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PREDICTORS AND THEIR DOMAIN FOR STATISTICAL DOWNSCALING OF CLIMATE IN BANGLADESH

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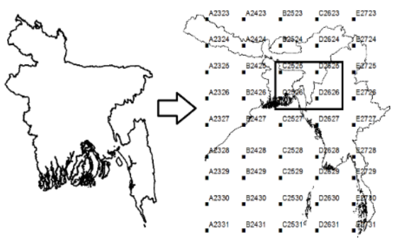
Graphical abstract



Abstract

Reliable projection of future rainfall in Bangladesh is very important for the assessment of possible impacts of climate change and implementation of necessary adaptation and mitigation measures. Statistical downscaling methods are widely used for downscaling coarse resolution general circulation model (GCM) output at local scale. Selection of predictors and their spatial domain is very important to facilitate downscaling future climate projected by GCMs. The present paper reports the finding of the study conducted to identify the GCM predictors and demarcate their climatic domain for statistical downscaling in Bangladesh at local or regional scale. Twenty-six large scale atmospheric variables which are widely simulated GCM predictors from 45 grid points around the country were analysed using various statistical methods for this purpose. The study reveals that large-scale atmospheric variables at the grid points located in the central-west part of Bangladesh have the highest influence on rainfall. It is expected that the finding of the study will help different meteorological and agricultural organizations of Bangladesh to project rainfall and temperature at local scale in order to provide various agricultural or hydrological services.

Keywords: General circulation model, statistical downscaling, climate domain, Bangladesh

1.0 INTRODUCTION

Bangladesh is one of the most vulnerable countries of the world to climate change [1-3]. It has projected that the climate change will affect agriculture [4], public health [5], water [6], energy [7], and people's livelihood [8] in Bangladesh. Therefore, assessment of possible impacts of climate change on various sectors is urgent for the country in order identify the necessary adaptation and mitigation measures [9-11]. Reliable but computationally inexpensive approach for projecting future climate at local or regional scale is very important for this purpose. GCMs are usually used to simulate the present climate as well as to predict the future [12]. However, due to their coarse spatial resolutions, GCMs cannot be used to project local- and regional-scale climate. Therefore, GCM simulations are downscaled into much finer spatial resolution for climate change impact studies at local and regional scales [13]. Statistical downscaling method establishes statistical relationships between large-scale atmospheric variables and local climate variables for downscaling GCM simulations at local scale [14]. Statistical downscaling method needs much simpler computational skill and therefore, most widely used for climate downscaling [15-16].

One of the major challenges in climate downscaling using statistical approach is the selection of climatic domain and appropriate predictors. The climatic system is influenced by the combined action of multiple atmospheric variables in the wide space [17]. Therefore, small climatic domain or single atmospheric predictor cannot predict climate reliably, as they fail to capture key rainfall or temperature mechanisms based on thermodynamics and vapor content [18]. In order to select the appropriate predictors for downscaling, it is required to know the climatic domain that influences the climate of a region. The objective of the present study is to demarcate the climatic domain as well as to identify the large-scale atmospheric variables as predictors for statistical downscaling of daily rainfall, maximum and minimum temperatures in Bangladesh.

2.0 METHODOLOGY

2.1 Data and Methodology

Bangladesh Meteorological Department (BMD) has 36 meteorological stations distributed over the country for measuring daily rainfall and other weather parameters.

However, daily rainfall and temperature records for the climatic base years (1961-2000) are available only at nine stations and therefore, those nine stations were selected for the present study to demarcate the climatic domain and identify the predictor variables Description of climate at selected stations is given in Table 1. Location of selected stations in the map of Bangladesh is shown in Figure 1. Twenty-six large scale atmospheric variables usually projected by most of the GCMs for climate change simulated are used for selection of predictors.

Table 1 Time periods of rainfall records at different stations used in the study

Station Name	Latitude	Longitude	Annual rainfall (mm)	Daily mean Temp (⁰C)
Barishal	22°43'N	90°22'E	2086	25.8
Bogra	24°51'N	89°22'E	1779	25.7
Chittagong	22°13'N	91°48'E	2856	25.9
Cox's Bazar	21°27'N	91°58'E	3624	25.9
Dhaka	23°47'N	90°23'E	2064	26.0
Jessore	23°12'N	89°20'E	1629	26.1
Mymensingh	24°44'N	90°25'E	2206	25.2
Rangpur	25°44'N	89°16'E	2154	24.9
Sylhet	24°54'N	91°53'E	4108	24.8

National Center for Environmental Prediction (NCEP) reanalysis large-scale atmospheric variables are widely used as a proxy of those GCM variables. Therefore, NCEP reanalysis variables are used in the present study for demarcation of climate domain and selection of predictors. The NCEP variables were collected from the website of the Canadian Climate Change Scenarios Network (CCCSN) for this purpose. The list of 26 NCEP variables used in the present study is given in Table 2. To demarcate the climate domain, the NCEP variables from 45 grid points in and around Bangladesh were used. The location of NCEP grid points used in the present study is shown in Figure 2.

2.2 Selection of Predictors

There are no general guidelines for demarcation of climate domain or selection of predictors for downscaling. Therefore a comprehensive search of predictors is necessary [18]. However, it is expected that predictors in the climate domain should be highly correlated with local climate parameters. Therefore, following the suggestions of Wilby and Wigley [19], the regional synoptic circulation patterns that contributed to the anomalous rainfall pattern in Bangladesh were considered as the domain covered by 45 grid points surrounding the country.

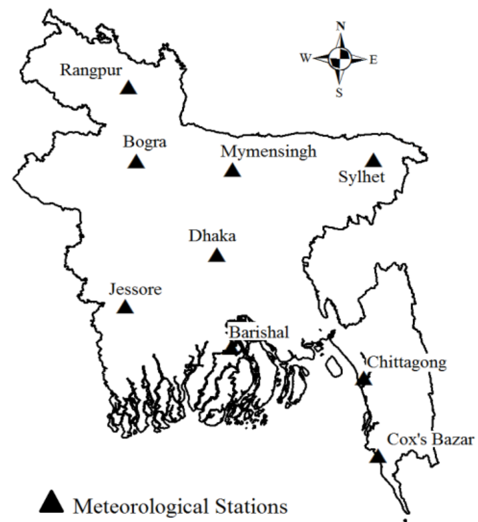


Figure 1 Location of rain gauges in Bangladesh used in the present study

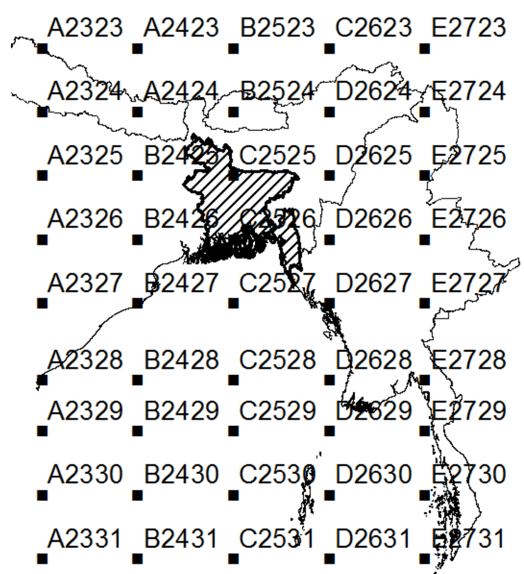


Figure 2 Grid points used to select NCEP predictor data sets

In the present study, all the twenty-six NCEP variables at 45 NCEP grid points surrounding Bangladesh (Figure 2) (total 26 × 45 = 1,170) were individually correlated with local daily rainfall, daily maximum temperature and daily minimum temperature. As the climatic data often does not follow a normal distribution, non-parametric Spearman Rank correlation method was used for the estimation of correlation. The Spearman rank correlation coefficient was estimated as:

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \qquad (1)$$

Where, d_i is the difference between the ranks of variables *x* and *y*, and n is the sample size. The highly correlated NCEP variables were used for the selection of predictors through stepwise Multiple Linear Regression (MLR) analysis. The basic equation of stepwise MLR can be given as:

$$Y = \alpha_o + \sum_{j=1}^{n} \alpha_j X_j \qquad (2)$$

Where, Y is the dependent variable predictand; X_j is predictor set; n is the number of predictors, and α is the model parameters show the influence of each predictor.

Table 2 Description of 26 NCEP variables used for predictor selection

No	NCEP Variable	Description	No	NCEP Variable	Description
1	Mslp	Mean sea level pressure	14	p5zh	500 hPa divergence
2	p_f	Surface airflow strength	15	p8_f	850 hPa airflow strength
3	p_u	Surface zonal velocity	16	p8_u	850 hPa zonal velocity
4	p_v	Surface meridional velocity	17	p8_v	850 hPa meridional velocity
5	p_z	Surface vorticity	18	p8_z	850 hPa vorticity
6	p_th	Surface wind direction	19	p800	850 hPa geopotential height
7	p_zh	Surface divergence	20	p8th	850 hPa wind direction
8	p5_f	500 hPa airflow strength	21	p8zh	850 hPa divergence
9	p5_u	500 hPa zonal velocity	22	rhum	Near surface relative humidity
10	p5_v	500 hPa meridional velocity	23	r500	Relative humidity at 500 hPa
11	p5_z	500 hPa vorticity	24	r850	Relative humidity at 850 hPa
12	p500	500 hPa geopotential height	25	shum	Near surface specific humidity
13	p5th	500 hPa wind direction	26	temp	Mean temperature

MLR is a popular technique used for measure the influences of various dependent variables on independent variable [20]. Stepwise MLR is a semi-automated process of building a model by successively adding or removing variables based on the t-statistics.

3.0 RESULTS AND DISCUSSION

3.1 Selection of Predictors

For the selection of predictors, the NCEP variables from 45 grid points surrounding Bangladesh were correlated separately with local rainfall and temperature for two time periods namely, 1961-1979 and 1980-2000. The NCEP variables from different grid points, having high and consistent correlation in both the time periods were preliminary selected. Those predictors were then used for the selection of final set of predictors using step-wise multiple regression method. A cut-off value of adjusted-R^2 after which the adjusted-R^2 was not found to vary much was used to select the predictors. The selection of final set of predictors for downscaling daily rainfall at Cox's Bazar Station of Bangladesh using stepwise regression method is shown in Figure 3.

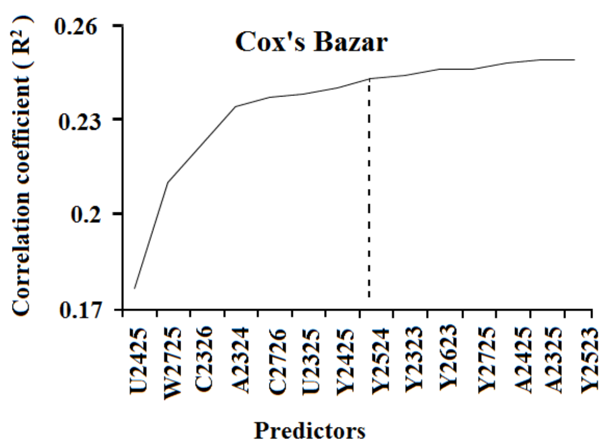


Figure 3 Selected predictor at Cox's Bazar station

The procedure is followed for all stations for the selection of predictors for downscaling daily rainfall. The list of predictors that can be used for downscaling daily rainfall in different stations of Bangladesh are given in Table 3. The table shows that four atmospheric variables namely, surface meridional velocity, relative humidity at 850 hPa, 850 hPa meridional velocity, and 500 hPa geopotential height have the highest influence on daily rainfall events in Bangladesh.

Table 3 List of predictor of rainfall for downscaling

Station Name	Predictors
Barishal	C2326,U2324,U2425,W2725,Y2425,Y2725
Bogra	C2326,Y2424,Y2425,Y2523,Y2724
Chittagong	A2325,A2425,C2326,C2726,U2425,W2725
Cox's Bazar	A2324,A2425,C2326,C2726,U2325,U2425,W2725,Y2323,Y2425,Y2524,Y2623,Y2725
Dhaka	A2324,C2326,C2726,W2725,Y2525,Y2723, Y2725
Jessore	A2324 ,C2326,U2425,Y2425,Y2623
Mymensingh	C2326,W2725,Y2524,Y2525,Y2725,Z2323
Rangpur	C2326,U2324,U2325,Y2425,Y2524, Y2623,Y2724
Sylhet	A2324,C2326,U2324,U2325,W2725,Y2525, Y2723,Y2725

Similar approach was used for the selection of predictors for downscaling daily maximum and minimum temperatures in Bangladesh. The predictors selected at different stations of Bangladesh are given in Table 4. The Table shows that surface meridional velocity, relative humidity at 850 hPa, meridional velocity at 850 hPa, and geopotential height at 500 hPa are the major controlling parameters for both the daily maximum and minimum temperatures in Bangladesh.

Table 4 List of predictor of Maximum and Minimum Temperature used for downscaling

Station Name	Predictors	
	Maximum Temperature	Minimum Temperature
Barishal	T2731,X2624,O2626, E2523,Q2728,Z2524, Z2523	T2731, X2624, O2626, E2523,Q2524, X2623, K2731, X2431, X2723, N2725, Q2531, K2424
Bogra	X2424,E2725,D2423, D2328,O2726,G2525	X2325, D2623, G2328, N2631,X2428, E2729, G2323
Chittagong	X2624,O2626, W2431, Y2327,Q2728,X2731	X2725,W2431, O2626, O2729, B2629, X2731, B2627
Cox's Bazar	F2329,G2423,S2624, O2423,2627,D2423, R2727,X2730,K2425, G2623	Q2525, D2326, T2631, D2427, R2431, V2523, X2523
Dhaka	T2731,X2525,O2727, U2731,Z2629,Q2629, J2430,X2331	T2731, X2726, O2727, U2731, Z2629, Q2629, T2331
Jessore	X2424,D2424,Y2524, Z2423,A2725,Y2424, C2723,V2623	P2523, Z2630, Z2531, Z2631, Y2623, Y2523, Y2624
Mymensingh	T2731,U2729,A2725, U2731,P2723,Q2629, G2323,A2624	Z2629, D2728, P2726, X2624, P2724, Q2626, E2323, Q2423
Rangpur	O2727,T2331,U2626, A2523,C2625,P2724, B2326,A2524	O2727, T2631, U2626, A2523, B2524, O2630
Sylhet	H2323,T2631Q2726, O2626,B2327,Z2731, E2525,P2323	O2727, T2631, U2626, U2324, C2630, E2624, E2725, Y2423

3.2 Climate Domain

Different NCEP variables from 45 grid points are individually correlated and average rainfall of all stations of Bangladesh. The correlation coefficients calculated for each grid point are used for preparation of contour maps using kriging method [21]. It process produces 26 contour maps. The contour maps of relative humidity at 850 hPa and surface meridional velocity are shown in Figures 4(a) and 4(b), respectively. The contour maps of influential variables were analyzed to find the extents up to which those variables have relation with the rainfall of Bangladesh. Figure 5 shows selected influential grid points, in black box, to climate domain over the study area. The predictors selected in this study can be justified through the analysis of synoptic climatic pattern of Bangladesh.

(a)

(b)

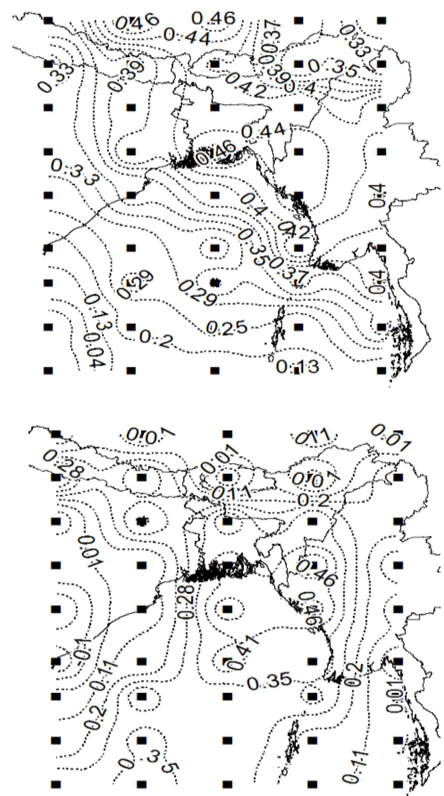


Figure 4 the contour showing the correlation of a NCEP variable with the rainfall of Bangladesh of (a) relative humidity at 850 hPa and (b) surface meridional velocity

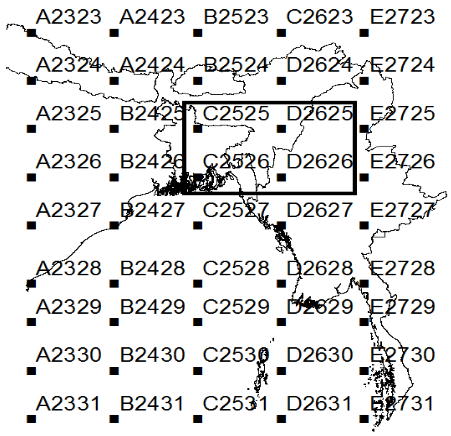


Figure 5 Grid points used to selected climatic domain and black box shows most influences area

Rainfall in Bangladesh mostly occurs in monsoon, caused by weak tropical depressions that are brought from the Bay of Bengal into the country by the wet monsoon winds. The monsoon depressions enter Bangladesh with south-to-north trajectory and then turn toward the northwest and west being deflected by the Meghalaya Plateau. As these depressions move farther and farther inland, their moisture content decreases, resulting in decreasing rainfall toward the northwest and west of Bangladesh [22].

On the other hand, the additional uplifting effect of the Meghalaya plateau increases the rainfall in the northeast of Bangladesh. Therefore, the climatic variables at the grid points located in the central west part of the country have most influence on the rainfall of the country. Therefore, the finding of the present study collaborates with the synoptic mechanism of rainfall occurrence in Bangladesh.

4.0 CONCLUSION

Downscaling climate in the context of global warming is very important for Bangladesh in order to mitigate the negative impacts of climate change. An attempt was taken to demarcate the climate domain and identify the large-scale atmospheric variables for statistical downscaling of climate in Bangladesh. The present study revealed that four large-scale atmospheric variables, namely surface meridional velocity, Relative humidity at 850 hPa, 850 hPa meridional velocity, and 500 hPa geopotential height from the climate domain covered by four NCEP grid points located in the central west part of the country have highest influence on the rainfall and temperature of the country. Therefore, those variables and climatic domain can be used for downscaling rainfall in Bangladesh.

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