Type of the paper: Article

Title

Assessment of Better Prediction of Seasonal Rainfall by Climate Predictability Tool (CPT) using Global Sea Surface Temperature in Bangladesh

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Abstract: The main objective of this study is to search better prediction result of rainy seasonal rainfall (15 June-15 August).

A correlation between rainfall of Bengali rainy seasons at Rangpur, Dhaka, Barisal and Sylhet and global sea surface temperature (SST) of different areas of the world was studied by using the both data of 1975- 2008 years with the help of the Climate Predictability Tool (CPT) to find more positive correlated SST with observed rainfall and use as predictor for giving the prediction of the year 2009.

Using SST of one month before rainy season as predictor, the positive deviation of predicted rainfall from observed rainfall was 1.34 mm/day at Sylhet and 0.9 mm/day at Dhaka. The negative deviation of mean rainfall was 1.16 mm/day at Rangpur and 1.10 mm/day at Barisal. Again, using of starting one month SST of rainy season as predictor, positive deviation of predicted rainfall from observed rainfall was 4.03 mm/day at Sylhet. The positive deviation of daily mean rainfall was found 6.58 mm/day at Dhaka and 6.23 mm/day over southern Bangladesh.

The study reveals that sea surface temperature (SST) of one month before rainy season was better predictor than SST of starting month of rainy season.

Keywords: CPT, Rainfall, Prediction, Season, SST

1. Introduction

1.1 Brief description of the study field:

Climate is the statistics of weather over long periods of time up to 30 years. Modern climate prediction started back in the late 1700s with Thomas Jefferson and continues to be studied around the world today. The use of seasonal climate prediction has been essential in present time due to climate change. As Climate prediction shows the future atmosphere state for a given location which is the application of science and technology to predict. Weather data predictions are made by collecting quantitative weather data about the current state of the atmosphere at a given place.

1.2 Global situation

The CPT is a software package developed by the International Research Institute for Climate and Society (IRI) designed for making seasonal climate forecasts. The CPT is an easy-to-use tool that runs on Windows. The software was initially developed to enable forecasters at National Meteorological Services (NMSs) in Africa to produce updated seasonal forecasts for their country, and to provide greater consistency in inputs to the Regional Climate Outlook

 doi:10.20944/preprints201901.0023.v1

Forums (RCOFs) to facilitate consensus building, but the CPT has been used widely beyond the RCOFs.

There are two main approaches to generating seasonal forecasts: using large-scale models of the global atmosphere, known as general circulation models (GCMs), or using a statistical approach to relate seasonal climate to changes in sea-surface temperatures, such as those associated with El Niño, or to other predictors. In the former case, predictions are made for large-areas, and are often not very relevant for specific locations. In addition, because of the coarse scale at which the GCMs operate, the geography in the models is often distorted, and so geographical locations can be displaced. These GCM outputs therefore need to be adjusted so that they can be applied at the local level. The CPT tool is designed to perform both forms of prediction, namely downscaling of GCM output, and purely statistical predictions.

The statistical approach to making seasonal forecasts from sea-surface temperatures has been used for a number of years at many National Meteorological Services. Since the late 1990s, these statistical forecasts have been combined to produce a consensus forecast, representing a patchwork of nationally-based forecasts for sub-continental areas, in Regional Climate Outlook Forums [1]. While such forums have been very successful in building the capacity to produce seasonal climate forecasts, a number of problems have emerged, and some systematic errors in the forecasts have been identified [2]. Hence, CPT is being used in the world wide like Africa, America, and Asia.

1.3 Study area situation

Bangladesh is a typical country of the most vulnerable countries to Natural Disasters in the world, in the context of Physical, Social as well as Economic conditions. Now Bangladesh is expected to be highly affected for any global climate change because of its geographical location, low-lying landscape, population density, poverty, illiteracy, etc. So climate prediction has been necessary for this country. In the present study prediction of seasonal rainfall is assessed based on anomalies in rainfall in four Divisions, namely Rangpur, Dhaka, Borisal and Sylhet weather stations to cover whole Bangladesh considering the data from 1975 to 2008 periods

1.4 Literature review

Seasonal climate prediction is potentially very useful for planning agricultural activities and as a starting point for early warning and response planning [3]. So seasonal climate prediction is getting higher demand as policy makers, planers and stakeholders of the vulnerable sectors such as agriculture, food security and water resources are making plan to minimize the losses due to weather hazards. Prediction of short range weather has become easy with the advent state of the art numerical models and improved data assimilation techniques using numerical models is still questionable as boundary forcing play a crucial role in seasonal time scale. This is mainly due to slow evolving ocean variability in longer time scale. There had been many studies on predicting Indian region monsoon rainfall by many researchers in the past. After experiencing a severe famine, India Meteorological Department (IMD) had started prediction of monsoon rainfall based on the Himalayan snow cover in 1877. [4] developed an operational monsoon rainfall forecast for India and Burma. [5, 6] developed a sixteen parameter power regression model and it had been operational for forecasting monsoon rainfall over India till 2002. As the model was not able to predict the all-India drought in 2002. [7] introduced a new ten parameter model for forecasting monsoon rainfall over India. Further improved version of eight parameter model was introduced by [8] and it is being operational since then. Monsoon rainfall forecasts are issued in two stages in April (with six parameters) and updated in June with all eight parameters. Most of the models that were used to forecast Indian summer monsoon rainfall (ISMR) come under empirical modeling approach. [9] developed a general overview of forecasting models for Indian monsoon rainfall. Excellent reviews of the empirical models used to predict ISMR are presented in some studies [10, 11]. In this study, we have

 doi:10.20944/preprints201901.0023.v1

considered Artificial Neural Networks (ANNs) as the forecasting tool. Artificial Neural Networks have been used in various fields for predicting and forecasting complex nonlinear time series, including the forecast of Indian monsoon rainfall. The neural network technique is able to learn the dynamics within the time series data [12]. In the past, ANNs have been successfully used to predict Indian monsoon rainfall [13, 14,, 15, 16]. [13] used the time series approach, in which previous values from the time series were used to predict future values. [14] has used neural network technique to predict monsoon rainfall of India using few predictors and compared the results with linear regression techniques, showing that the model based on neural network technique performed better. [15] has used hybrid principal component and Neural Network approach for long range forecast of the Indian summer monsoon rainfall. They observed improved accuracy in prediction. The neural network technique contains the advantages of both the regression analysis and nonlinear dynamics that need to be incorporated in order to predict the dynamic rainfall values.

[17] applied the ANN technique to five time series of June, July, August, September monthly and seasonal rainfall. The previous five years values from all the five time-series were used to train the ANN to predict for the next year. They found good performance in predicting rainfall. Other studies, using ANNs for summer monsoon rainfall forecasting over India include [16]. They decomposed the Indian monsoon rainfall data into six empirical time series (intrinsic mode functions). Then they identified the first empirical mode as a nonlinear part and the remaining as the linear part of the data. The nonlinear part was handled by ANN techniques, whereas the linear part was modeled through simple regression. They showed that their model can explain 75 to 80% of the inter-annual variability (IAV) of eight regional rainfall series considered in their study. A study was made on high resolution mesoscale model MM5 to observe rainfall estimation over Bangladesh. The model was run at two resolutions 45km and 15km for two durations (31 March to 05 April 2002 and 20 to 25 May 2002). In both cases [18]

has showed that MM5 model good capability to estimate rainfall over Bangladesh. Seasonal variation in winds or reversal of winds is named as monsoon. Temperature gradient between the ocean and adjacent land is the main cause of this variation [19]. In another study Weather Research and Forecast Model (WRF) was used to gauge Lightening Potential Index (LPI). The potential for charge generation in a convective thunderstorm is calculated by LPI. For the study two heavy rainfall events having significant lightening activity were simulated by WRF at different horizontal grid sizes. WRF was found reasonable after comparison of simulated and observed lightening [20]. Another study was made for the predictability of an extreme warm season precipitation event over central Texas on 29 June to 07 July 2002 using MM5. The event was explored through MM5 with various grid resolutions, initial and boundary conditions. The results showed that MM5 at high resolution convective resolving simulations do not produce the best simulations or forecast [21]. Global warming and climate change have been posing a great challenge to the weather forecasters to predict the weather in changing climate pattern. High Resolution Regional Models are required to predict the weather events in a particular region. Such High Resolution Regional Model (HRM) has been adapted by Pakistan Meteorological Department (PMD) for operational weather forecast up to 72 hours. In the era of global warming and climate change, extreme events (precipitation) have been observed. Accurate and advance prediction of such events may be very useful for human beings [22]. Seasonal Forecast Model (SFM) of Experimental Climate Prediction Centre (ECPC) of United States was adopted by the IMD for issuing experimental ensemble forecasts for the Indian region for 2005 and 2006 (www.imd.gov.in). It is a General Circulation Model (GCM) with model resolution T63 L28. Since GCM has the capacity to simulate large scale features over the region, statistical downscaling technique is being used to forecast rainfall over the desired regions. National Center for Medium Range Weather Forecast (NCMRWF) of India has also been using GCM with statistical downscaling technique to issue seasonal weather outlook for Indian states for the benefit of farmers on experimental basis.

Sri Lanka Meteorological Department (SLMD) has been issuing experimental seasonal weather forecasts for southwest monsoon, northeast monsoon and individual months based on statistical downscaling techniques built in Climate Predictability Tool (CPT) (www.meteo.slt.lk.) SMRC has also been using the Seoul National University (SNU) coupled GCM and APEC Climate Centre (APCC) Multi Model Ensemble (MME) products with statistical downscaling technique built in CPT for making seasonal weather forecasts (JJA and DJF) for Sri Lanka [23]. [24] compared in their paper CPT generated forecast (JJA) mean rainfall and observed rainfall for all Bangladesh and they have shown that CPT generated forecast (JJA) rainfall is overestimated 0.47% and it is almost same with the observe value. They have also studied on twelve selected stations rainfall in the western, southwestern and southeastern parts of Bangladesh. Results reveal that forecasted rainfall of seven stations is overestimated and five stations are underestimated over Bangladesh. [25] predicted JJAS seasonal rainfall using Canonical Correlation Analysis (CCA) by CPT. Canonical Correlation Analysis (CCA) applied to predict seasonal rainfall over Ethiopia using global sea surface temperature (SST) predictor data and historical monthly total Ethiopian rainfall as well as merged both satellite and rain gauge rainfall data predictand data, It is found that in general, ENSO is the main source of predictive skill for Ethiopian seasonal rainfall. As a result, the rainfall predictability using CCA the forecast and the observed one are in agreement over much of the country however, some discrepancy over northwestern parts of the country.

[26] studied on Predictability of May To August (Mjja) Seasonal Rainfall In Northern Philippines and found that the observed SST predictor yields the lowest CC of 0.65 and Goodness Index (GI) of 0.55. On the other hand, Observed MJJA rainfall of Batac (324.80

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mm) in 2014 was comparable with the forecasted rainfall of 325.53 mm, showing the remarkable ability of the model to predict MJJA rainfall for that year

1.5 Research gaps

The research is a new field of study**.** Because the researcher reviewed more than 60 documents like books, journals, reports web pages and articles on relevant field. Some studies on temperature and rainfall were reported but not found any specific research on prediction of Bengali rainy seasonal rainfall in Bangladesh. Since Bangladesh is a country of six season. Agricultural crop Amon of Bangladesh depends on the rainfall of rainy season (15 June-15 August).Now it is not raining timely in Bangladesh because of climate change. Climate change has important role on the changing pattern of seasons. So rainfall prediction is very need in present time. This research study will fulfill this research gap.

1.6 Importance of the study

Climate predictions are called warning of future weather situation which is important because they are used to protect life and property. Prediction of rainfall is immensely important to agriculture, and therefore, to traders within commodity markets. The people use climate prediction to determine what to wear on given day. Since outdoor activities are severely curtailed by heavy rain. So rainfall prediction is very need to plan activities ahead and survive. In 2014, the US spent $5.1 billion on weather prediction

1.7 Objectives

1. To predict seasonal rainfall of rainy season (15 June-15 August) by Climate Predictability Tools using global sea surface temperature (SST) of starting month of rainy season considering the range from1975 to 2008 periods
2. To predict seasonal rainfall of rainy season (15 June-15 August) by Climate Predictability Tools using global sea surface temperature (SST) of one month before rainy season considering the range from1975 to 2008 periods
3. To evaluate the better prediction of seasonal rainfall of rainy season (15 June-15 August) by Climate Predictability Tools (CPT) in the context of using SST of starting month of rainy season compare to using SST of one month before rainy season

1.8 Expected benefits

Seasonal climate predictions provide gesture of the weather conditions that helps us to take advance decision in many areas. Climate predictions may help to get indications of the expected level of temperatures, precipitation, wind, humidity and sunshine. This information will be useful to industries that are exposed to direct or indirect impacts of weather events. Three-six months ahead of time perfect predictions of climate can potentially allow farmers and others in agriculture to make decisions to reduce unexpected impacts or take advantage of expected favorable climate. However, potential benefits of climate predictions vary considerably because of many physical, biological, social and political factors [27]. For example, in a study of the value of seasonal predictions in corn production in the Corn Belt of U.S.A. [28], it was found that consumers were the vivid winners and producers were the losers over the entire 10 years of the study.

2. Materials and Methods

2.1 Data sources and collection technique

A Multi Model Ensemble (MME) global product of Asia Pacific Climate Centre (APCC) data (sea surface temperature) was used as predictors for the CPT to predict seasonal rainfall (rainy season) in Bangladesh. The APCC data was taken through International Centre for Theoretical

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Physics (ICTP) DODS server. After downloading data from this site, binary data is transformed into ASCII format using a FOTRAN code. Station data means observed daily rainfall data of Rangpur, Dhaka, Barisal, and Sylhet of Bangladesh was collected from the Bangladesh Meteorological Department (BMD) and processed to obtain JJA seasonal rainfall as the predictands for the CPT. All-Bangladesh and station-wise aerial precipitation was calculated for rainy season and transformed into a format (text), which suits for the CPT software. The location of stations was shown in figure 1

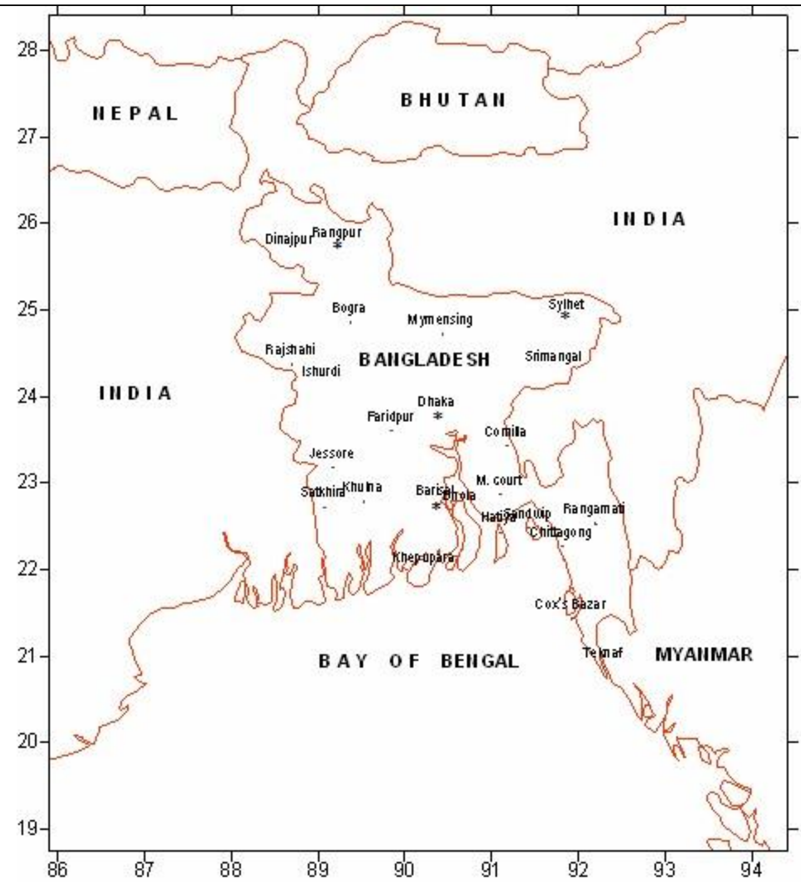

Fig.1: The location of study area which are denoted by star (*) symbol

2.2 Sampling design

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The data of observed rainfall and see surface temperature were considered from 1975 to 2008 periods. Since the period 1975 to 2008 focus the climatologically period. So this period is considered.

2.3 Variables selection

Observed rainfall is considered as predictand. On the other hand sea surface temperature is considered as predictor

2.4 Statistical tools

Principal Component Regression (PCR) and Canonical Correlation Analysis (CCA) are the two methods used in CPT.

The brief description of PCR and CCA are given below-

Principal Component Regression (PCR): In statistics, principal component regression (PCR) is a regression analysis technique that is based on principal component analysis (PCA). Typically, it considers regressing the outcome (also known as the response or the dependent variable) on a set of covariates (also known as predictors, or explanatory variables, or independent variables) based on a standard linear regression model, but uses PCA for estimating the unknown regression coefficients in the model [https://en.wikipedia.org/wiki/Principal_component_regression].

Canonical Correlation Analysis (CCA): Canonical Correlation Analysis (CCA) is a way of making sense of cross covariance matrices. Canonical correlation analysis is a method for exploring the relationships between two multivariate sets of variable (vectors), all measured on the same individual. One approach to studying relationship between the two sets of variables is to use canonical correlation analysis which describes the relationship between the first set of variables and the second set of variables. A typical use for canonical correlation in experimental context is to take two sets of variables and see what is common amongst the two sets. If we have two vectors $X = (X_1......X_n)$ and $Y = (Y_1......y_m)$ of random variables, and there are correlations

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among the variables, then canonical-correlation analysis will find linear combinations of the Xi and Yj which have maximum correlation with each other.

2.5 Statistical software

Climate Predictability Tool (CPT) has been used in this study as statistical software that is described below

The CPT was developed by the International Research Institute for Climate and Society (IRI) at Columbia University, is a package that facilitates the construction of seasonal climate prediction models, investigations into model validation and producing predictions given updated data. The CPT design has been tailored to produce seasonal climate predictions using model output statistic (MOS) corrections to climate predictions from general circulation models, or to produce predictions using fields of sea-surface temperatures

Principal Component Regression (PCR) and Canonical Correlation Analysis (CCA) are the two methods used in CPT. Each of these techniques can be used to address more than one kind of problems. This involves data that represent predictors, and data that represent what is to be predicted—i.e. predictands. Often, the predictor data is set up to occur earlier than the predictand data, with each spanning a historical period, so that predictive relationships become detectable and describable, and can be used for real-time predictions. However, the predictor and predictand data can also be set up to occur at the same time, not staggered, so that the techniques describe diagnostic relationships between them, as may be desired for their own sake in climate research, perhaps preceding a study of predictive relationships. CPT cannot generate predictability where it does not exist. What it can do, however, is identify model errors that are characteristic, and correct the predictions in such a way as to maximize their average accuracy over the long historical period for which there are samples of model prediction data along with the corresponding actually observed data. Thus, CPT calibrates, or corrects, model predictions. This process is the same as what is commonly known as model output statistics, or MOS.

 doi:10.20944/preprints201901.0023.v1

In this model correction design, and regardless of whether the CCA or the PCR tool is selected for the analysis, CPT does its job in the same basic manner. The way it works is that the predictand (the *y variable*) is related to the predictor (the *x variable*) linearly. The simplest case of a linear relationship is when there is one x and one y, such as the Southern Oscillation Index (SOI) for x, and the rainfall at a station (or the average rainfall over several stations) for y, and

$$y = \mathrm{b}x + a \qquad (1)$$

Here y is predicted by getting the value of the predictor, x, multiplying it by some factor b, and then adding a constant number a. In general, the prediction of y from x is not perfect: in some instances y is over-predicted while in others it is under-predicted. In linear regression, upon which both CPT techniques are based, a and b are determined such that the sum of the squared errors over all of the historical cases used to make the equation is minimised. Squared errors rather than the absolute value of the errors are minimized because this nicely fits the huge collection of linear statistical theory.

A number of different varieties of linear regression can be identified, and can be classified using various criteria. One criterion that helps to describe the two techniques used in CPT is the level of complexity of the predictor and predictand data. Three commonly recognized levels can be identified:

(a) *simple regression*: a single predictor and a single predictand

$$y = \mathrm{b}x + a \qquad (1)$$

(b) *multiple regression*: two or more predictors, and a single predictand

$$y = b_1x_1 + b_2x_2 + \text{........} + b_nx_n + a \qquad (2)$$

(case of n predictors; a is the accumulated constant)

The PCR tool in CPT is in this category of regression, with the x's themselves being defined in a special way in order to need much fewer of them.

(c) multivariate (pattern) regression: two or more predictors, two or more predictands

$$\mathbf{Y} = \mathbf{BX} + a \qquad (3)$$

($\mathbf{Y}$, $\mathbf{B}$ and $\mathbf{X}$ are matrices; can be CCA)

The CCA tool in CPT is in this category of regression, with the x's and the y's themselves being defined in a special way in order to need much fewer of each.

The CPT software was initially designed for use in prediction development by national meteorological services, especially in Africa, to simplify the production of seasonal climate predictions. It can be used in any region, and for diagnostic research as well as prediction. It can be used to perform CCA or PCR on any pair of data sets, for any application.

The daily rainfall data was used to compute seasonal daily mean rainfall for Bengali rainy season (15 June-15 August). Observed global sea surface temperature was used as predictor for CPT with a view to predicting seasonal daily mean rainfall. This SST was one of the Multi Model Ensambles (MME) products of APEC Climate Centre (APCC) of South Korea. The MME products were generally released about one month before any season. So, SST of one month before of rainy season was used as the predictor in the CPT used in the study

3. Results

An attempt was made to generate seasonal climate prediction, in particular seasonal daily mean rainfall at Rangpur, Dhaka, Barisal, and Sylhet, using statistical downscaling tool developed by the International Research Institute (IRI) of University of Columbia, USA. This tool known as Climate Predictability Tool (CPT) is a powerful statistical downscale tool that provides user friendly interface to downscale General Circulation Model (GCM) field variables (as predictors) using station level rainfall (as predictands). This tool is much popular in Climate Outlook forums in African countries for making Climate Outlook as it requires less computer power. Dynamical models are also used to downscale these GCM field variables to finer grid. However, for simulating seasonal scales weather, as far as the predictions skill concerns dynamical models are far behind due to poor resolving lower boundary forcing of the model.

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3.1. Seasonal prediction of rainfall

CPT was employed for predicting rainy seasonal rainfall over Rangpur, Dhaka, Barisal and Sylhet using SST of one month before rainy season and SST of starting one month of rainy season as predictor for comparing the prediction result of rainy seasonal rainfall. In order to understand the accuracy of predictions, some skill scores such as Root Mean Square Error (RMSE), Hit Score (HS), Bias and Mean Absolute Error (MAE) were calculated. Root Mean Square Error (RMSE) is the measure of difference between observed value and the value being predicted or estimated by the model. Bias was a measurement or estimate of model value relative to a given actual observed value. It could be negative or positive depending on model produced value. Hit score (HS) is defined as percentage value of the ratio of model predicted value to the observed value. Hence, if the model prediction would be perfect, HS should be 100%. Mean Absolute Error (MAE) is a quantity used to measure how close predictions or predictions are to the observed values. It is the average of the absolute errors.

3.2. Seasonal prediction of rainfall over four stations (Rangpur, Dhaka, Barisal and Sylhet) using sea surface temperature (SST) of one month before rainy season as predictor

The correlation between rainfall of Bengali rainy seasons at Rangpur, Dhaka, Barisal and Sylhet and global sea surface temperature (SST) of different areas of the world was studied by using the data of the period between 1975 and 2008 with the help of the Climate Predictability Tool (CPT) to find more positive correlated SST with rainfall of Bengali rainy seasons at Rangpur, Dhaka, Barisal and Sylhet and use obtaining more positive correlated **SST as predictor.** In this case maximum goodness index was obtained by changing the x domain for SST and Cross-valided window (CVW) using both the Pearson's and Spearman processes, and the correlation coefficients and predicted value of seasonal rainfall for the year 2009 was obtained. The results are given in Table 1.

Table 1: The results of Goodness Index, CVW, Correlation Coefficients

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and Predicted rainfall in the different x-domain during of the period1975-2008 using sea surface temperature (SST) of one month before the rainy season as a predictor

Stations and Season	x-domain	Goodness Index		CVW	Correlation Coefficients		Predicted rainfall (mm/day) in 2009
		Pearson's	spearman		Pearson's	Spearman	
Rangpur	8S-18N 2-58E	0.267	0.825	29	0.268	0.319	12.12
Dhaka	18S-8N 21-58E	0.351	0.953	31	0.351**	0.115	12.77
Barisal	15S-17N 22-49E	0.214	0.765	31	0.215	0.162	12.91
Sylhet	2S-36N 2-124E	0.536	0.994	21	0.536***	0.511***	16.72

Note: *** and ** means, significant at 0.1% and 1% level, respectively

The x-domains of the sea surface temperature for different stations are shown in Figs. 2-5.

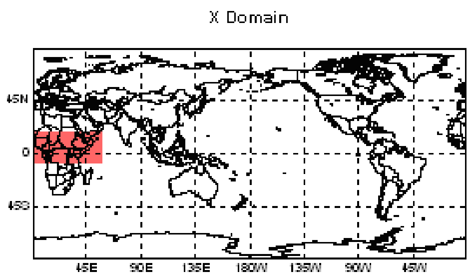

Figure 2. x-domain of SST during rainy season for prediction of rainfall at Rangpur.

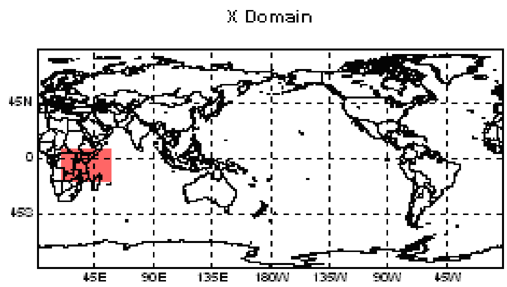

Figure 3. x-domain of SST during rainy season for prediction of rainfall at Dhaka.

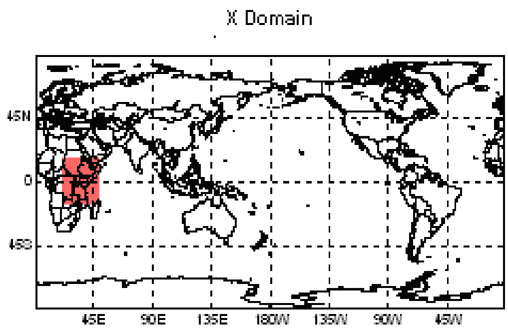

Figure 4. x-domain of SST during rainy season for prediction of rainfall at Barisal.

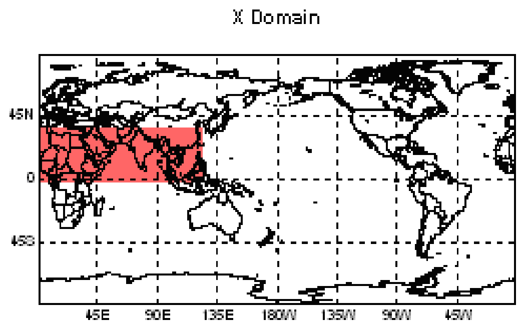

Figure 5. x-domain of SST during rainy season for prediction of rainfall at Sylhet.

It is seen from the Table 1 and Figures 2-5 that maximum goodness index could not be obtained for the same x domain. The x domain differed from one station to another for getting maximum goodness index as well as maximum correlation coefficient. The Table 1 shows that the

 doi:10.20944/preprints201901.0023.v1

correlation coefficients ware positive in both the Pearson's and Spearman processes in the seasons. The correlation coefficients were found significant at different levels. The predicted values of rainfall during 2009 were found closer to the observed rainfall. So, it could be said that a good prediction of rainfall was obtained by using Climate Predictability Tool (CPT).

The skill scores of seasonal rainfall prediction over Rangpur, Dhaka, Barisal and Sylhet using SST of one month before rainy season as predictor are shown in Table 2.

Table 2. Skill scores of seasonal rainfall (rainy season) forecast over Rangpur, Dhaka, Barisal and Sylhet using sea surface temperature (SST) as a predictor.

Name ofSeasons	RMSE(mm/day)	Hit Score(%)	Bias	Mean Absolute Error (mm/day)
Rangpur	5.81	35.29	0.82	4.28
Dhaka	3.01	38.24	-0.67	2.35
Barisal	6.72	32.35	-0.42	5.14
Sylhet	1.11	44.12	-0.17	0.76

Note: RMSE means root mean square error

It is seen from the Table 2 that the root mean square errors (RMSE) were reasonably very lower (1.11) at Sylhet and big (6.72) at Barisal. The mean absolute error (MAE) was lower at Sylhet and relatively higher in other stations. But the bias was very low only at Sylhet. The hit score ranged from 32.35 to 44.12 which were relatively lower. Because of the lower hit score the predicted seasonal rainfall was not so closer to the observed rainfall as could be seen from the Figures. 6-9. But the predicted and observed rainfall shows almost the same patterns of variation which is very encouraging.

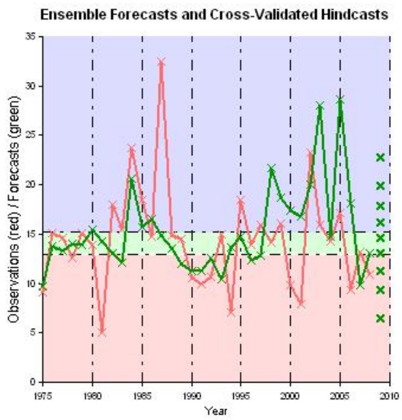

Figure 6. Ensemble prediction of rainfall and Cross-Valided Hindcasts for rainy season at Rangpur.

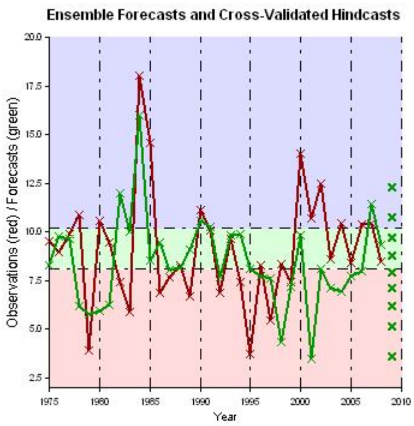

Figure 7. Ensemble prediction of rainfall and Cross-Valided Hindcasts for rainy season at Dhaka.

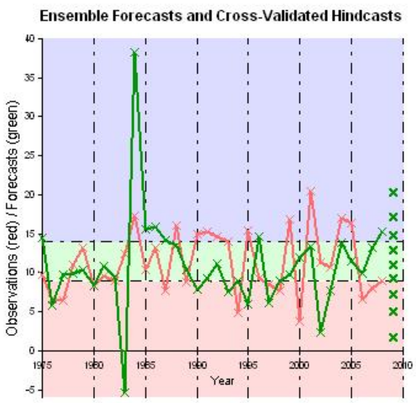

Figure 8. Ensemble prediction of rainfall and Cross-Valided Hindcasts for rainy season at Barisal.

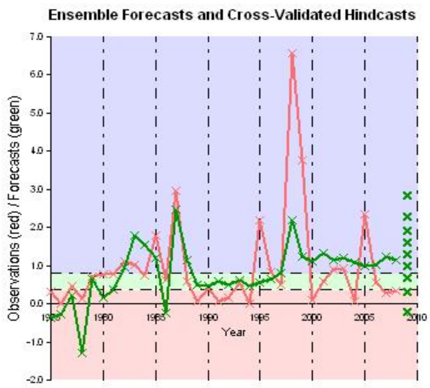

Figure 9. Ensemble prediction of rainfall and Cross-Valided Hindcasts for rainy season at Sylhet.

3.3. Seasonal prediction of rainfall over four stations (Rangpur, Dhaka, Barisal and Sylhet) using sea surface temperature (SST) of starting month of rainy season as predictor

The correlation between rainfall of rainy season for four stations (Rangpur, Dhaka, Barisal and Sylhet) of Bangladesh and global sea surface temperature (SST) of different areas of the world was studied by using the data of the period between 1975 and 2008 with the help of the Climate Predictability Tools (CPT) to find more positive correlated SST with rainfall of Bengali rainy seasons at Rangpur, Dhaka, Barisal and Sylhet and use obtaining more positive correlated SST as predictor. In this case also maximum goodness index was obtained by changing the x domain

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for SST and Cross-Valided Window (CVW) using both the Pearson's and Spearman processes, and the correlation coefficients and predicted value of seasonal rainfall during rainy season for the year 2009 was found. These results are given in Table 3.

Table 3: The results of Goodness Index, CVW, Correlation Coefficients and Predicted rainfall in the different x-domain during of the period1975-2008 using sea surface temperature (SST) **of starting month of the rainy season as a predictor.**

Stations and Season	x-domain	Goodness index		CVW	Correlation Coefficients		Predicted rainfall (mm/day) in 2009
		Pearson's	Spearman		Pearson's	Spearman	
Rangpur	17S-37N 4-53E	0.287	0.950	13	0.2712 Significant at 10% level	0.2234 Significant at 10% level	6.02
Dhaka	13S-41N 6-53E	0.296	0.946	13	0.2339 Significant at 10% level	0.1914 insignificant	7.09
Barisal	13S-41N 6-53E	0.296	0.946	13	0.2958 Significant at 5% level	0.2285 Significant at 10% level	5.58
Sylhet	13S-41N 6-53E	0.296	0.946	13	0.3547 Significant at 5% level	0.2717 Significant at 10% level	14.03

The x-domains of the sea surface temperature for rainy season of different stations **are shown in Figures 10-11.**

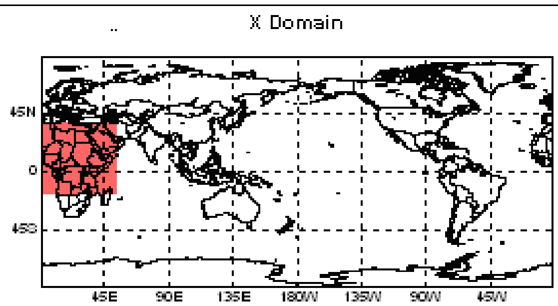

Figure 10. x-domain of SST during rainy season for prediction of rainfall at Rangpur.

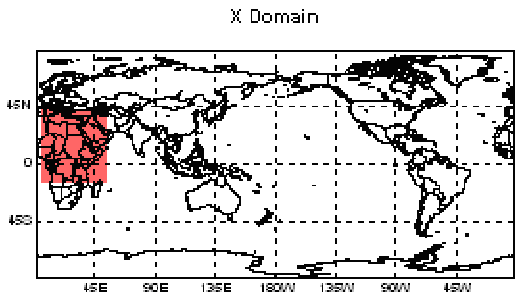

Figure 11.x-domain of SST during rainy season for prediction of rainfall at Dhaka, Barisal, and Sylhet.

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From the Table 3 and the Figures 10-11 it is seen that the maximum goodness index could not be found for the same x domain. The x domain differed from one station to another in order to get maximum goodness index and maximum correlation coefficients. The table shows that the correlation coefficient was positive in both the Pearson's and Spearman processes and significant at 5% and 10% level. The predicted value of rainfall during 2009 was not found closer to the observed rainfall.

The skill scores of seasonal rainfall (rainy season) prediction over Rangpur, Dhaka, Barisal and Sylhet using SST of starting month of rainy season as predictor are shown **in Table 4.**

Table 4. Skill scores of seasonal rainfall (rainy season) forecast at Rangpur, Dhaka, Barisal, and Sylhet using SST as a predictor.

Name of Seasons	RMSE (mm/day)	Hit Score (%)	Bias	Mean Absolute Error (mm/day)
Rangpur	2.78	23.53	0.01	2.18
Dhaka	3.57	50.00	-0.05	2.73
Barisal	2.35	41.18	-0.03	1.92
Sylhet	3.95	52.94	-0.01	3.02

Note: RMSE means root mean square error.

It is seen from the Table 4 that the root mean square error (RMSE) was small at Barisal and higher at Sylhet. The mean absolute error (MAE) was lower at Barisal and relatively higher at sylhet. But the bias was very low at all stations. The hit score ranges from 23.53 to 52.94 which was not relatively higher. Because of the lower hit score the predicted seasonal rainfall was not so closer to the observed rainfall which could be seen from the Figures 12 to 15. The figures show almost similar patterns of variation between the predicted and observed rainfall.

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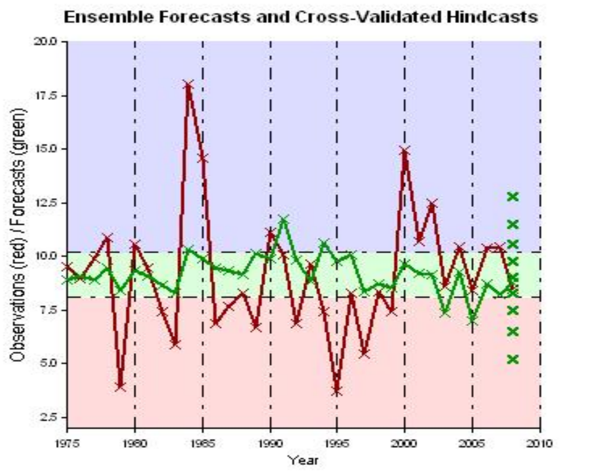

Figure 12. Ensemble prediction of rainfall and Cross-Validated Hindcasts for rainy season at Rangpur.

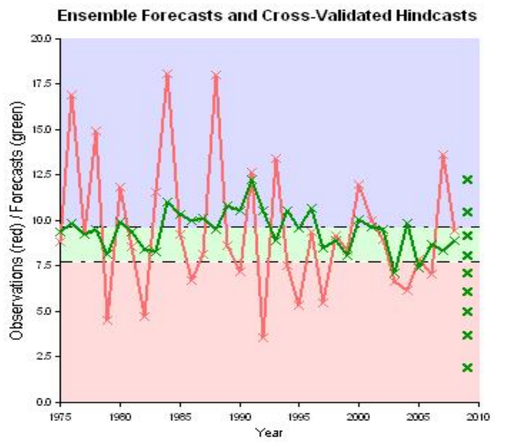

Figure 13. Ensemble prediction of rainfall and Cross-Validated Hindcasts for rainy season at Dhaka.

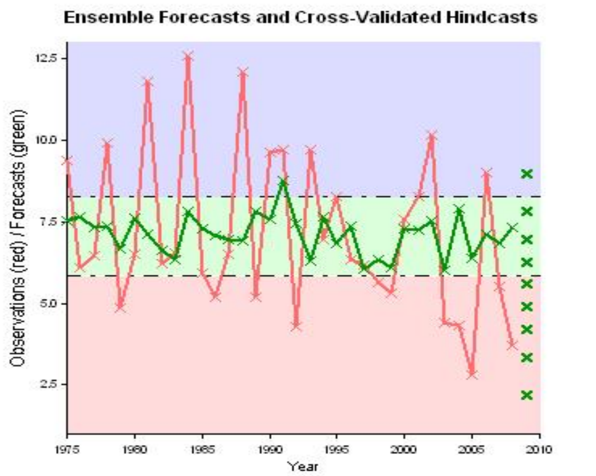

Figure 14. Ensemble prediction of rainfall and Cross-Validated Hindcasts for rainy season at Barisal.

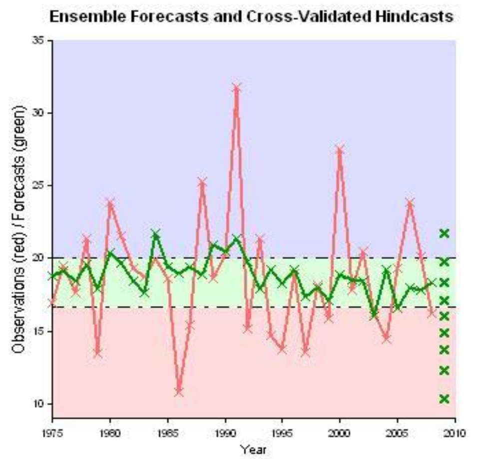

Figure 15. Ensemble prediction of rainfall and Cross-Validated Hindcasts for rainy season at Sylhet.

4. Discussion

4.1. From this study using SST of one month before rainy season as predictor: CPT was found to determine underestimated rainfall at Dhaka and Sylhet, and overestimated rainfall at Rangpur and Barisal during rainy season (15 June-15 August). The maximum positive deviation of mean rainfall was 1.34 mm/day at Sylhet. On the other hand, the minimum positive deviation of mean rainfall was 0.9 mm/day at Dhaka. Besides, the maximum negative deviation of mean rainfall of 1.16 mm/day at Rangpur and minimum negative deviation of mean rainfall

 doi:10.20944/preprints201901.0023.v1

of 1.10 mm/day at Barisal was obtained during rainy season. The observed and predicted values of daily mean rainfall are shown below **in Table 9.**

[24] observed that CPT generated forecast (JJA) rainfall for all Bangladesh 0.08 mm/d is overestimated and also taken individual selected twelve stations in which seven stations rainfall forecast is overestimated namely Faridpur (5.42 mm/d), Jessore (3.67 mm/d), Khulna(0.05 mm/d), Rajshahi(1.54 mm/d), Barisal(1.34 mm/d), Comilla(4.67 mm/d), and Rangamati(1.60 mm/d) and five stations are underestimated over Bangladesh specifically Bogra(1.34 mm/d), Teknaf(3.54 mm/d), Chittagong(6.11mm/d), Sandwip(3.54mm/d) and Dinajpur(0.31mm/d) which is located western, southwestern and southeastern parts of Bangladesh.

[29] found that JJA (June, July, August) rainfall for the whole Bangladesh was quite accurate. Forecast for individual stations are also accurate over the high and low rainfall areas of the country during summer-monsoon season (June, July, August, and September). Sandwip, Rangamati, Teknaf, Chittagong, Cox’s Bazar and Patuakhali stations are good examples for high rainfall regions whereas Rajshahi and Dinajpur are example for low rainfall stations. This study also found that the predicted values of rainfall during 2009 were closer (not accurate) to the observed rainfall over low and high rainfall regions of Bangladesh. The slight difference results may be occurred due to lower rainfall received at Rangpur and Barisal and higher rainfall received at Dhaka and Sylhet during rainy season.

[23] found that the forecasted June-July-August seasonal mean-rainfall is slightly overestimated especially over the individual districts, except Kandy and Nuwara Eliya, due to fairly higher rainfall received during the southwest monsoon in 2008 in Sri Lanka. This study also found that the predicted June-July-August (rainy season) seasonal mean-rainfall is slightly overestimated especially over the individual stations.

[26] studied on Predictability of May to August (MJJA) Seasonal Rainfall in Northern Philippines and found that the observed MJJA rainfall of Batac (324.80 mm) in 2014 was

comparable with the forecasted rainfall of 325.53 mm, showing the remarkable ability of the model to predict MJJA rainfall for that year. This study also found a remarkable ability of the model to predict rainy seasonal (15 June-15 August) rainfall for the year 2009.

Table 9. Observed rainfall and predicted rainfall by CPT using SST of one month before the rainy season as a predictor.

Stations and season	Observed rainfall (mm/day) in 2009	Predicted rainfall (mm/day) in 2009	Deviation of Predicted rainfall from Observed rainfall (mm/day) in 2009
Rangpur (rainy season)	10.96	12.12	-1.16
Dhaka (rainy season)	13.67	12.77	0.9
Barisal (rainy season)	11.81	12.91	-1.10
Sylhet (rainy season)	18.06	16.72	1.34

4.2. Again from this study using SST of starting one month of rainy season as predictor

Predicted value of seasonal daily mean rainfall was found lower than the observed seasonal daily mean rainfall during rainy season (15 June-15 August) at Rangpur, Dhaka, Barisal, and Sylhet. The deviation of predicted rainfall from observed rainfall was minimum positive at Sylhet having the minimum value of 4.03 mm/day, but the maximum positive deviation of daily mean rainfall was found in middle part of Bangladesh having the value of 6.58 mm/day at Dhaka. Nearest value of maximum positive deviation of mean rainfall was 6.23 mm/day over southern Bangladesh. The observed and predicted values of rainfall are shown below **in Table 10.**

[30] studied on prediction of rainfall. This prediction of rainfall for the year 2011 to 2015 is done by using the Climate Predictability Tool for the Karimnagar and Prakasam districts of India. The results indicated the values of prediction of rainfall for Karimnagar for the years 2006, 2007, 2008 and 2011. The prediction was fairly consistent showing an error within the range of ±5%. Prakasam showed highly erratic values between the forecasted and predicted

and actual data which was not more similar to this study due to atmospheric disturbance and study location.

[25] predicted JJAS seasonal rainfall over Ethiopia. As a result, the rainfall predictability using CCA the forecast and the observed one are in agreement over much of the country however, some discrepancy over northwestern parts of the country. This study also found some discrepancy between observed and predicted rainfall over the study area.

Table 10. Observed rainfall and predicted rainfall by CPT using SST of starting one month of the rainy season as a predictor.

Stations and season	Observed rainfall (mm/day) in 2009	Predicted rainfall (mm/day) in 2009	Deviation of Predicted rainfall from Observed rainfall (mm/day) in 2009
Rangpur (rainy season)	10.96	6.02	4.94
Dhaka (rainy season)	13.67	7.09	6.58
Barisal (rainy season)	11.81	5.58	6.23
Sylhet (rainy season)	18.06	14.03	4.03

4.3 Limitations of the study and further study

The study was conducted within Dhaka, Sylhet, Rangpur and Barisal Division. On the other hand, only one season has been predicted within six Bengali seasons namely Summer, Rainy season, Autumn, Late autumn, Winter and Spring. Due to budget, time and lab facilities constraints, the study couldn't predict rainfall of the other seasons and other stations.

5. Conclusion

5.1 Summary of the results

From the present study, the following conclusions are drawn:

Underestimated rainfall at Dhaka and Sylhet, and overestimated rainfall at Rangpur and Barisal was found by CPT. The maximum positive deviation of mean rainfall was 1.34 mm/day at

Sylhet, on the other hand, the maximum negative deviation of mean rainfall was determined 1.16 mm/day at Rangpur.

Using SST of starting month of rainy season, predicted value of seasonal daily mean rainfall during rainy season was found lower than observed daily mean rainfall at Rangpur, Dhaka, Barisal and Sylhet. The deviation of predicted rainfall from observed rainfall was minimum but positive at Sylhet with value of 4.03 mm/day, but the maximum positive deviation of daily mean rainfall was found in the middle part of Bangladesh having the value of 6.58 mm/day at Dhaka.

The study also reveals that SST of starting month of Rainy season was not good predictor but SST of one month before of Rainy season is suitable for CPT. So it is said that CPT has shown some skills in prediction of rainy season rainfall at some selected division in Bangladesh.

5.2 Recommendations

- Develop climate-prediction system for reducing natural hazards.
- Reduce percentage of error in climate-prediction system.

Acknowledgements: This research work was analyzed by CPT Software which was developed by the International Research Institute for Climate and Society (IRI) at Columbia University and this work completed in SAARC Meteorological Research Centre, Dhaka, Bangladesh.

Author contributions:

The first author (Z.H) collected data, prepared data into required format, literature search, ran the software for prediction, analyzed the data, discussed results, formulated recommendations and wrote the paper. M.A.K.A, M.N.I.M. and M.A.H did writing-review and editing. S.K worked on conceptualization, writing-original draft preparation and final revision of the paper and M. K. D and M.M.R. helped me by methodology, software, validation and see surface temperature (SST).

Funding: This research received external funding from Rajshahi University, and Climate Change Unit, Ministry of Environment and Forests, Government of the People's Republic of Bangladesh

Conflicts of Interest: The authors declare no conflict of interest.

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