Assessing the impact of climatic factors on dengue fever transmission in Bangladesh

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Abstract

Dengue fever is a virus-borne disease spread by mosquitos, and its global prevalence has risen significantly in recent years. The aim of this study was to analyze the impact and association of climatic factors on the spread of dengue incidence in Bangladesh. From January 2011 to December 2021, the study used secondary data on monthly dengue cases and the monthly average of climatic factors. In addition to the descriptive statistics, bivariate analyses of Kendall's tau b and Spearman's rho have been performed for measuring the association of climatic factors on dengue infection. The multivariate generalized linear negative binomial regression model was applied to evaluate the impacts of climatic factors on dengue transmission. The model revealed that temperature (OR: 152.745,$p<0.01$), humidity (OR: 1.15, $p<0.01$), precipitation (OR: 1.131, $p<0.01$), wind speed (OR: 1.148, $p<0.10$), and air pressure (OR: 152.745, $p<0.01$) were significantly influenced the spread of dengue incidence in Bangladesh. The climatic season also significantly influenced dengue transmission, and a higher infection rate (OR: 140.704, $p<0.01$) was found in the monsoon season at August month. The findings of this study can assist policymakers and public health authorities in taking the essential steps to control the dengue infection in Bangladesh.

1. Introduction

Dengue virus currently poses a threat to almost half of the world's population, with 390 million cases reported annually (WHO 2021). The virus that causes dengue fever infects humans when infected mosquitoes bite them. There is substantial evidence that dengue disease will continue to spread over the world (Y. Li et al. 2020). Dengue is a significant cause of morbidity and mortality in Bangladesh (Ahsan et al. 2021; Sharmin et al. 2015). *Aedes aegypti (Ae. aegypti)* and *Aedes albopictus (Ae. albopictus)* are the two species of Aedes mosquitoes that serve as the main vectors for the spread of the dengue virus in the environment (Lambrechts, Scott, and Gubler 2010). According to a study, the number of dengue cases will rise to 2.25 billion globally by 2080 (Messina et al. 2019).

The risk of dengue varies locally depending on factors like rainfall, temperature, relative humidity, and unplanned rapid urbanization (WHO 2021). It has become a global public health concern in the world's tropical and subtropical areas (Gubler 2011). The virus that causes dengue fever infects humans when infected mosquitoes bite them. Dengue fever is the most severe in Latin America, Pacific Asia, and South-East Asia. However, South Asian countries such as Pakistan, India, and Bangladesh have also reported a significant increase in the number of infections, which has had a substantial impact on public health (Anders and Hay 2012; Bhatt et al. 2013; Stanaway et al. 2016).

Surprisingly, local climatic conditions (temperature, precipitation, and humidity) have been shown to interact with vector population dynamics, viral circulation, and transmission probability (Correia Filho 2017a; Ruzman and Rahman 2017; Xiang et al. 2017). An increasing number of researches have been conducted on the relationship between climatic factors and dengue incidence. The majority of earlier studies (Adnan et al. 2020; S. C. Chen et al. 2010; Y. Li et al. 2020; Malik et al. 2017; Ruzman and Rahman 2017; Shaheen 2020; Singh et al. 2022) revealed that climatic conditions are significantly connected to dengue infection. Those studies had just a link between climatic factors and dengue cases. Most of the authors applied spearman's rho and kendall's tau for assessing the association types. However, a few studies (Banu et al. 2014; Sulekan, Suhaila, and Abdul Wahid 2021) have been done on the modeling of dengue infection on weather variables.

Moreover, a few studies have been conducted on dengue infection in Bangladesh (Chowdhury et al. 2018; Riad, Cohnstaedt, and Scoglio 2021) as well as worldwide (Cheong et al. 2013a; FAN and LIU 2019; Prakash, Ranasinghe, and Karunadasa 2018). However, earlier studies focused on dengue infection, particularly in the most populated region like Davao (Iguchi, Seposo, and Honda 2018), Manila (Carvajal et al. 2018) in Philippines, Guangzhou (Xiang et al. 2017), Guangdong (Zhu et al. 2019), Guangxi (Yu et al. 2018), and Jiangsu (Zhang et al. 2018) in China, Jakarta in Indonesia (Wijaya et al. 2021), and Dhaka (Banu et al. 2014; Dhar-Chowdhury et al. 2016; Islam et al. 2021; Karim et al. 2012; Paul et al. 2018). Since dengue transmission is not limited to a specific region of the country. So, in this study, we applied data covering the entire country and extreme weather conditions caused by regional climate change may influence dengue transmission. Hence, it is crucial to understand environmental changes and their impacts on dengue transmission. Overall, covering the entire country the present study was undertaken to assess the impact of climatic factors on dengue transmission in Bangladesh.

2. Materials And Methods

2.1 Study Area

Bangladesh (23.6850° N - 90.3563° E) is the world's largest deltaic south Asian country, located in the tropical monsoon region in the northeastern part of the Indian subcontinent. Its climate is subtropical in the center-north and tropical in the south with three distinct seasons (Maciej Serda et al. 2013). Summer (March to May) is the hot season with an average temperature 29 to 37°C (84 to 99°F). April is the warmest month of this season with mean temperatures ranging from 27°C in the east and south to 31°C in the west-central part of the country (Climate - Banglapedia n.d.). The sky remains clear and bright at summer season. Only 19% of the annual rainfall occurs during this time. March and April are the least humid months and the recorded lowest average relative humidity was 0.57 (Climate - Banglapedia n.d.). Stronger winds speed is observed in summer (8-16 km/hr) than in winter (3-6 km/hr) (Climate - Banglapedia n.d.). The average air pressure remains 1005 millibars during the summer season.

Monsoon season in Bangladesh is from June to October. The country experiences heavy rains during this season. This season accounts about 80% of annual rainfall and humidity ranges from 90% to almost 100%. Average recorded temperature of this season is 31°C (88°F). Wind speed continues to be mild to moderate. Air humidity is extremely high during this period.

Winter season starts with October month and ends by March. This is a very dry season which accounts less than 4% of the total annual rainfall. Cold air flows in this season and the average temperature is 5°C to 22°C (41°F to 72°F). During this season, the northwestern part region of India faces a centre of extreme air pressure (Climate - Banglapedia n.d.). As a result, a stream of cold air flows over the northwest corner of Bangladesh (Climate - Banglapedia n.d.).

2.2 Data Collection

This study used secondary data of monthly hospitalized dengue cases of Bangladesh from January 2011 to December 2021. Dengue infection data were collected from Directorate General of Health Services (Directorate General of Health Services (DGHS)-Government of the People's Republic of Bangladesh n.d.). The climatic variables considered in this study were temperature (°C), relative humidity (%), sky clearness, winds peed (m/s), and Precipitation (mm) which were extracted from the NASA Power Data Access Viewer (POWER | Data Access Viewer n.d.).

2.3 Data Analysis

The number of monthly dengue infections was the major outcome variable in this study. As descriptive statistics, mean, standard deviation (SD), minimum, maximum, skewness, and kurtosis were calculated for the selected environmental variables. For this study, a variety of statistical techniques were employed because the study variable under consideration was the count variable. Shapiro-Wilk normality test was applied for testing the normality assumption of each of the predictors and study variable. Results of this test showed no evidence of normality ( ). Kendall's tau_b and Spearman's rho correlation coefficients were computed for assessing the bivariate relationship between the spread of dengue infection and selected environmental variables. The multivariate generalized linear (GLM) was applied to determine influential significant factors of dengue spread in Bangladesh. Since the study variable consisted of count and over dispersion dataset, the Generalized Poisson regression (GPR) and Negative binomial regression (NBR) were applied for the final analysis of this study. Deviance statistic, likelihood ratio (LR) test, Akaike Information Criteria (AIC), and Bayesian Schwartz Information Criteria (BIC) were employed in this study as goodness of fit tests (Ismail and Jemain 2007). We obtained deviance statistic (368791.5), AIC (368827), and BIC (368879.4) for generalized poisson regression model and deviance statistic (1594.121), AIC (1632.1), and BIC (1686.894) for negative binomial regression model. The likelihood ratio statistic (367197, $p<0.01$), reveals rejection of the null hypothesis. As a result, the negative binomial regression model outperforms the generalized poisson regression model in terms of fit. Comparing the goodness of fit tests results with least value of deviance, AIC, and BIC we observed that the negative binomial regression model fits the data well. All the analyses were performed in R 4.1.2.

3. Results And Discussion

3.1 Descriptive Analysis

Before examining the relationship between environmental factors and dengue cases, a descriptive analysis was performed for both the study and explanatory variables, and the results are shown in Table 1. Individual year wise descriptive measures were not shown here. The highest average temperature was observed 26.28°C in 2016. In contrast, the minimum value was recorded 24.74°C in 2018. The 11-year mean temperature was 26.625°C which ranges from 24.74°C (2018) to 26.28°C (2016), and the average humidity was 74.14%. In the study period, the maximum and minimum average humidity was recorded 79.75% (2020), and 69.32% (2012) respectively, and it showed negatively skewed distribution. For the whole study period (2011 to 2021), the observed average minimum and maximum humidity were 37.75% and 91.12% respectively with average humidity 74.14%. Furthermore, it was observed that the dengue cases follow a seasonal pattern, with most cases reported in August and September (**Figure 1a & 1b**). According to **Fig. 1b**, the highest and lowest dengue cases were 102354 (2019) and 375 (2014), respectively. Overall, the incidence and risk of dengue was found highest and lowest in August (67270) and March (136) respectively (**Fig. 1a**).

Table 1: Descriptive statistics of Dengue cases and meteorological variables in Bangladesh (2011-2021)

Variables	Min	Max	Mean	SD	Skew	Kurt
Cases	0	53636	1199.886	5188.9089	8.45	81.57
Pressure	99.69	101.53	100.6723	0.53648	-0.07	-1.346
Temperature	14.28	33.51	25.625	4.66522	-0.699	-0.7
Humidity	37.75	91.12	74.145	14.91353	-0.712	-0.698
Clearness	0.49	0.66	0.6075	0.03216	-1.184	1.85
Wind speed	4.98	21.3	9.5565	2.47585	1.149	2.988
Precipitation	0	25.75	6.0045	6.06874	0.937	0.15

3.2 Bivariate Analysis

Besides descriptive statistics, the correlation coefficient between dengue cases and environmental factors was also calculated and presented in **Table 2**. Results showed that humidity (%) (r=0.534, p<0.01), sky clearness (r=0.284, p<0.01), and precipitation (r=0.285, p<0.01) were significantly positively correlated with dengue transmission. Air pressure (KPa) (-r=0.182, p<0.01) was found to have a substantial negative correlation with dengue, while temperature (°C) (r=0.008, p>0.05) and wind speed (m/s) (r=0.046, p>0.05) were insignificant. It has been observed that both Kendall's tau_b and Spearman's rho correlation coefficient showed consistent results for determining the association between dengue cases and meteorological variables.

A positive relationship had been observed between precipitation and humidity with the dengue infection. **Figure 2b** and **2f** revealed that cases increase with the increase in humidity and precipitation, and vice versa. Humidity and precipitation seemed to be more closely related to dengue cases than other variables (**Figure 2b & 2f**).

There were three climate variables that had a positive correlation with dengue fever cases, namely humidity, sky clearness and precipitation, while air pressure had negative correlation. Humidity had the highest correlation value, with a strong positive correlation category. Sky clearness and precipitation had a weak positive correlation with dengue cases, whereas air pressure had a negative correlation with the negligible category (**Table 2**).

Some previous studies conducted in the association of various climatic factors on dengue infection and found significant correlation. A study was conducted in Dhaka and Chittagong, two major cities in Bangladesh to know the association between dengue disease and climate variability. The authors observed that the monthly mean temperature, total rainfall, and mean humidity were significantly associated with dengue incidence in Dhaka, whereas monthly total rainfall and mean humidity were associated with dengue incidence cases in Chittagong (Banu et al. 2012). Like our study wind speed (Arsin et al. 2020) and temperature (Ruzman and Rahman 2017) did not show significant correlation with dengue fever cases. In a study of Southeast Asian Philippines country, it was observed that no significant correlation identified either on rainfall or temperature to the prevalence of dengue cases (Picardal and Elnar 2012).

In comparison to other climatic factors, humidity had a substantial association with dengue fever incidence. Previous studies also demonstrated that humidity was a key factor in dengue fever incidence (Correia Filho 2017b; Descloux et al. 2012). At the time when virological issues were addressed, humidity had a more consistent effect on dengue cases than temperature (Xu et al. 2014). Additionally, relative humidity may have a significant impact on the growth of A. aegypti eggs and the number of adults present, both of which may be related to vectorial capacity (Morales Vargas et al. 2010). Significant association also observed between humidity and dengue incidence in Yogayakarta, Indonesia (Zannah and Sulistyawati 2020).

Precipitation is another important climatic factor that has a connection with dengue incidence. Our study also found a positive association with dengue. Precipitation was found to have the significant positive correlations with dengue cases with a lag time of eight weeks, while relative humidity was statistically significant correlation with all lag times (WHO 2001) which is in line with our study. Precipitation and humidity showed a significant correlation with dengue fever cases in Jakarta 201-2015 (Ekasari, Susanna, and Riskiyani 2018).

Table 2: Correlation of dengue incidence with environmental factors.

Environmental Factors	Number of Dengue cases	
	Kendall's Tau_b	Spearman's rho
	Corr. coeff. (r)	Corr. coeff. (r)
Air Pressure (kPa)	-0.182[a]	-0.28[a]
Temperature (˚c)	0.008	0.026
Humidity (%)	0.534[a]	0.743[a]
Sky Clearness	0.284[a]	0.400[a]
Wind speed (m/s)	0.046	0.064
Precipitation (mm)	0.285[a]	0.432[a]

[a]indicates a significant correlation at 0.01 (2-tailed)

3.3 Impact of climatic factors on dengue fever cases

In this study, the influential factors that significantly impact the dengue infection cases were also determined by employing a generalized linear model. Negative binomial regression model has been carried out in **Table 4** to find the significant meteorological factors that influence the dengue incidence cases.

Dengue fever is one of the most common vector-borne diseases affecting humans globally, with the majority of cases occurring in tropical and subtropical regions of the world. People living in a dengue-endemic zone can have several dengue infections in their lifetime (ECDC 2020). The presence of infectious diseases may be strongly affected by changes in meteorological variables such as air pressure, temperature, humidity, clearness, wind speed, and precipitation. When it comes to the effects of climate change, dengue is a common disease that has frequently been recorded. Climate affects the growth and development of Dengue vectors. Climate Change is a significant factor in increasing dengue severity in Bangladesh (Alto and Bettinardi 2013). Aedes mosquitoes can breed more easily in warmer, humid conditions with frequent precipitation. The frequency of vector-borne diseases is rising in Bangladesh as the country's weather patterns change. The increased incidence of dengue in Bangladesh is largely due to climate change.

Temperature is one of the significant Meteorological factors which influence mosquito interactions with viruses (Karim et al. 2012). The NBR model was applied to this study to identify the most significant factor influencing the spread of infectious disease. **Table 3** represents the NBR model assessing the impact of climatic factors that substantially affect dengue transmission. **The Table 3** shows that temperature (OR:1.585,CI: (1.173-2.138), p<0.01) has a significant positive impact on disease spread. The odds ratio of 1.585 indicates that for a one-unit increase in temperature, the dengue transmission also increases by 1.585 times more.

Another important climatic factor that has a significant impact on dengue fever cases is humidity. The odds ratio, 95% confidence interval and value of this factor were 1.15, 1.083 to 1.218, and 0.000 respectively. The mentioned OR for humidity elucidates that dengue fever cases also increases with the increase in humidity. Since mosquitoes are responsible for transmitting the virus that causes dengue, humidity has an impact on the lifespan of the mosquito, with high humidity lengthening its lifespan. Therefore, the humidity was considered to be an influencing factor in this study. The findings demonstrate that humidity is a significant factor in spreading the dengue incidence (OR:1.15, CI: (1.083-1.218), p<0.01) (**Table 3**). It also positively impacts on dengue incidence. The odds ratio 1.15 demonstrates that for one unit increase in humidity, the dengue incidence also increases by 1.15 times more. Of all climate factors, wind speed is also an important climatic factors which was found to have a significant effect (OR:1.148, CI: 0.987-1.335, p<0.01) on dengue fever cases at confidence level 10%. Air pressure is another essential component that has a significant impact on the transmission of dengue where sky clearness was no significant impact.

Precipitation is the most important climatic component that is regarded as a major risk factor for dengue fever. Results (Table 3) demonstrate that precipitation has a favorable and significant impact on the incidence of dengue fever transmission (OR:1.131, CI: 1.051-1.216), p<0.01).

Moreover, there is a seasonal variation in dengue incidence. Dengue fever transmission is most favorable and risky in August, followed by November, July, September, and October. The month August (OR:140.705, CI: 15.502-1275.38, p<0.01)) had a 140.705 times more significant risk of dengue fever infection than April. Similarly November (OR:47.784, CI: 3.6-633, p<0.01), July (OR:28.375,CI: 2.652-.303.275, p<0.01), September (OR:18.714,CI: 3.073-.114.105, p<0.01), and October (OR:13.667,CI: 2.495-.74.688, p<0.01) were 47.784, 28.375, 18.714, and 13.667 times higher risky respectively in dengue fever transmission than April. May month was found to be at a lower risk of dengue incidence.

Table 3: Negative binomial regression model impacting the spread of Dengue cases on seasonal and climatic factors in Bangladesh (2011-2021).

Variables	Estimate	Std. Error	Z -Value	OR	95% CI (OR)		
					Lower limit	Upper limit	p value
Intercept	-527.67	121.2	-4.354	0	0	1.01E-126	0.000
January	3.318	2.14	1.551	27.623	0.416	1830.601	0.120
February	2.789	1.704	1.637	16.271	0.576	458.903	0.101
March	1.777	0.989	1.796	5.914	0.85	41.076	0.072
May	-0.65	0.754	-0.862	0.521	0.119	2.288	0.389
June	1.865	1.134	1.645	6.46	0.699	59.599	0.099
July	3.345	1.209	2.767	28.375	2.652	303.275	0.005
August	4.946	1.125	4.394	140.705	15.502	1275.38	0.000
September	2.93	0.922	3.147	18.714	3.073	114.105	0.001
October	2.614	0.867	3.014	13.667	2.495	74.688	0.002
November	3.866	1.319	2.931	47.784	3.599	633.487	0.003
December	3.096	1.843	1.679	22.11	0.596	819.16	0.093
Pressure	5.028	1.194	4.212	152.745	14.698	1584.842	0.000
Temperature	0.46	0.153	2.995	1.585	1.173	2.138	0.002
Humidity	0.139	0.03	4.719	1.15	1.083	1.218	0.000
Sky clearness	-0.276	5.439	-0.051	0.758	1.78E-05	32352.29	0.959
Wind speed	0.138	0.077	1.796	1.148	0.987	1.335	0.072
Precipitation	0.123	0.037	3.327	1.131	1.051	1.216	0.000

Temperature is a crucial environmental factor that is considered to play a significant role in the spread of viral disease. In this study, the temperature was found to have a significant beneficial impact on dengue incidence; when the temperature rises, the infection tends to climb significantly. A previous study in Guangzhou, China observed that maximum and minimum temperature were significantly positively impacted on dengue incidence and for a 1°C increase in temperature (maximum or minimum) within 21.6-32.9°C was associated with 11.9% and 9.9% increase in dengue at lag0, respectively (Xiang et al. 2017). Temperatures in our study were typically suitable for A. aegypti's life span. Temperature fluctuations between 15 and 35 °C can have an impact on the dengue fever vector, either directly or indirectly (Chan and Johansson 2012; Padmanabha et al. 2012; Tun-Lin, Burkot, and Kay 2000; Yang et al. 2009). A rise in temperature within the mentioned range may considerably boost the development and oviposition rates and shorten the extrinsic incubation period of the vectors, with varying rate changes at different levels of temperature (Chan and Johansson 2012). Another study also found that the dengue virus transmission increase, as diurnal temperature increase when mean temperature is greater than 18°C (Lambrechts et al. 2011). A time series analysis based on the association between weather factors and dengue incidence in Dhaka, Bangladesh, discovered a statistically significant negative impact of temperature on dengue incidence, while average humidity showed a statistically significant positive impact, which was consistent with the findings of our multivariate negative binomial regression model (Shaheen 2020).

Furthermore, temperature rises (<18°C) accelerate dengue incidence by reducing the growth period of Aedes aegypti larvae and boosting blood feeding and oviposition (Ouattara et al. 2022). Same to our findings, a study in Dhaka, Bangladesh disclosed that if ambient temperatures increased by 1°C in 2100 compared to 2010, the dengue incidence increases 1.5 times. Dengue incidence in Dhaka will increase by seven times if the temperature rose by 2 degrees Celsius, and by 43 times if the temperature rose by 3.3 degrees Celsius in 2100 compared to 2010 (Banu et al. 2014).

The Poisson regression model was employed in an earlier study (Pinto et al. 2011) to investigate the impact of climatic factors on dengue cases in Singapore. They observed that every 2-10°C rise in maximum temperature increased dengue cases by 22.2-184.6%. According to their findings, the variable temperature (maximum and minimum) was the best indicator of the increasing number of cases (Pinto et al. 2011). The finding of this study is supported by entomological evidence that the optimal temperature range for dengue disease transmission is between 15 and 35 degrees Celsius (Padmanabha et al. 2012; Wu et al. 2007).

Humidity is another important factor that affects the life cycle of mosquitos at different phases. This study also investigated the impact of humidity on the spread of dengue incidence. The result found humidity as a positive significant component in dengue fever transmission. The humidity odds ratio of 1.15 reveals that for every unit increase in humidity, the risk of dengue infection increases by 1.15 times. A previous study in Bangladesh found that relative humidity was significantly positively connected to an increase in dengue incidence, which is consistent with our findings (Karim et al. 2012). In a previous study conducted in Dhaka, Bangladesh, found that humidity had a positive impact on dengue transmission, which was consistent with our findings (Banu et al. 2014).

Several studies demonstrated that relative humidity is a crucial factor in predicting fluctuations in dengue transmission (Descloux et al. 2012; Earnest, Tan, and Wilder-Smith 2012). Humidity and rainfall also affect dengue incidence in Yogyakarta, Indonesia (Kesetyaningsih et al. 2018).

Regional climate phenomena played a role in the transmission of dengue cases. Therefore, the impact of each climatic factor varies from one place to another. The results of the multivariate analysis showed no impact of sky clearness in the incidence of dengue.

In our study, wind speed was observed to have a significant influence on dengue fever incidence but at low confidence level (10%). Moreover, in contrast several studies showed contradictory results regarding the effect of wind speed on dengue transmission. Wind speed has a positive impact on dengue incidence in Sri Lanka's Eastern Province (Karunarathna and Sriranganesan 2020), but has a negative impact on dengue cases in Malaysia (Cheong et al. 2013b). wind speed has no significant impact on dengue cases (Minarti et al. 2021; Pakaya 2017; Salim and Syairaji 2020). Although wind speed reduces the flying ability of mosquitoes, we did not get any impact of it. One of the main reasons is that during the acute dengue infection season in Bangladesh, the wind speed remains mild and stable. Furthermore, a study in Guangzhou, China revealed that for each one unit increase in wind speed corresponds to an increase of 43.8% or 107.53% in the monthly number of dengue fever cases (T. G. Li et al. 2013) which is consistent with our finding.

Atmospheric pressure is another major factor which has a great impact in spread of dengue disease. The climatic variable air pressure was used as an explanatory variable in this study. Although air pressure and wind speed seems to be unrelated to each other, they are actually the same property for all fluids, including air and water. The odds ratio 152.745 for atmospheric pressure disclosed that for each one unit increase in air pressure the dengue infection also increases 152.745 times more.

Precipitation is one of the key climatic factors in dengue transmission since the disease is sensitive to changes in precipitation. Precipitation has been shown in certain studies to be a significant risk factor for dengue epidemics. This study also looked into the effect of humidity on the transmission of dengue fever. Our findings explored that humidity is favorable in the spread of dengue cases. The odds ratio 1.131 for precipitation revealed that for each one unit increase in rainfall, the risk of dengue infection also increases by 1.131 times more. Some previous studies results is in line with our findings that precipitation can increase dengue incidence. A study in southern, Taiwan revealed that precipitation (moderate to high) can accelerate dengue incidence rates (Chuang, Chaves, and Chen 2017).Various studies reported varying effects of precipitation (M. J. Chen et al. 2012; S. C. Chen et al. 2010). On the other hand, high precipitation may result in a washout impact in the short term that would reduce mosquito survivability and the likelihood of transmission. Precipitation has its own potentiality in creation of mosquitoes development at aquatic stage habitats and also has a distributional effects. Many earlier studies demonstrated that precipitation has a non-linear impact on dengue cases (Chien and Yu 2014; Colón-González et al. 2013; Hashizume et al. 2012). A study in Singapore also revealed that high precipitation had a positive impact on dengue transmission at a 5-20 weeks lag and negative impact at 1-4 weeks lag (Hii et al. 2009). Another study conducted in Mexico observed that higher precipitation increases dengue infection which is in line with our study (Colón-González et al. 2013).

3.3.1 Limitations

However, our study has some limitations. There were some unmeasured confounders those could have affected the results. In addition to the weather factors, several socio-economic, demographic, air pollution, industrial pollution etc. may influence the spread of dengue incidence. The limitation of this study is that it did not include mentioned factors as confounders. Time duration is also another limitation of this study. To obtain more accurate and consistent results, the time range should be expanded as well. We collected dengue incidence data from DGHS, Bangladesh. There also may be miss enumeration error of dengue patients. Moreover, a few dengue infected people in Bangladesh do not go to hospital for treatment or diagnosis. For this reason, these types of patients were not correctly enumerated by DGHS which arise an under-enumeration problem. If we could include all the mentioned confounders as explanatory variables, the study results would be more reliable and consistent. Furthermore, the findings of this study were not validated by a comprehensive lab-based experiment. As a result, future studies on the extensive lab-based experiment (Design of Experiment) should be carried out to obtain more reliable statistical results.

4. Conclusions

Dengue is a mosquito-borne viral disease that is the leading cause of arthropod-borne viral disease across the world. Our study uses Spearman's rho and Kendall's tau-b statistics to examine the association between climatic factors and dengue incidence. In order to explore the important climatic and temporal factors impacting the risk of dengue outbreaks in Bangladesh, a negative binomial regression model was finally employed using the aggregate dataset. The NBR model revealed that temperature, precipitation, air pressure, wind speed, and humidity significantly impacted the spread of dengue incidence. There was also a seasonal and temporal impact observed in the model. Five months (July to

November) have been observed to be significantly influenced on the spread of dengue infections. The most risky month for dengue infection is August followed by November, July, September, and October. Therefore, the dengue incidence is common at monsoon season in Bangladesh. Furthermore, future research will need to include some unmeasured confounders like degradation of water quality, air pollution, wastage management etc. to identify the substantial reasons for dengue infection. As a result, Bangladesh should implement a highly effective measure to control the increasing trend of dengue transmission in Bangladesh. The findings of this study will help the policymakers and public health authorities in taking the necessary steps for dengue prevention based on the seasonal climate variability in Bangladesh.

Declarations

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Author contributions

Md. Mamun Miah: conceptualization, methodology, data collection, data compiling, data analysis; supervision, visualization, writing- original draft preparation; **Sumiya Nur Jannat:** data collection, data compiling writing- original draft preparation; **Md. Rashedur Rahman:** writing the manuscript; **Yasin Arafat:** writing the manuscript; **Farjana Haque Pingki:** conceptualization, methodology, data collection, data compiling, formal analysis; writing- original draft preparation.

Data availability

Data will be made available on request.

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Conflict of Interest

The author declares that they do not have any conflict of interest.

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Figures

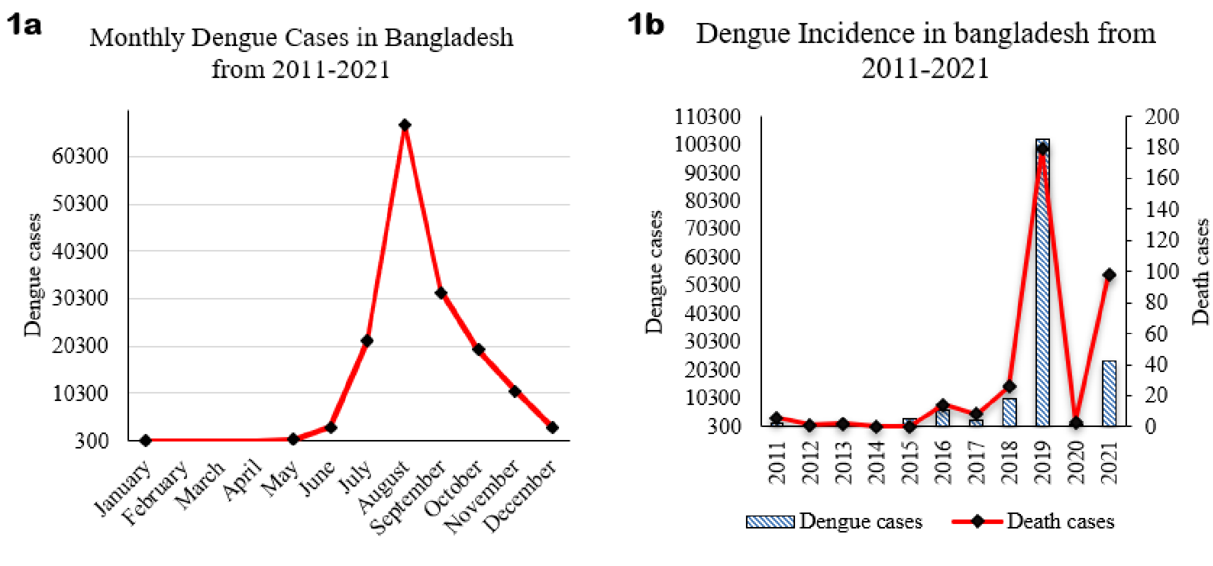

Figure 1

Monthly dengue cases (**1a**) and year wise dengue cases and death cases (**1b**) in Bangladesh (2011-2021)

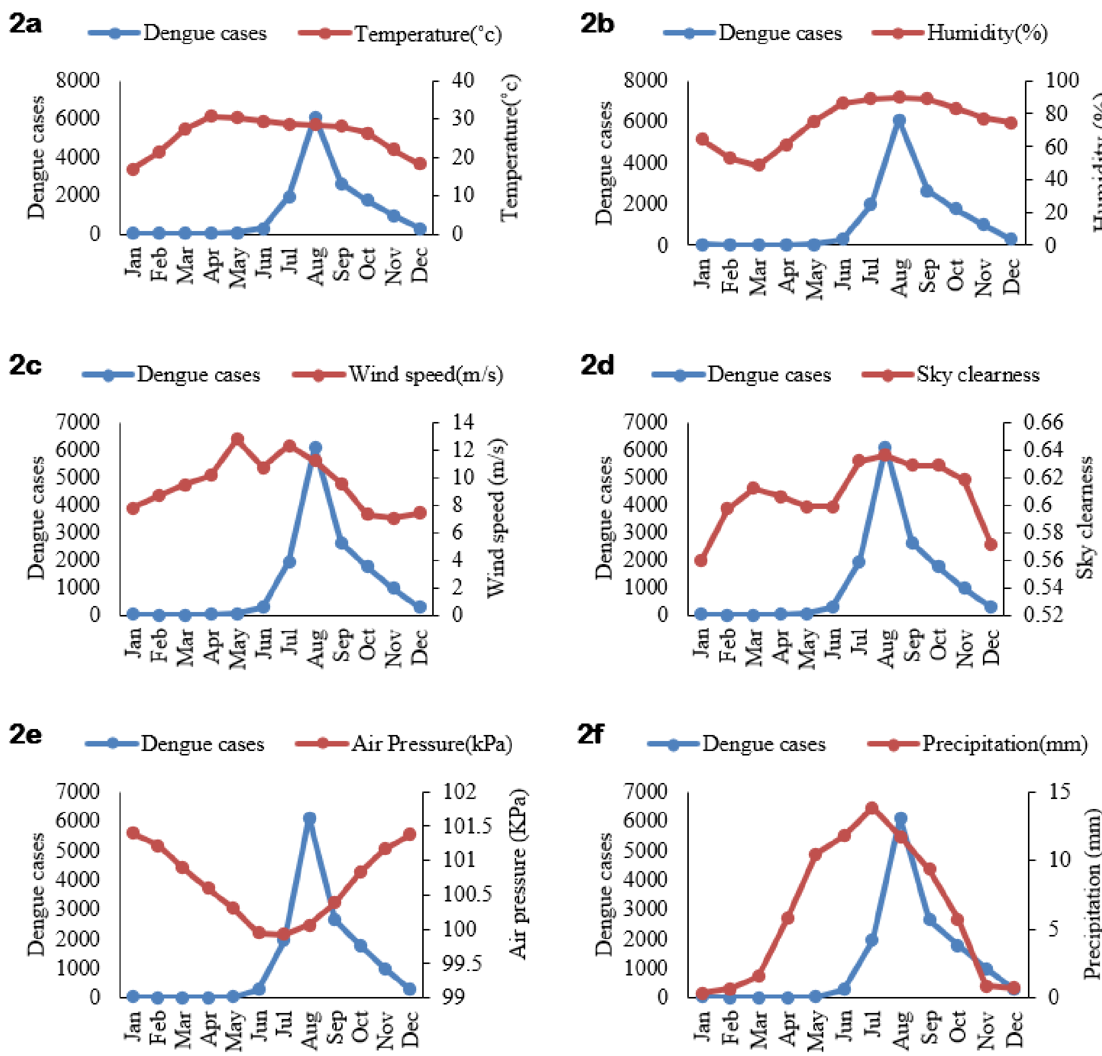

Figure 2

Monthly average dengue cases with the average of climatic factors in Bangladesh (2011-2021).