Climatic factors influencing dengue cases in Dhaka city: a model for dengue prediction

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Background & objectives: Transmission of dengue virus depends on the presence of *Aedes* mosquito. Mosquito generation and development is known to be influenced by the climate. This study was carried out to examine whether the climatic factors data can be used to predict yearly dengue cases of Dhaka city, Bangladesh.

Methods: Monthly reported dengue cases and climate data for the years 2000-2008 were obtained from the Directorate General of Health Services (DGHS) and Meteorological Department of Dhaka, Bangladesh, respectively. Data for the period 2000 to 2007 were used for development of a model through multiple linear regressions. Retrospective validation of the model was done with 2001, 2003, 2005 and 2008 data. Log transformation of the dependent variable was done to normalize data for linear regression. Average monthly humidity, rainfall, minimum and maximum temperature were used as independent variables and number of dengue cases reported monthly was used as dependent variable. Accuracy of the model for predicting outbreak was assessed through receiver operative characteristics (ROC) curve.

Results: Climatic factors, *i.e.* rainfall, maximum temperature and relative humidity were significantly correlated with monthly reported dengue cases. The model incorporating climatic data of two-lag month explained 61 per cent of variation in number of reported dengue cases and this model was found to predict dengue outbreak ($\geq$ 200 cases) with considerable accuracy [area under ROC curve = 0.89, 95%CI = (0.89-0.98)].

Interpretation & conclusions: Our results showed that the climate had a major effect on the occurrence of dengue infection in Dhaka city. Though the prediction model had some limitations in predicting the monthly number of dengue cases, it could forecast possible outbreak two months in advance with considerable accuracy.

Key words Climate - dengue - humidity - outbreak - prediction model - rainfall - temperature

The dengue virus, one of the arboviruses causes classical dengue fever (DF) and dengue haemorrhagic fever (DHF) primarily in the tropical and subtropical regions. Bangladesh with the tropical climate has become an ideal land for dengue virus transmission. Though the first documented outbreak of DF from Bangladesh was in 1964[1] in Dhaka city followed by a few scattered cases of DF during 1977-1978 and 1996-

1997, the first epidemic of DHF occurred in mid 2000, which was reported from all the major cities[2]. Presence of both the vectors, *Aedes. aegypti* and *Ae. albopictus*, was also identified during different outbreaks[3,4].

The *Aedes* mosquito is a climate sensitive vector. It is the primary amplification and transmission host for dengue and yellow fever virus. The geographic distribution of the *Aedes* mosquito is largely determined by climate. Several studies found that the climate of a specific geographic region and number of dengue cases have a strong and consistent relationship[5]. Some found the climate likely to play a small but significant part[6], others ruled out any significant role[7]. To predict a possible dengue outbreak, different models have been developed by relating dengue cases with climatic data[8,9]. In this study we aimed to develop a model to predict monthly dengue cases using eight years monthly data on climate factors and reported cases of dengue infection from the Dhaka city, Bangladesh.

Material & Methods

Data analysis, model development and validation: The number of monthly reported dengue cases admitted or treated at various government and private health facilities in Dhaka city was obtained from the Diseases Control room of Directorate General of Health Services (DGHS) and the climatic data from Bangladesh Meteorological Department at Dhaka.

The monthly climate data were correlated with the number of monthly reported dengue cases. Data of 2000 to 2007 were used for development of the model through multiple linear regression analysis and of 2001, 2003, 2005 and 2008 were used for retrospective validation of the proposed model. As the data were positively skewed (skeweness = $3.9 \pm$ SE 0.246), log transformation of the dependent variable was done to normalize the data for linear regression. Assumption for independence of data points were checked through generation of Durbin-Watson estimate[10]. Average monthly humidity, rainfall, minimum and maximum temperature were used as independent variables and number of dengue cases reported monthly was used as dependent variable. A one-way analysis of variance (ANOVA) was used to see if each one of the climate variables differs significantly between seasons.

The accuracy of model was judged based on explanatory capacity (coefficient of determination, adjusted R^2). We tried to predict the number of cases that would occur (forecasted) in the years 2001, 2003, 2005 and 2008 with the regression equation obtained from

our best-fit model and later on compared the number of cases that were actually reported in that year. Both the forecasted and observed dengue data were plotted for correlation. Pearson correlation coefficient was obtained to see the strength of correlation. Accuracy of the model for predicting outbreak (≥ 200 cases) was assessed through receiver operative characteristics (ROC) curve.

Results

Temporal distribution of dengue cases: Over the 9-year (2000-2008) period, a total of 22,705 cases of dengue were reported to the surveillance system. The number of reported dengue cases varied by year. Over the study period, highest cases of dengue were reported in 2002 (n=5851) and lowest in the following year (n=450) (Fig. 1). Interestingly every second year had an explosive number of cases, followed by lower number of cases in the following year.

In each year, dengue cases showed a specific pattern of occurrence. During pre-monsoon period barely any cases of dengue were reported (Table I). Most of the cases were reported during monsoon in each year except in the year 2003 where monthly dengue cases reported were only two during monsoon period, and interestingly in this year lowest number of dengue cases were reported (n=450) among all the years. In this particular year more cases were reported in the post-monsoon period. During the nine years, hardly any case was found to occur during January to June (Fig. 2). Significant number of cases were reported in the month of July and reaching a peak in August and gradually declined at the end of the year.

Climatic influence: The dengue outbreak in Dhaka city coincided mainly with the monsoon period with
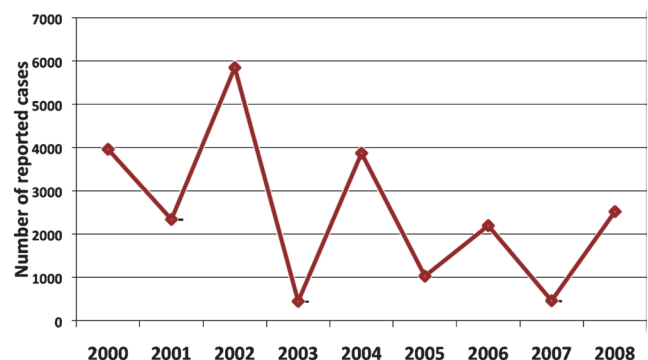

Fig. 1. Total number of reported dengue cases, by year (2000-2008), Dhaka city, (n = 22,705).

Table I. Seasonal variation in number of reported dengue cases in each year (2000-2008)

Year	Pre-monsoon	Monsoon	Post-monsoon	Total
2000	0 (0-0)	682 (0-1690)	309 (0-544)	330 (0-1690)
2001	1.25 (0-5)	285 (24-655)	299 (0-577)	195 (0-655)
2002	0 (0-0)	1304 (0-3155)	159 (0-506)	488 (0-3155)
2003	0.25 (0-1)	0.50 (0-2)	112 (0-351)	38 (0-351)
2004	0.50 (0-1)	767 (143-1234)	201 (0-394)	323 (0-1234)
2005	0 (0-0)	128 (2-334)	130 (0-318)	86 (0-334)
2006	0 (0-0)	491 (100-972)	59 (0-145)	183 (0-72)
2007	0 (0-0)	107 (0-179)	10 (0-39)	39 (0-179)
2008	0.25 (0-1)	407 (34-928)	160 (0-311)	189 (0-928)

Each section of a year *i.e.* pre-monsoon, monsoon and post-monsoon covers four months. During those four months the total number of cases was averaged and that's why the numbers are fractioned (like 0.25).
Pre-monsoon: February, March, April and May, Monsoon: June, July, August and September and Post-monsoon: October, November, December and January. Data are average number of dengue cases per month for the respective season (monthly lowest number of cases – monthly highest number of cases)

heavy rainfall started from June and lasted up to September, followed by relatively less rainfall during the post-monsoon period from October to January. The period from February to May is considered as pre-monsoon period. Temperature, rain and humidity varied significantly over three distinct periods in each year (Table II). Average monthly pre-monsoon rain was recorded 118.2 mm; during monsoon, which raised to 349 mm and during post-monsoon the amount sharply falls to 67 mm only. The overall variation was significant (ANOVA $P<0.001$). Rainfall during monsoon was significantly higher than the other two periods ($P<0.01$) but was not significantly different between pre- and post-monsoon period. The average relative humidity recorded during the pre-monsoon period was 65.0 per cent, which was found to be 79.4 per cent during the monsoon period and 70.04 per cent during the post-monsoon period (Table II). The overall variation was statistically significant (ANOVA $P<0.001$). The relative humidity during monsoon was significantly higher than the other two periods ($P<0.001$). Average highest and lowest temperatures were 31.7°C and 21.6°C, respectively during the pre-monsoon period. During monsoon and post-monsoon periods the mercury rose to 31.9 and 25.8 °C and fell to 27.7°C and 18.1°C, respectively. The overall variation of both maximum and minimum temperatures across the three seasons was found to be significant ($P<0.001$). The minimum temperature was higher in the monsoon than the other two periods ($P<0.001$) but the maximum temperature during monsoon was significantly higher only from the post-monsoon period ($P<0.01$).
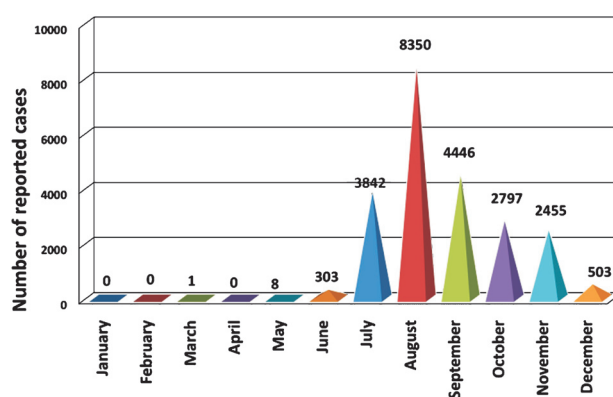

Fig. 2. Total number of reported dengue cases, by month (January to December), Dhaka city, 2000-2008 (n = 22,705)

The number of dengue cases was plotted against the climatic factors (rain, temperature and humidity) to assess their contribution across the years (Fig. 3). As the rainfall increased, the cases of dengue also started rising from June. With declining rainfall from October to December, dengue cases also showed gradual decline. Over the years, the average relative humidity showed increasing trend during the dengue outbreak period and the concavity started at least two months before the starting of the increase in the number of dengue cases and lasted two months ahead of outbreak period. There was narrowing of the gap between the average maximum and minimum temperature for a period of time, which corresponded with the monsoon period and highest number of dengue infection of a year.

Table II. Distribution of climatic parameters of Dhaka city, by season (2000 - 2008)											
Year				Temperature ($^{\circ}$C)							
	Rain fall (mm)			Maximum			Minimum			Relative humidity (%)		
	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon
2000	224.0	234.3	72.8	30.3	32.0	27.9	21.1	26.0	18.4	68.0	79.5	72.8
2001	120.5	250.5	48.8	31.9	31.7	27.7	21.6	25.2	17.5	65.0	81.8	73.5
2002	109.5	311.8	47.5	31.1	31.8	27.9	20.8	25.3	18.3	66.3	81.5	71.8
2003	96.0	282.5	44.8	31.5	32.0	27.1	21.2	25.9	18.1	67.8	80.0	73.3
2004	84.5	450.3	52.0	32.1	31.6	27.7	22.1	25.6	18.0	65.3	81.3	71.5
2005	135.0	419.0	105.3	32.2	32.4	27.8	22.3	26.3	18.5	66.3	80.8	71.5
2006	91.5	371.8	16.5	33.0	32.3	28.5	22.5	26.3	18.5	59.6	75.8	63.0
2007	97.3	516.3	107.8	31.7	32.1	27.7	21.5	26.1	17.8	61.4	74.0	63.6
2008	105.3	303.8	104.3	31.8	31.8	27.6	21.5	25.7	18.3	66.0	80.1	73.0
Average	118.2	348.9	66.6	31.7	31.9	27.7	21.6	25.8	18.1	65.0	79.4	70.4
Each value is a monthly average value of the climatic parameters												

Development of prediction model: The notification of dengue cases increased in a particular season *i.e.* monsoon, indicating a positive relation of dengue infection and climate. This correlation provided us a basis for a possible dengue prediction model. For prediction of number of dengue cases we initially pooled average monthly rainfall in mm, average maximum temperature, average minimum temperature, temperature fluctuation and average humidity in percentage in a particular month. Minimum temperature and temperature fluctuation were excluded from the initial set of variables due to their collinearity with maximum temperature. Automated model, selection through sequential entry of factors also reached similar

conclusion on set of factors to be included. For the final model, average monthly rain, average maximum temperature and humidity were considered. We used tolerance measure to see collinearity between final set of factors included in the model. The tolerance value of collinearity diagnostics for humidity (0.584), rain (0.490) and maximum temperature (0.783) lied clearly above the acceptable value of 0.4. We also checked the independence of the data points through Durbin Watson estimates. The value (0.759) was clearly away from zero suggesting the considerable independence of the data points.

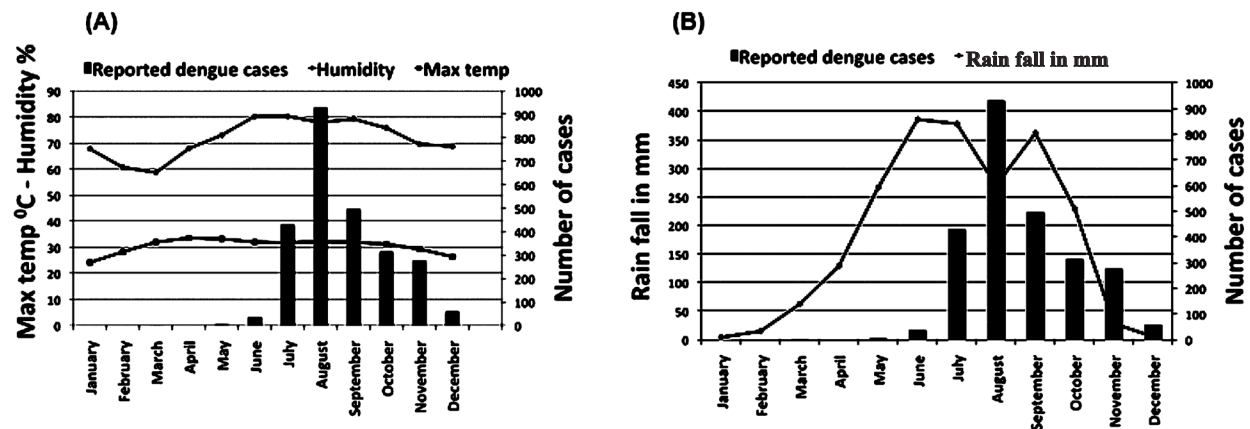Three models were developed using the multiple regression analysis (Table III). In the first model,

Fig. 3. Monthly average rainfall **(A)**, humidity and maximum temperature **(B)** was plotted against average monthly dengue cases reported during 2000 and 2008.

Table III. Estimates and their standard errors (SE) based on the fitting of a multivarite linear regression model relating the monthly number of dengue cases with the climate variables

Model	Variables	Estimates	SE	t-value	P value	Collinearity statistics	
						Tolerance	VIF
1	Constant	-5.4378	1.753	-3.10	0.003		
	Humidity	0.0888	0.017	5.13	0.001	0.584	1.712
	Rainfall	0.0006	0.001	-0.81	0.420	0.490	2.041
	Maximum temperature	0.0105	0.042	0.25	0.804	0.783	1.277
2	Constant	-8.1190	1.432	-5.668	0.001		
	Humidity	0.0919	0.014	6.495	0.001	0.584	1.712
	Rainfall	0.0003	0.001	0.476	0.636	0.490	2.041
	Maximum temperature	0.0856	0.035	2.478	0.015	0.783	1.277
3	Constant	-8.094	1.277	-6.338	0.001		
	Humidity	0.070	0.013	5.583	0.001	0.584	1.712
	Rainfall	0.001	0.001	2.394	0.019	0.490	2.041
	Maximum temperature	0.129	0.031	4.173	0.001	0.783	1.277

Model-1: No time lag; $Log\ D_m = Humidity_m \times 0.0888 + Rainfall_m \times (0.0006) + Max\ temperature_m \times 0.010 - 5.44$; Adjusted $R^2 = 0.264$; Durbin-Watson estimate: 0.808

Model-2: One month time lag; $Log\ D_m = Humidity_m \times 0.0919_{m-1} + Rainfall_{m-1} \times 0.0003 + Max\ temperature_{m-1} \times 0.0856 - 8.11$; $R^2 = 0.509$; Durbin-Watson estimate: 1.863

Model-3: Two months time lag. $Log\ D_m = Humidity_{m-2} \times 0.0709 + Rainfall_{m-2} \times 0.0014 + Max\ temperature_{m-2} \times 0.1285 - 8.09$; $R^2 = 0.610$; Durbin-Watson estimate: 0.759

Where D is the number of dengue cases; m, month; SE, standard error; VIF, variance inflation factor

we incorporated data of all the seasons of eight consecutive years (2000-2007) and developed a model considering data of the present month (pm) and found the model to demonstrate capacity of explaining only 26.4 per cent of the total variations in the occurrence of dengue case. Due to direct but variable influence of the climatic factors, it takes 7 to 45 days to become an adult mosquito from an egg[8]. Therefore the influence of climate is expected to be visible 1 or 2 months later. In the next model (Model-2) we incorporated the data of one lag month as a lag phase allowing time for a new generation of mosquitoes to appear. With this model the explanatory capability seems to be increased to around 50.9 per cent. We tried another model (Model-3) with the assumption of average 2 months lag phase. In this model the explanatory capability further increased over the model-2 and could explain 61 per cent of the variation in dengue case occurrence. We tried another model with even higher lag period, however, the models failed to add to explanatory capacity, rather showed sharp decline. Hence model-3 was chosen as final model.

While generating the model all the relevant assumptions were checked for assuring best possible

model to be selected. For model-3 standardized residual of the model (ranged between -3.0 and 2.2) did not exceed the tolerable limit suggesting minimal outlier in the data points. Normal probability plot of residuals also satisfied the normality assumption. Besides scatter plot of standardized residual against standardized predicted value depicted no clear pattern suggesting a desirable constant variance for the model. Among the variables included in the final model humidity ($\beta = 0.591$) demonstrated highest influence on number of dengue cases reported followed by maximum temperature ($\beta = 0.025$) and the average rainfall ($\beta = -0.102$).

Considering the fact that higher dengue cases were notified during the monsoon, we attempted to develop a prediction model with only monsoon period data (data not shown). The model demonstrated very poor explanatory capability (8.2%). The explanatory capacity of this model was not improved when we tried to generate models using the data of both 1 and 2 - lag month from the monsoon period.

Retrospective model validation: We retrospectively attempted to evaluate the prediction capability of our proposed model (Model-3) for predicting the number of dengue cases that occurred in 2001, 2003, 2005 and

2008 in Dhaka city. The forecasted notified dengue cases were plotted against the actually reported cases of the respective year. This model showed significant correlation between predicted and observed number of cases in 2001 (r =0.706 *P*=0.010), 2005 (r=0.837 *P*=0.001) and in 2008 (r=.627 *P*=0.029), although in 2003 (r=0.396 *P*=0.202) the correlation was not significant (Fig. 4).

Accuracy of the model for predicting outbreak (≥200 cases) was assessed through ROC analysis. Area under ROC = 0.89, 95%CI = 0.89-0.98 suggested high accuracy of the model.

Discussion

The growth and development of dengue vector is climate dependent. Being a vector borne disease, transmission of dengue virus is greatly dependent on the availability, density and extension of its vector. Worldwide studies have proposed that ecological and climate factors influence the seasonal prevalence of both the vector *Ae. aegypti* and dengue virus[11,12].

The climate of Bangladesh, which is a part of tropical Asia, is mainly dominated by two monsoons (wet and dry monsoon) with year-to-year time variation. In the present study, three periods in the year considered for the analysis were the monsoon (June–September) with heavy rain fall of average 348.9 mm, the post–monsoon (October– January) with average rainfall of 66.6 mm and pre-monsoon (February–May) with an average rain fall of 118.2 mm. There was a significant difference not only in the amount of rainfall but also in the maximum and minimum temperature and relative humidity between these periods. Anecdotal evidences show significant increase in dengue infection during the monsoon season starting from the month of June, reaching the peak in August and gradually coming down to about zero during the post-monsoon time. Season-specific pattern of dengue cases in Southeast Asia has been reported by others also[13]. Our observations matched with other long-term studies from the same geographical region, Myanmar and India[14,15], as also studies from the region of the Gulf of Thailand and from Puerto Rico[5,16]. The increase in vector density due to rainfall and subsequent increase in dengue cases has been reported before[17,18].

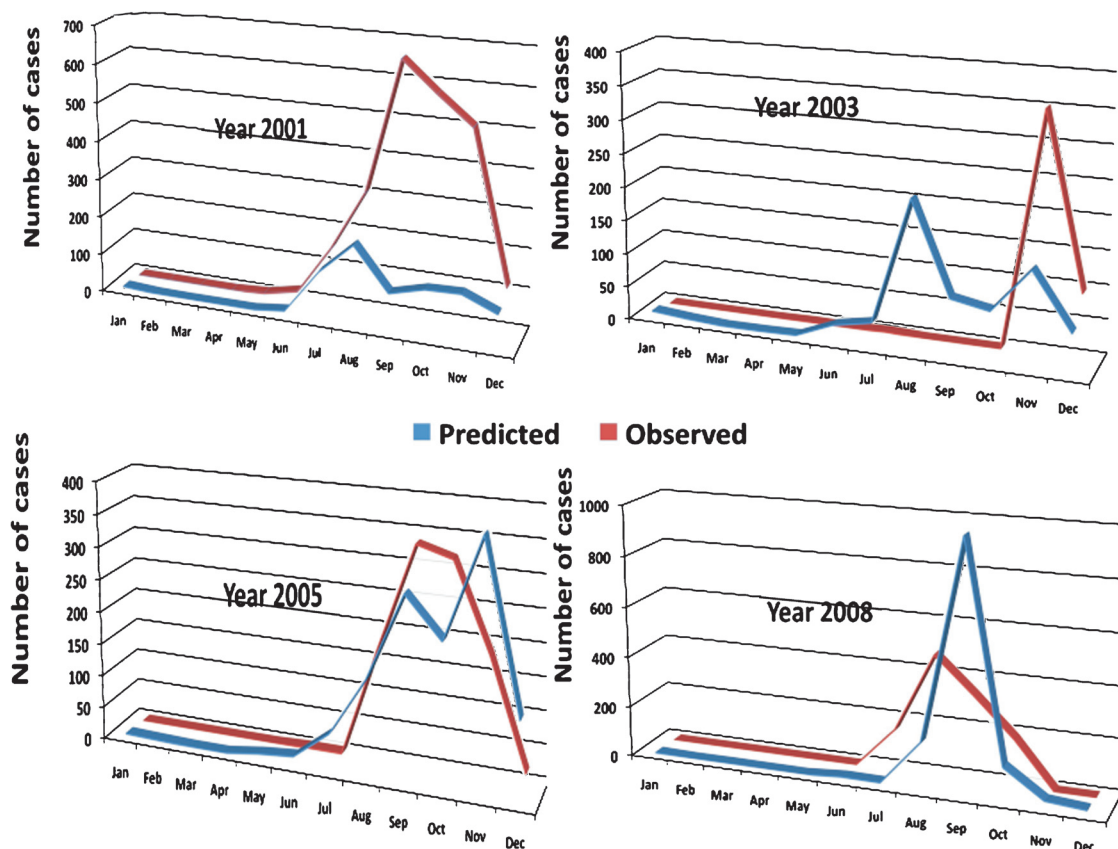It is considered that increase in global temperature may lead to expansion of area of involvement and

Fig. 4. Corelation of observed and predicted dengue cases in 2001, 2003, 2005 and 2008 by Model-3.

number of cases of vector-borne diseases[19,20]. This will increase the proportion of mosquitoes that become infectious at a given time[21,22] leading to an exponential increase of dengue cases. In our study, temperature was found to be closely related with the rise of dengue infection. The minimum temperature was significantly different between the study periods, number of dengue cases also varied in accordance with temperature. It has been shown that increase of temperature from 26-28 to 30^{0}C decreases the extrinsic incubation of the dengue virus (serotype 2 & 4) which may facilitate the transmission of virus[22,23]. Dengue cases were found to be reported more during the months of monsoon in the present study when relative humidity was higher similar to earlier reports[16]. Higher humidity during rainy season facilitates the growth and survival of mosquitoes[24,25] leading to an increase in the number of infected mosquitoes for successful propagation of virus. According to Barbazan *et al*[25], an increase in mosquito longevity disproportionately enhances the number of potential transmissions by as much as five times when the survival rate rises from 0.80 to 0.95[25]. Though availability of dengue vectors was reported during our study period from Bangladesh[3,4], we could not verify our finding due to unavailability of information regarding the seasonal variation of mosquito population.

During the study period every second year had an explosive nature of outbreak followed by lower number of cases in the following year. This type of fluctuation of dengue outbreaks was also observed in Thailand[26,27]. In a massive urban dengue outbreak 70-80 per cent of a population can be involved[28] which may lead to development of herd immunity to the circulating dengue serotype/serotypes and thus it may prevent another outbreak in the following year. Molecular studies showed that the 2000 outbreak in Dhaka city was due to DEN-3[29] and during the 2002 outbreak, both serotypes DEN-3 and DEN-2 were circulating[30]. This indicates that besides climatic factors, introduction of new serotype or new virulent strains of existing serotypes in a naïve population is one of the factors that could contribute to new outbreak[31].

This study had two interesting findings. First, the years with explosive nature of outbreak coincided with the monsoon period with 2-8 times added number of dengue cases than the post-monsoon period. On the other hand, the years which had comparatively lower number of cases, both the periods *i.e.* monsoon and post-monsoon, either had almost equal number of infections or more number of infections occurred in post-monsoon period. The second finding is that the significant difference between the minimum and maximum temperature, rainfall and humidity of monsoon and post-monsoon period remained almost the same in every year but the number of dengue cases varied. It was observed that the seasonal dengue infection rate of a particular period was related with climatic factor changes when we compared within that year, but when we checked with the same period of time in different years, it did not correlate with the number of infections. Both these points signify the attribution of other factors which in co-occurrence with climate influence dengue infection outcome in a given geographical area. However, in a few studies from different parts of the world, it has been reported that individually or collectively climatic factors had no role in dengue infection[6,7].

Since our findings indicated that dengue outbreaks in the Dhaka city had to some extent, a linear relationship with the climatic factors, we attempted to convert the relationship in to a mathematical equation for developing a model suitable for prediction of possible toll of dengue cases in Dhaka city in a given month. Our predictive model-3 with climate factors as predictors could explain only 61 per cent of the variation in the occurrence of dengue cases. The remaining 39 per cent unexplained variation could be due to the influence of other factors. The other probable influencing factors of dengue infection include multiple serotypes and strain polymorphism, immune-mediated serotype interactions and environmental variables. Therefore, future attempt to develop a model to predict the total number of dengue case in each month should include data on immunological, entomological and demographical factors along with climatic factors. Otherwise, oversimplification of prediction model without establishing significant correlations with other factors may lead to wrong forecast of dengue outbreaks and might hamper the dengue prevention and control programme.

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