance that has led to an increase in dengue cases in Bangladesh (Mutsuddy et al. 2019). This suggests that the dengue transmission season could eventually extend year-round, with a higher 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 study were to: i) compare the annual and monthly cases in the first [2000-2010] and recent decade [2011-2022], ii) identify the trend and seasonality of dengue cases, iii) quantify the impact of climatic parameters for the monthly incidence of dengue cases in the country and iv) forecast the annual incidence of dengue cases for next decade.

Methods:

Data sources:

The data on the number of reported dengue-infected people have been extracted from the Directorate General of Health Services (DGHS)'s website from January 2000 to December 2022 (DGHS 2023). We used the definition of dengue cases used by the Ministry of Health and Family Welfare, Bangladesh, which was discussed in our earlier article (Ahsan et al. 2021). We collected three-hourly temperature and daily rainfall data from Bangladesh Meteorological

Department (BMD) over the period 2000–2022 (BMD 2023) for the meteorological station located in Mirpur, Dhaka.

Variables

The monthly number of dengue cases was used as the primary outcome variable. Two climatic variables- temperature and rainfall are 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 the predictors for the incidence of monthly dengue cases to capture the actual impact of those meteorological parameters. We also used monthly mortality data for comparison between the two decades.

Statistical analysis

We analyzed the monthly dengue incidence and meteorological data for the period of 2000-2022. In the first stage, descriptive analyses were conducted to determine the characteristics of confirmed dengue cases and deaths with mean, and standard deviation in each year and each month for the entire period. Then, we compared dengue cases, deaths, and weather parameters in two decades (2000-2010 and 2011-2022) using paired sample t-test. 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 (Haider et al. 2021). The formula for the growth factor can be given by

$$GF_t = \frac{N_{t+1} + 1}{N_t + 1}$$

where N_t indicates the number of dengue cases in t^{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 first natural log transformation before the data was further examined. However, we have also performed a reverse transformation of the log (GF) values by exponentiating values to convert them to the original scale for ease of interpretation(Haider et al. 2021).

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) (Kumar and Susan 2020). 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," indicates the number of times the time series is 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 (Hasan et al. 2021). 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 (Yue and Pilon 2004). We also performed the Sen's slope test to assess variations in annual dengue cases and deaths(Sen 1968).

We, then used a time series count generalized linear model (GLM), more specifically, a time-series Poisson regression model to determine whether the climatic factors were associated with the dengue cases over time (Sumi et al. 2021). The non-normality, heteroscedasticity, and non-linearity that characterize count data can be fitted easily using GLMs. The time-series observations may possess autocorrelation and they might be nonnegative integers, and thus GLM is useful in overcoming both issues (Quddus 2008, Fokianos 2012). 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. To capture the actual impact of rainfall on dengue incidence across time, we additionally employed two lagged variables of meteorological elements, mainly rainfall in lag 1 and 2. After eliminating predictors with a higher multicollinear relationship, we have arrived at average temperature, rainfall (in lag 1), and rainfall (in lag 2) as the final set of predictors for the monthly dengue incidence in Bangladesh. We used the statistical program RStudio, version 3.5.2.2 for the analyses (R Core Team 2022).

Results:

Between 2000 and 2022, Bangladesh reported a total of 244,246 dengue cases with an annual mean of 10,161 cases (± standard deviation [SD]=23,971) including 849 fatal outcomes indicating a case-fatality ratio (CFR) of 0.34%. Between 2000 to 2010, the mean annual number of dengue cases was 2,216 (±2,123) which has increased over eight folds in the following decade (2011-2022) at 18,321 (±31,778) **(Table 1)**. Between these two periods, the mean number of annual deaths due to DENV infection increased by 2.2 times, from 21.2 to 46.6 cases. However, the CFR of DENV infection decreased from 0.69% to 0.23% **(Table 1)**.

The highest monthly average number of cases was recorded in August (n=3407 cases) and the lowest was in March (n=6.7 cases) **(Fig 1)**. 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 of the dengue-related deaths were recorded after 2018, with more than 65% (n=550) deaths recorded during this time **(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-hour/year of heat (365 days X 24 hours X 0.49 °C). The annual 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, the unusual rainfall (more than 3rd quantile value of monthly rainfall for the decade) increased in the second decade **(Fig 2)**.

The overall mean GF from month to 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) indicating an upward trend in upcoming months (**Table 2**).

In the GLM, the estimated effect of each variable is presented as the incidence risk ratio (IRR). The model suggests that dengue cases would rise by 26% for 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 increase the cases by 17% [IRR=1. 17 (95% CI: 1. 17 -1.18)] **(Table 3)**.

In the ARIMA model, we detected an increasing trend for the first few years, which then started to decline. However, a stiff 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 of DENV infection in Bangladesh **(Fig 4)**.

Discussions:

Dengue is currently a worrying and important public health challenge for Bangladesh. Our analysis showed that the number of DENV infections 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 rainfall patterns with unusually early or late rainfall outside the typical monsoon season in Bangladesh (July-October) (Haider et al. 2014). The monthly growth factor remains above one for four months (April to July) which overlaps 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 incidence in Bangladesh.

The increase of 0.49 °C temperature adds approximately 4292-degree-hours equivalent heat per year in the country. This additional heat would favor VBD transmission. For dengue virus transmission, approximately 305-degree-hours equivalent heat is needed to accomplish the extrinsic incubation period in Aedes mosquitoes at 26° C (Focks et al. 1995). Thus, the additional 0.49°C temperature will add the burden of more than 14 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 (Soneja et al. 2021).

Rainfall facilitates mosquito breeding and plays an important role in mosquito-borne disease 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 season allowing an extended 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 are consistent with earlier studies in Bangladesh that showed that peak dengue cases occurred two months after the peak rainfall(Salje et al. 2016) or an additional rainy day per month increased dengue cases by 6% in the succeeding month (Rahman et al. 2020). Similar findings were reported in Vietnam with the dengue incidence being associated with both first and second-lagged months(Cuong et al. 2011). In Timor-Leste, a 47% increase in dengue incidence was recorded with an additional 1 mm seasonal rainfall increase (Wangdi et al. 2018). These findings are biologically plausible as rainfall allows approximately two generations of dengue cases over a month. A generation interval is a time difference between a primary human infection and a second human infection originating from the first human case through two bites of the mosquitoes(Siraj et al. 2017). To accomplish a generation interval the virus and mosquito undergo several phases including intrinsic incubation period in humans, human-mosquito transmission (first bite), extrinsic incubation period in mosquitoes, blood meal digestion period, and finally mosquitoes-to-human transmission (2^{nd} bite) (Siraj et al. 2017). Ideally, for DENV, the generation interval completes at around 16 days at 28-32 °C (Siraj et al. 2017).

Bangladesh's dengue season is characterized by hot and wet periods running between June to August. This is the period with the highest amount of rainfall in the country facilitating Aedes mosquito breeding in the country (Haider et al. 2023). The monthly mean growth factor above 1 for April – June indicates that for each of these months, the incidence of dengue cases will surpass the current month. Thus, we suggest starting vector control intervention in April in Bangladesh.

Globally and regionally in South and Southeast Asia, dengue cases are increasing. DENV infection increased by more than 46% between 2015 and 2019 in the region (WHO South-East Asia 2023). In 2023, up until 31 May, a total of 1515,460 DENV infections were recorded in Brazil with 387 deaths(European CDC 2023). In Malaysia, a total of 43,619 DENV infections have been recorded by 21 May 2023(European CDC 2023). We found an increasing trend of DENV infection in Bangladesh. This increasing trend was much stiffer after the serotype DENV-3 was introduced in the country in 2018 (Ahsan et al. 2021). This increased trend is possibly linked with climate change in the region attributed to increased temperature and unusual rainfall, urbanization, population growth, inadequate water supply and storage practice, poor sewer, and waste management system, rise in global commerce and tourism (WHO South-East Asia 2023).

The case fatality ratio (CFR) of primary dengue infection is very low with an estimation of 0.018% - 0.1% (Huits and Schwartz 2021). However, the CFR of secondary or tertiary DENV infection is high, although precise estimates are not available, some studies show more than 1% and reaching up to 4% (Liu et al. 2020). Bangladesh's overall CFR of dengue infection (0.34%) seems slightly higher considering the overall CFR reported in other South and Southeast Asian countries (WHO South-East Asia 2023). However, more than 65% of dengue-related deaths in Bangladesh were recorded after the introduction of the serotype DENV-3 in 2019. Earlier, DENV serotypes 1-3 had been reported over different years between 2000 and 2019 (Rahim et al. 2021) and DENV-4 had reappeared in 2022 (Haider et al. 2023). Thus, secondary, or tertiary infections are likely contributing to higher dengue-related deaths in Bangladesh. In addition, the CFR of the dengue virus infection might have been affected by a lack of active surveillance and missing the mild and asymptomatic cases, and not recording the cases outside the public hospitals and few selected private hospitals in Bangladesh or a weaker health care system in the country (Ahsan et al. 2021). In some years, the CFR was very high, for example, in 2003, the CFR was 2.1 (total cases 486), in 2000, 1.68 (total cases 5,551), and in 2022, 0.45 (total cases 62,382). On the other hand, the CFR of DENV infection decreased in the second decade in Bangladesh. This improvement is probably associated with improved access to the health care system, a better understanding of the treatment protocol including the availability of clinical management guidelines and training for the health care providers, better availability of Information, Education, and Communication (IEC) materials, community engagement and expansion of surveillance system to more hospitals in the surveillance system across the county in the recent years, and overall improvement of the economic condition of the country (Diseases Control Division (DGHS) 2013, WHO 2017, Albis et al. 2019).

Two large dengue outbreaks occurred in Bangladesh in the years 2019 and 2022 both characterized by unusual weather patterns and the occurrence of two different 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 (Ahsan et al. 2021). 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, and thus prolongation of vector transmission season along with the introduction of a new serotype, DENV-4 in the country (Haider et al. 2023). The occurrence of a new serotype exposed a large naïve population in a densely populated country like Bangladesh. A large proportion of the population has already been infected with one or more serotypes of DENV with more than 80% of people living in

Dhaka having antibodies against DENV (Salje et al. 2016). Another study predicted an estimated 40 million people being infected with DENV nationally and 2.4 million annual infections (Salje et al. 2019). Thus, any subsequent infections raise the risk of developing severe dengue hemorrhagic fever through antibody-dependent enhancement (ADE) (Teo et al. 2023). The deaths of many people in 2022 when DENV-4 was introduced were probably associated with secondary and/or tertiary DENV infection (Haider et al. 2023).

Controlling vector-borne diseases in tropical countries where temperatures, humidity, and rainfall remain favorable for breeding mosquitoes during most periods of the year is a difficult task(Haider et al. 2023). Concerns were raised over the development of insecticide resistance (Al-Amin et al. 2020, Ahsan et al. 2021) and the failure of developing a successful dengue vaccine (Wang et al. 2017). The prospect of *Wolbachia*-related intervention is bright but 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 in controlling dengue virus infection. Continuous active surveillance of DENV infections 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.

Regular destruction of mosquito developmental habitats and increasing surveillance for detecting active cases should be prioritized for controlling DENV infection in Bangladesh. Policymakers need to design an Aedes-borne disease management plan by considering a range of pathogens that Aedes mosquito can transmit including Chikungunya, yellow fever, Zika virus, West Nile, Japanese Encephalitis, Eastern Equine Encephalitis, Ross River, Rift Valley fever, and the LaCrosse virus (Haider et al. 2023).

Our data should be viewed in the light of instead of several weaknesses of 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(Ahsan et al. 2021). These numbers seem to underestimate the actual number of cases. A modeling study based on the national seroprevalence of DENV antibodies predicted an annual infection of 2.4 million cases (Salje et al. 2019). However, dengue infection is underestimated globally as it is difficult to diagnose 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, that is, our estimation, for example, estimated the higher CFR rather than the lower possible estimates.

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 is partly explained by the influence of 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 greater influence on the monthly incidence of DENV infection in Bangladesh. The mean monthly growth factor remains significantly above one during April-July, which coincides with the hot and rainy season of the country indicating an earlier vector control would benefit the country. The ARIMA model forecasts a continuously increasing trend of DENV infection for the next decade in Bangladesh. We recommend an integrated and holistic vector management plan while engaging the local communities in the regular destruction of mosquito breeding sites and increasing surveillance for detecting active DENV-infected 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 people with vectors, 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

Ahsan, A., N. Haider, R. Kock, and C. Benfield. **2021**. Possible Drivers of the 2019 Dengue Outbreak in Bangladesh: The Need for a Robust Community-Level Surveillance System. J Med Entomol. 58: 37–39.

Al-Amin, H. M., F. T. Johora, S. R. Irish, M. R. H. Hossainey, L. Vizcaino, K. K. Paul, W. A. Khan, R. Haque, M. S. Alam, and A. Lenhart. **2020**. Insecticide resistance status of Aedes aegypti in Bangladesh. Parasit Vectors. 13: 622.

Albis, M. L. F., S. K. Bhadra, and B. Chin. **2019**. Impact evaluation of contracting primary health care services in urban Bangladesh. BMC Health Serv Res. 19: 854.

BMD. **2023**. Climate and Weather Data Portal | Bangladesh Meteorological Department. (http://www.bmddataportal.com/#/).

CDC. **2019**. Transmission through mosquito bites. (https://www.cdc.gov/dengue/transmission/index.html).

Cuong, H. Q., N. T. Hien, T. N. Duong, T. V. Phong, N. N. Cam, J. Farrar, V. S. Nam, K. T. D. Thai, and P. Horby. **2011**. Quantifying the Emergence of Dengue in Hanoi, Vietnam: 1998–2009. PLoS Negl Trop Dis. 5: e1322.

DGHS. **2023**. DGHS. (https://old.dghs.gov.bd/index.php/bd/home/5200-daily-dengue-status-report).

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

European CDC. **2023**. Dengue worldwide overview. ECDC.

Focks, D. A., E. Daniels, D. G. Haile, and J. E. Keesling. **1995**. 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.

Fokianos, K. 2012. Count Time Series Models, pp. 315–347. *In* .

Haider, N., Y.-M. Chang, M. Rahman, A. Zumla, and R. A. Kock. **2021**. 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. 1: 100063.

Haider, N., M. N. Hasan, I. Khalil, D. Tonge, S. Hegde, M. A. B. Chowdhury, M. Rahman, M. Hossain Khan, R. Ansumana, A. Zumla, and M. J. Uddin. **2023**. The 2022 dengue outbreak in Bangladesh: hypotheses for the late resurgence of cases and fatalities. J Med Entomol.

Haider, N., M. S. Rahman, S. U. Khan, A. Mikolon, E. S. Gurley, M. G. Osmani, I. S. Shanta, S. K. Paul, L. Macfarlane-Berry, A. Islam, J. Desmond, J. H. Epstein, P. Daszak, T. Azim, S. P. Luby, N. Zeidner, and M. Z. Rahman. **2014**. Identification and Epidemiology of a Rare HoBi-Like Pestivirus Strain in Bangladesh. Transbound Emerg Dis. 61: 193–198.

Hasan, M. N., N. Haider, F. L. Stigler, R. A. Khan, D. McCoy, A. Zumla, R. A. Kock, and M. J. Uddin. **2021**. The Global Case-Fatality Rate of COVID-19 Has Been Declining Since May 2020. Am J Trop Med Hyg. 104: 2176–2184.

Huits, R., and E. Schwartz. **2021**. Fatal outcomes of imported dengue fever in adult travelers from non-endemic areas are associated with primary infections. J Travel Med. 28.

Kumar, N., and S. Susan. **2020**. COVID-19 Pandemic Prediction using Time Series Forecasting Models, pp. 1–7. *In* 2020 11th International Conference on Computing, Communication and Networking Technologies (ICCCNT). IEEE.

Liu, Y., K. Lillepold, J. C. Semenza, Y. Tozan, M. B. M. Quam, and J. Rocklöv. **2020**. Reviewing estimates of the basic reproduction number for dengue, Zika and chikungunya across global climate zones. Environ Res.

Murray, N. E. A., M. B. Quam, and A. Wilder-Smith. **2013**. Epidemiology of dengue: past, present and future prospects. Clin Epidemiol. 5: 299–309.

Mutsuddy, P., S. Tahmina Jhora, A. K. M. Shamsuzzaman, S. M. G. Kaisar, M. N. A. Khan, and S. Dhiman. **2019**. Dengue Situation in Bangladesh: An Epidemiological Shift in terms of Morbidity and Mortality. Can J Infect Dis Med Microbiol. 2019.

Quddus, M. A. 2008. Time series count data models: An empirical application to traffic accidents. Accid Anal Prev. 40: 1732–1741.

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

Rahim, R., A. Hasan, N. Hasan, E. E. Nakayama, T. Shioda, and M. Rahman. **2021**. Diversity of Dengue Virus Serotypes in Dhaka City: From 2017 to 2021. Bangladesh Journal of Medical Microbiology. 15: 23–29.

Rahman, K. M., Y. Sharker, R. A. Rumi, M.-U. I. Khan, M. S. Shomik, M. W. Rahman, S. M. Billah, M. Rahman, P. K. Streatfield, D. Harley, and S. P. Luby. **2020**. An Association between Rainy Days with Clinical Dengue Fever in Dhaka, Bangladesh: Findings from a Hospital Based Study. Int J Environ Res Public Health. 17: 9506.

Salje, H., I. Morales, E. S. Gurley, and S. Saha. **2016**. Seasonal Distribution and Climatic Correlates of Dengue Disease in Dhaka, Bangladesh. Am J Trop Med Hyg. 94: 1359–1361.

Salje, H., K. K. Paul, R. Paul, I. Rodriguez-Barraquer, Z. Rahman, M. S. Alam, M. Rahman, H. M. Al-Amin, J. Heffelfinger, and E. Gurley. **2019**. Nationally-representative serostudy of dengue in Bangladesh allows generalizable disease burden estimates. Elife. 8.

Sen, P. K. 1968. Estimates of the Regression Coefficient Based on Kendall's Tau. J Am Stat Assoc. 63: 1379–1389.

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

Siraj, A. S., R. J. Oidtman, J. H. Huber, M. U. G. Kraemer, O. J. Brady, M. A. Johansson, and T. A. Perkins. **2017**. Temperature modulates dengue virus epidemic growth rates through its effects on reproduction numbers and generation intervals. PLoS Negl Trop Dis.

Soneja, S., G. Tsarouchi, D. Lumbroso, and D. K. Tung. **2021**. A Review of Dengue's Historical and Future Health Risk from a Changing Climate. Curr Environ Health Rep. 8: 245–265.

Sumi, S. N., N. C. Sinha, and M. A. Islam. **2021**. Generalized linear models for analyzing count data of rainfall occurrences. SN Appl Sci. 3: 481.

Teo, A., H. D. Tan, T. Loy, P. Y. Chia, and C. L. L. Chua. **2023**. Understanding antibody-dependent enhancement in dengue: Are afucosylated IgG1s a concern? PLoS Pathog. 19: e1011223.

Wang, T. T., J. Sewatanon, M. J. Memoli, J. Wrammert, S. Bournazos, S. K. Bhaumik, B. A. Pinsky, K. Chokephaibulkit, N. Onlamoon, K. Pattanapanyasat, J. K. Taubenberger, R. Ahmed, and J. V. Ravetch. **2017**. IgG antibodies to dengue enhanced for FcγRIIIA binding determine disease severity. Science (1979). 355: 395–398.

Wangdi, K., A. C. A. Clements, T. Du, and S. V. Nery. **2018**. Spatial and temporal patterns of dengue infections in Timor-Leste, 2005–2013. Parasit Vectors. 11: 9.

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

WHO. **2017**. 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 .

WHO. **2023a**. Dengue and severe dengue. https://www.who.int/news-room/fact-sheets/detail/dengue-and-severe-dengue. WHO.

WHO. **2023b**. Dengue and severe dengue. (https://www.who.int/news-room/fact-sheets/detail/dengue-and-severe-dengue).

WHO South-East Asia. **2023**. Dengue in the South-East Asia. WHO Regional office for South-East Asia.

WHO-Bangladesh. **2022**. Dengue - Bangladesh. https://www.who.int/emergencies/disease-outbreak-news/item/2022-DON424.

Yue, S., and P. Pilon. **2004**. 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. 49: 21–37.

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

Table 2: The Mann-Kendell trend test for reported dengue cases in Bangladesh, 2000-2022

Table 3: The incidence risk ratio (IRR) of monthly average temperature and total rainfall for monthly incidence of Dengue cases in Bangladesh using time-series count Generalized Linear Model for the period 2000-2022.

Figures:

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

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 line indicates monthly growth factor 1 (the same number of DENV infections 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.

Tables

Table 1:

	First decade (2000-2010)	Recent decade (2011-2022)	p-value
Mean annual dengue cases (±Standard deviation [SD])	2216.64 (±2123.62)	18321.92 (±31,778.90)	0.219
Mean annual dengue deaths (±SD)	21.18 (±30.69)	46.58 (±90.90)	0.853
Mean Case-fatality ratio (± SD)	0.69 (±0.79)	0.23 (±13)	0.08
Mean temperature °C (±SD)	26.35 (±0.49)	26.84 (±0.37)	<0.001
Mean annual rainfall in mm (±SD)	2078.66 (±459.68)	1764.50 (±448.32)	0.188

Table 2:

Test		
Mann-Kendell trend analysis	**Tau**	**p-value**
	0.26	0.139
Sen's Slop test		
	Sen's Slope	95% Confidence Interval
	171.67	-46 to 687

Table 3:

	IRR (95% CI)	P-value
Average temperature	1.26 (1.258 – 1.265)	<0.001
Rainfall (lag 1) in centimeter	1.08 (1.079 – 1.086)	<0.001
Rainfall (lag 2) in centimeter	1.17 (1.168 – 1.175))	<0.001

Figures

Fig 1:

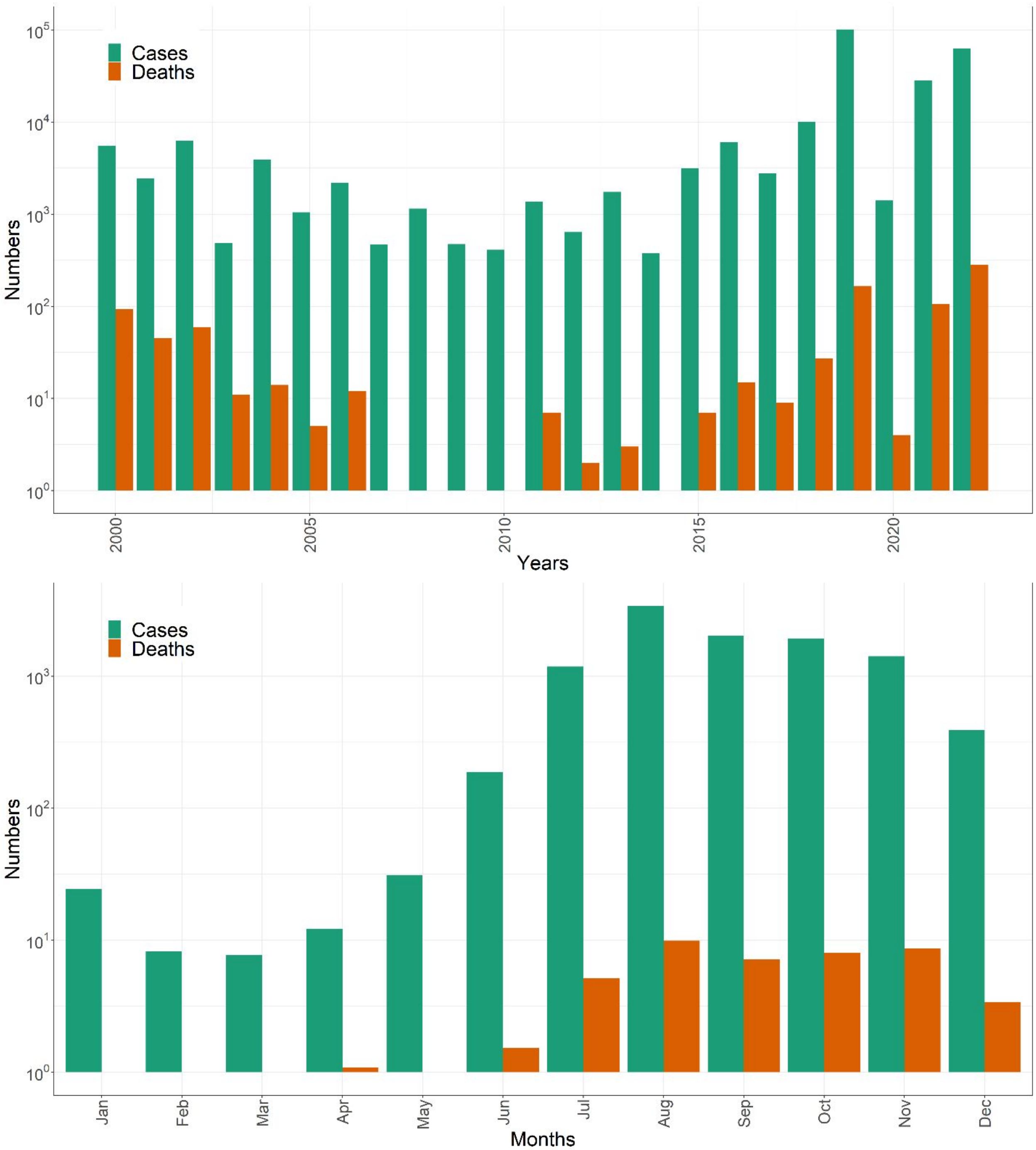


Fig 2:

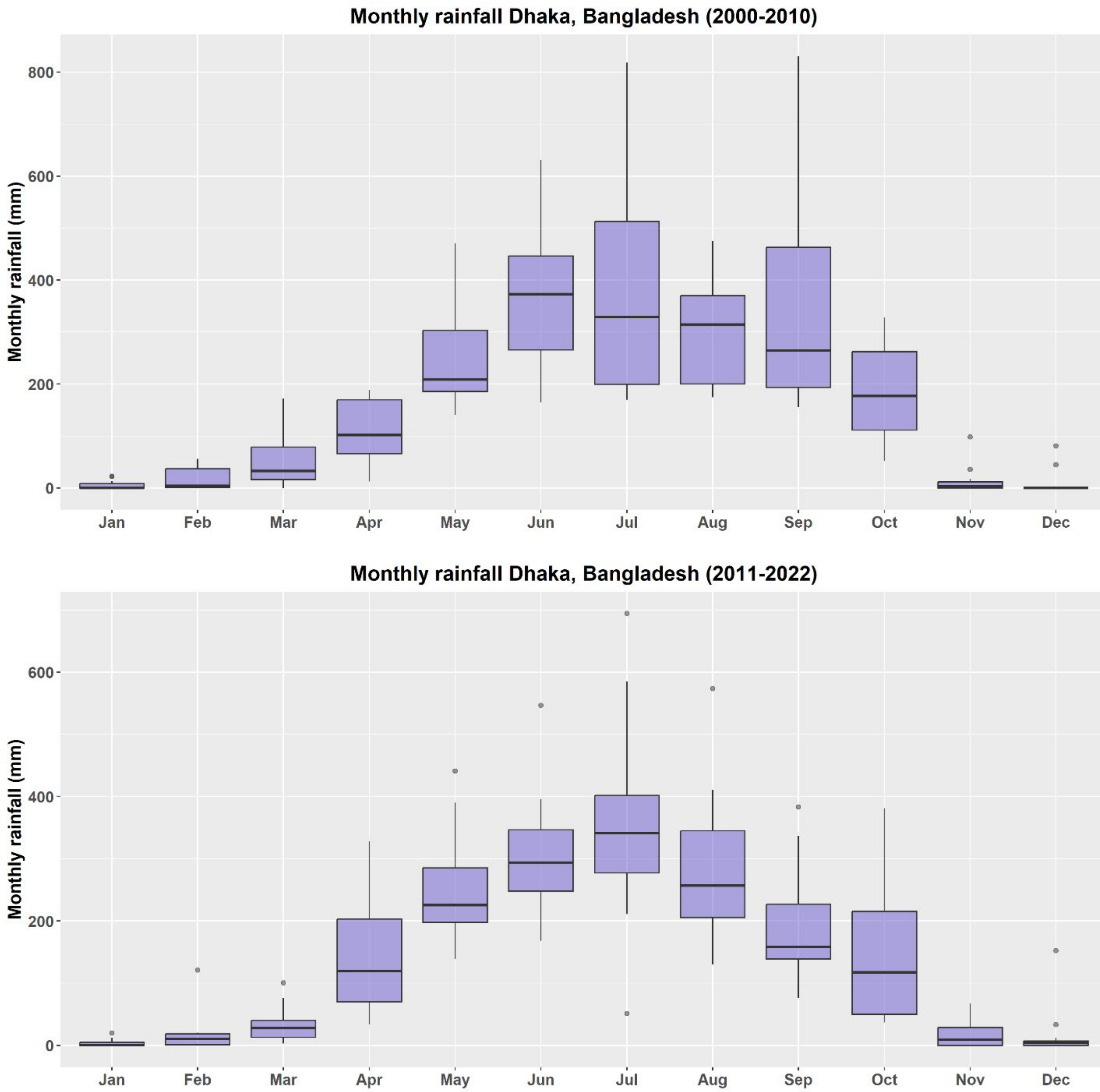
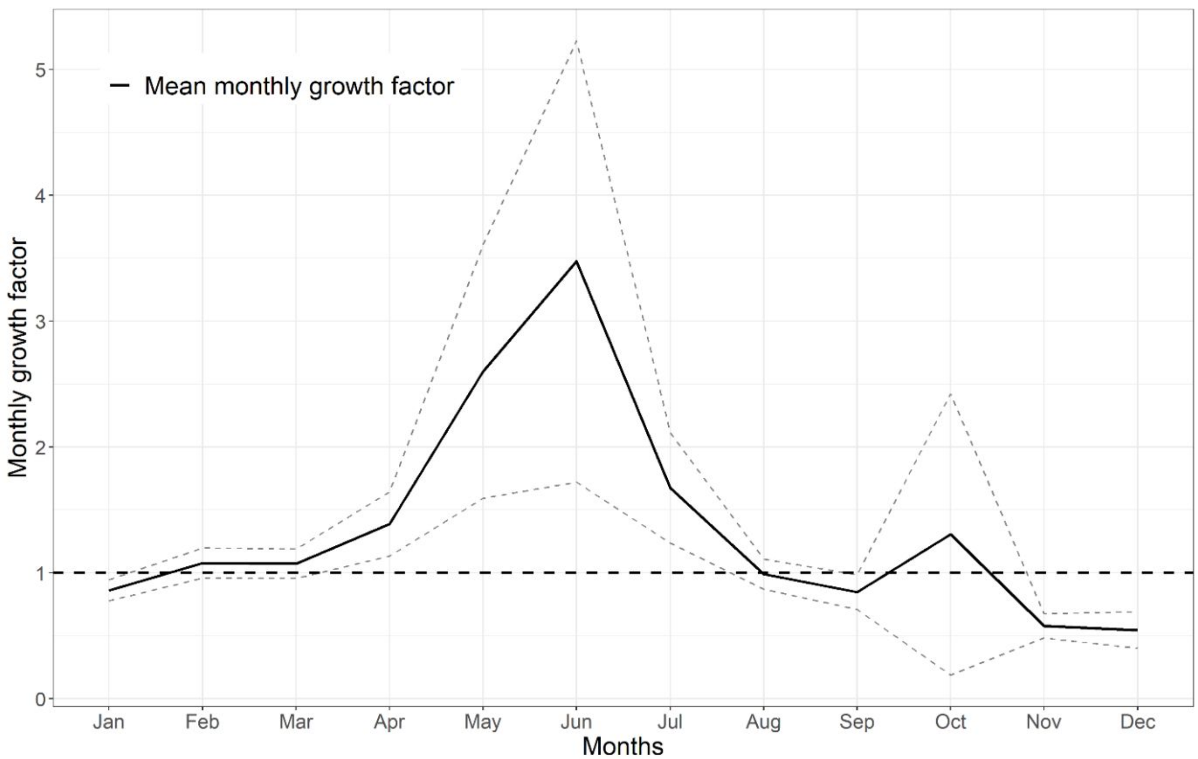

Monthly rainfall Dhaka, Bangladesh (2000-2010)
Monthly rainfall (mm)
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Monthly rainfall Dhaka, Bangladesh (2011-2022)
Monthly rainfall (mm)
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Fig 3:


Mean monthly growth factor
Monthly growth factor
0
1
2
3
4
5
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

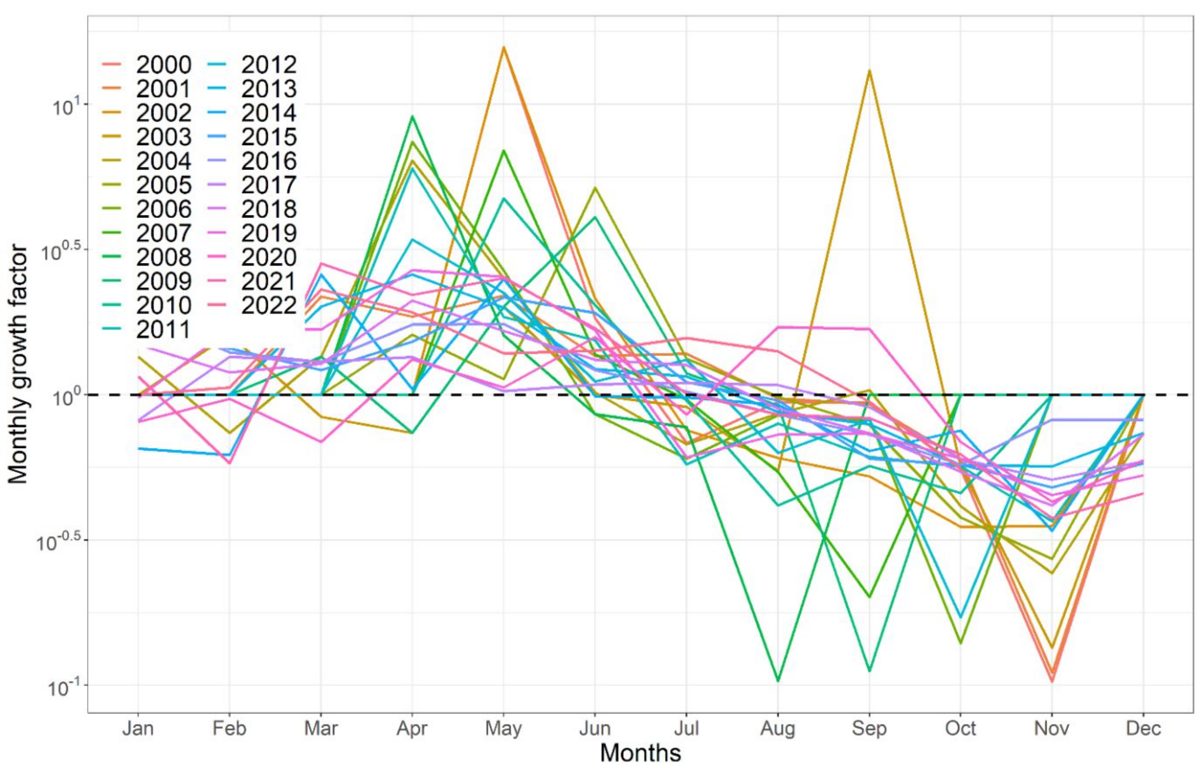
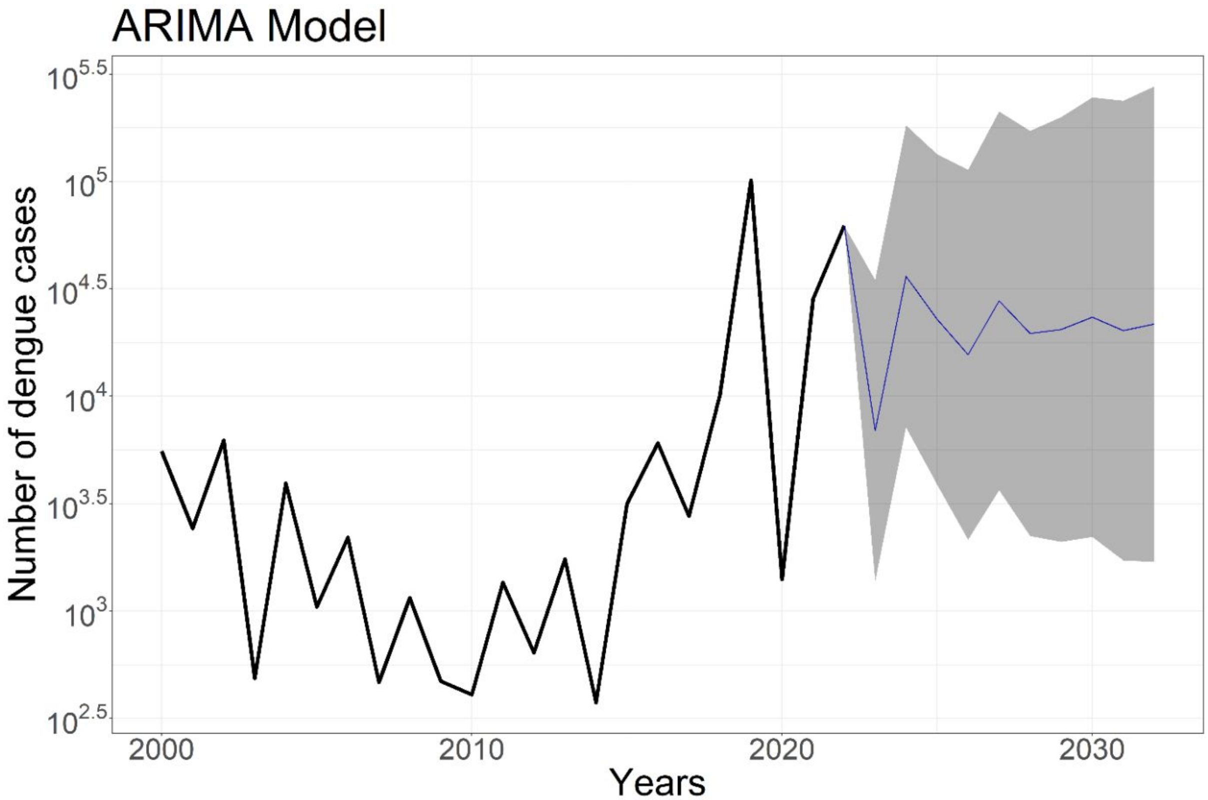

2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Monthly growth factor
10^{1}
$10^{0.5}$
10^{0}
$10^{-0.5}$
10^{-1}
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months

Fig 4:


ARIMA Model
$10^{5.5}$
10^{5}
$10^{4.5}$
10^{4}
$10^{3.5}$
10^{3}
$10^{2.5}$
Number of dengue cases
2000
2010
2020
2030
Years

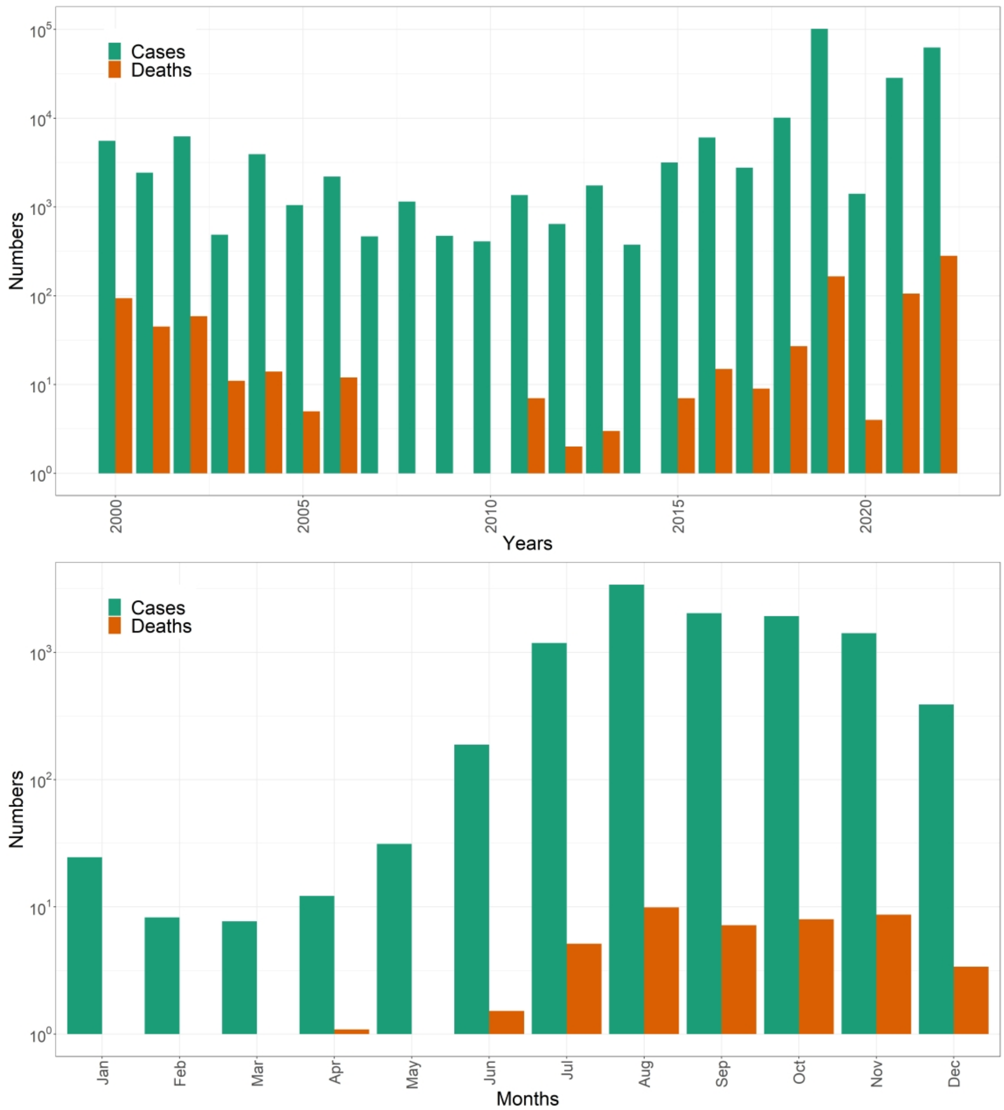
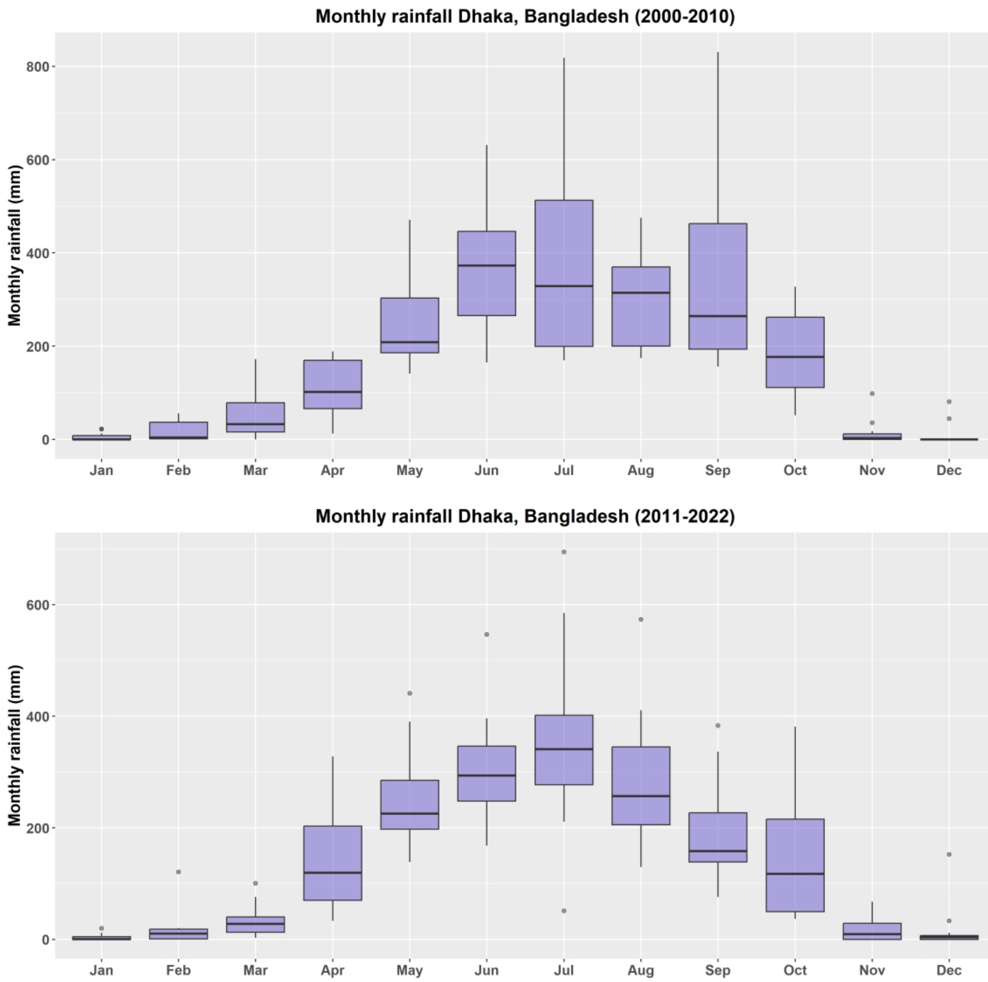


Fig 1: Top: Number of dengue cases and deaths over the period 2000-2022, Bangladesh. Bottom: Number of monthly dengue cases and deaths recorded in Bangladesh.

457x508mm (300 x 300 DPI)



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304x304mm (300 x 300 DPI)

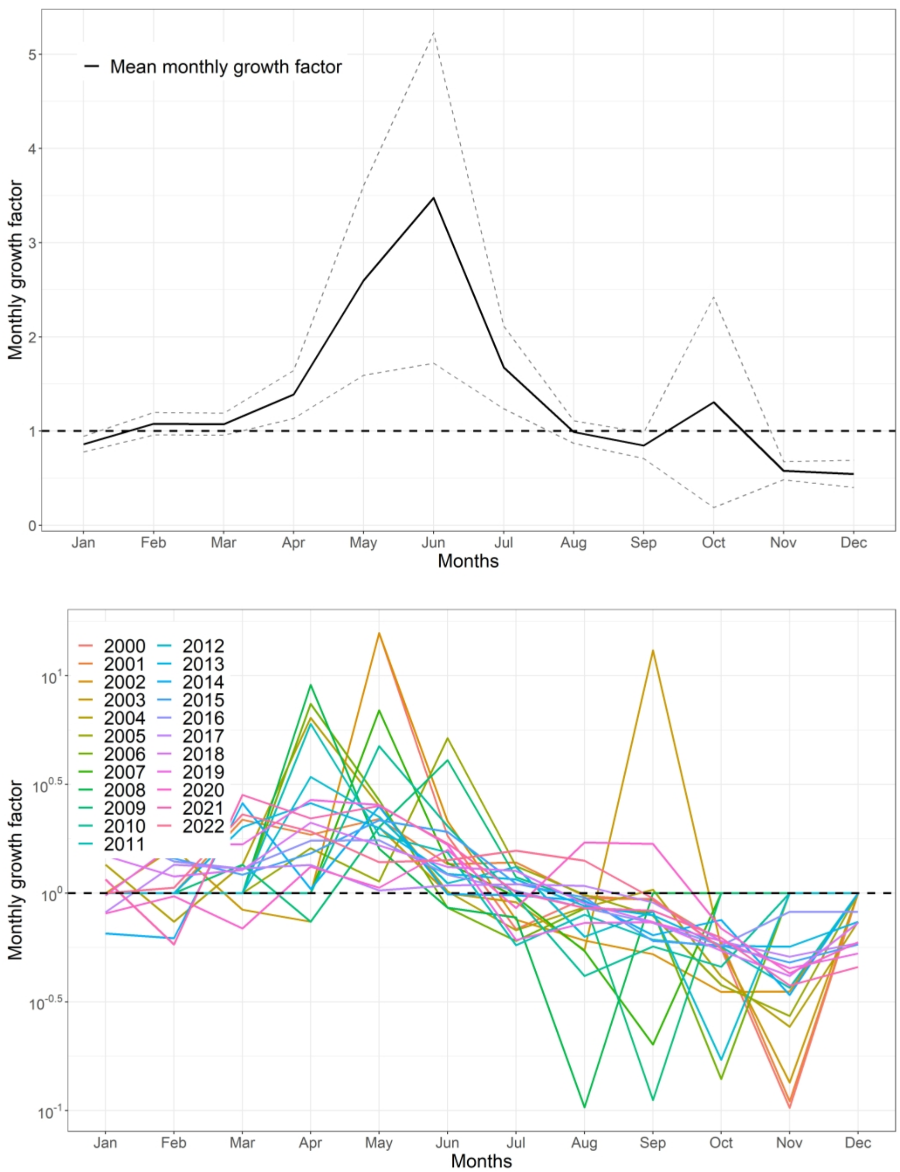

Fig 3: Top: Mean monthly growth factor for the period of 2000-2022. Bottom: The Monthly growth factor for the individual year 2000-2022. The dotted horizontal line indicates monthly growth factor 1 (same number of cases in two subsequent months).

304x406mm (300 x 300 DPI)

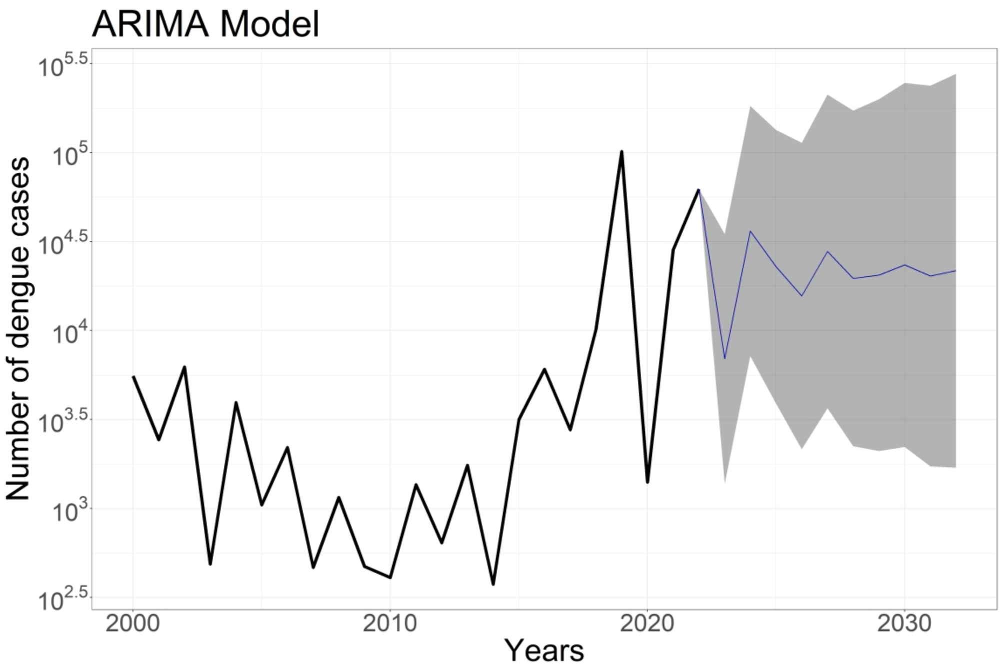

Fig 4: The observed and forecasted number of dengue cases in Bangladesh using the Autoregressive moving average (ARIMA) model including a 95% confidence interval.

457x304mm (300 x 300 DPI)