INVESTIGATING THE IMPACT OF CLIMATE CHANGE ON FLOODING IN THE TEESTA RIVER BASIN, BANGLADESH

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ABSTRACT

The Teesta basin is a sub-basin of the Brahmaputra basin and only 16.5% of the total basin lies inside Bangladesh. The people of this basin suffer from severe flooding every year and many of them become homeless and jobless. The main objective of this study is to assess past and future flood impacts using Global Climate Model (GCM) data and proposing sustainable countermeasures to cope with probable future floods. To assess the impacts of climate change on flooding, Rainfall-Runoff-Inundation (RRI) model was calibrated and validated with TRMM_gauge data as transboundary ground rainfall data are not available for Bangladesh. Then six climate models were selected by Data Integration and Analysis System (DIAS) under the scenario of Representative Concentration Pathways (RCP) 8.5. GCM rainfall data were bias corrected based on APHRODITE data both for current (1981-2000) and future climate (2046-2065) condition. Comparing current and future rainfall and discharge, it was observed that future extreme rainfall and discharges are higher than the current status which indicates the possibility of larger floods in near future. Inundation maps for 50 year and 100 year return period floods indicates more inundation area and depth for future climate condition. River dredging together with bank revetment work could be feasible countermeasures to cope with possible large floods in near future.

Keywords: Teesta basin, RRI, climate change, GCM

INTRODUCTION

Bangladesh is a flat and low-lying small country of south Asia with a huge population. The country is a large delta formed by the alluvial deposits of well-known Ganges-Brahmaputra-Meghna river system. More than 400 rivers pass through this country of which 57 are Transboundary Rivers. The Teesta River is one of those transboundary rivers. Although only 16.5% of this river basin lies inside Bangladesh, majority of the people live in Bangladesh portion. Most of those people are very poor and live on agriculture. Their agricultural land, houses and other properties are damaged by monsoon floods every year. Infrastructures like roads, schools, rural markets are inundated. The situation may worsen in future due to climate change.

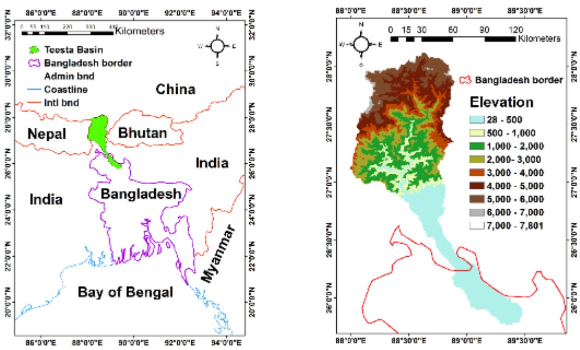

Figure 1. Location of the Teesta Basin.

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To address the aforementioned problems, the key objectives of this study are - (i) to set up the RRI model as well as calibration and validation by satellite rainfall data, (ii) to assess past and future floods using the RRI model with GCM rainfall data in order to examine climate change impacts, (iii) to perform frequency analysis of GCM rainfall data and generate inundations maps and (iv) to propose possible countermeasures to cope with probable future floods.

THEORY AND METHODOLOGY

The study is divided into four main steps: (i) rainfall selection, (iii) model preparation, (iii) climate change impact assessment and (iv) generation of inundation maps.

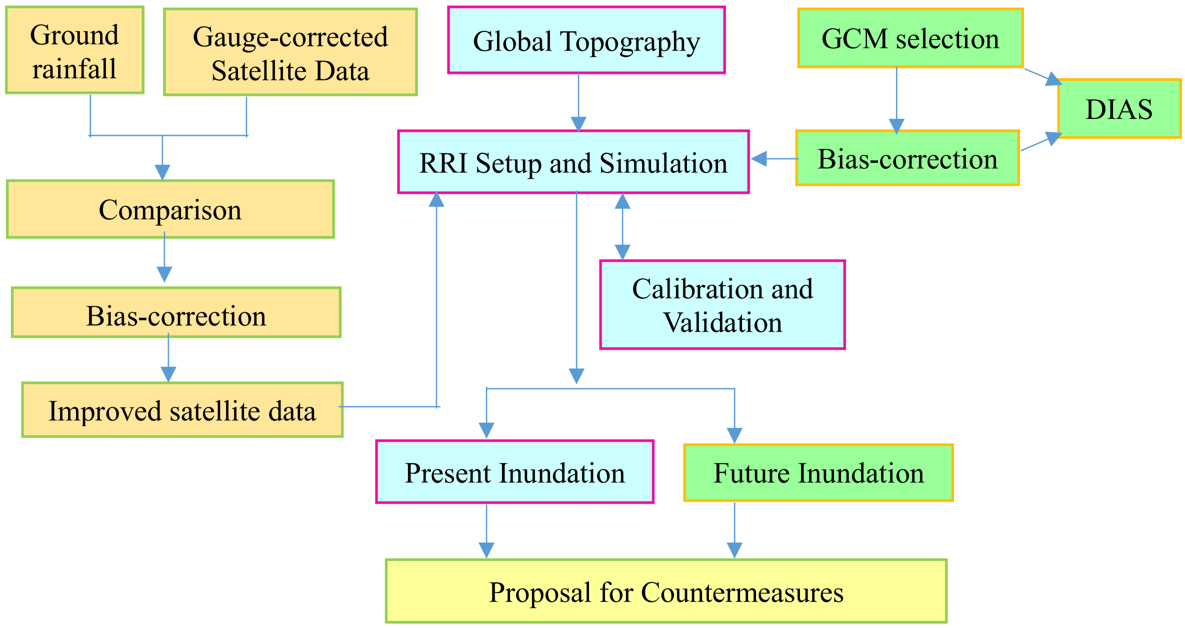

Figure 2. Methodology of the study

(i) **Rainfall Selection**:
Ground rainfall data in Indian portion are not available for Bangladesh, so satellite data were the only option for this study. Suitable satellite rainfall data were selected by comparing them to ground rainfall inside Bangladesh.

(ii) **Model Preparation** :
To simulate the discharge, a hydrological model namely Rainfall-Runoff-Inundation (RRI) model was considered for this study. The RRI model is a two dimensional model which is able to simulate rainfall-runoff and flood inundation at the same time (Sayama *et al*., 2012). It is a diffusion wave model capable of producing inundation. As upper Teesta is mountainous and there is significant snow component, the RRI-snow module was used to include snow component.

(iii) **Climate Change Impact Assessment** :
According to JICA report 2013, there are five steps of climate change impact assessment - (i) selection of emission scenario, (ii) GCM selection, (iii) bias correction of the rainfall from selected GCMs, (iv) assessment of changes in rainfall and (v) assessment of changes in discharge. RCP 8.5 scenario was selected as it corresponds to the pathway with the highest greenhouse gas emissions, thereby having largest impact on climate change. GCM selection was done by Data Integration and Analysis System (DIAS), an online data analysis tool considering spatial correlation (Scorr) and root mean square error (RMSE) for 9 parameters – precipitation, air temperature, outgoing longwave radiation, sea level pressure, zonal wind, meridional wind, specific humidity, ground temperature and geopotential height.

Bias-correction is required to eliminate the biases of GCM rainfall data. To achieve a reasonable bias correction, it is required to separate no-rain days from normal rain days and from extreme rain days. Bias-correction was done by DIAS by which GCM data were downscaled statistically. Assessment of changes in rainfall was done by comparing basin average monthly rainfall and extreme daily rainfall of past and future climate data. Changes in discharge was evaluated by running the RRI model with GCM rainfall data and comparing the extreme daily discharges of past and future climate.

(iv) **Frequency Analysis** :

Frequency analysis provides the information about the probability of future extreme events and it tells how often that event occur. In this study, the extreme flood events with different probability of exceedance were found using Cunnane method of plotting position formula. 7-day annual maximum basin average rainfall was used for frequency analysis as 7-day rainfall is capable of producing peak discharge and maximum inundation for the Teesta River basin. Frequency analysis was done for all selected climate models both for current and future climate condition. Based on this analysis, rainfall corresponding to 50 year and 100 year return period flood were obtained. Gumbel distribution was considered for this study. RRI model was run with these rainfall taking outlet point at Kaunia station and inundation maps were produced by GIS tool from '*hpeak'* ascii file generated by the RRI model.

DATA

Table 1. Data used for this study

Data	Type	Period	Source
Digital Elevation Model (DEM)	30 sec	-----	(USGS) HydroSHEDS
Ground Rainfall	Daily	2010-2017	BWDB
Discharge	Daily	2002-2017	BWDB
GSMaP_gauge	Daily	2015-2017	JAXA
TRMM_gauge (3B42)	Daily	1998-2017	NASA
APHRODITE	Daily	2002-03, 2006-07	DIAS
Snow cover	8-day composite	2001-2017	MODIS (NASA)
Temperature	Daily	2002-2017	BMD

To delineate the study area, the Digital Elevation Model (DEM) for Asia was acquired from USGS HydroSHEDS, which is a global scale dataset offered by the United States Geological Survey (USGS). Ground rainfall were used for bias correction of satellite data. Discharge simulation was done at Kaunia station where weekly discharge is taken by Bangladesh Water Development Board (BWDB). Rating curve was prepared to get the daily discharge. APHRODITE rainfall data were used for bias-correction of GCM rainfall data. Moderate Resolution Imaging Spectrometer (MODIS) snow cover data were used to investigate the snow extent and temperature data were used to obtain the snow-melt contribution.

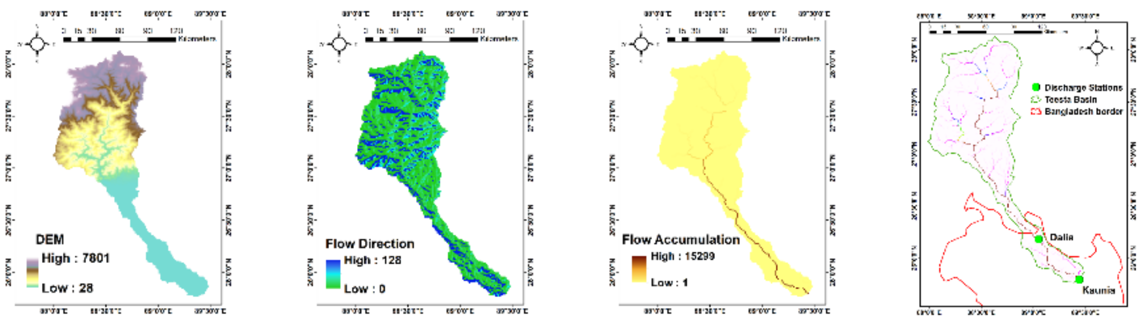

Figure 3. DEM, flow direction (FD), flow accumulation (FAC) and discharge station in Bangladesh.

To include snow component, MOD10A2 Terra 8 day L3 Global 500m SIN GRID V005 were downloaded from NASA. This snow data were processed by GIS tool to input it to RRI model. As transboundary temperature data are not available, the daily temperature data of Rangpur station inside Bangladesh were taken into account. Snow line was taken at the elevation of 4002 meter and the temperature at this elevation were obtained by using lapse rate.

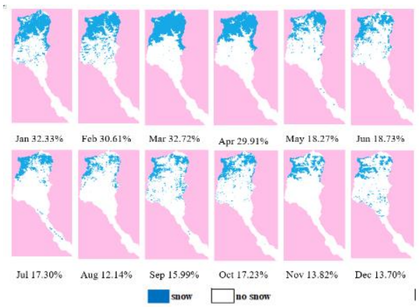

Figure 4. Average snow extent (2017)

RESULTS AND DISCUSSION

(i) **Rainfall Selection**:

Basin averaged monthly GSMaP and TRMM rainfall data were compared to the ground rainfall inside Bangladesh. It seems that the error between TRMM and ground rainfall is smaller, since TRMM rainfall is closer to ground rainfall in most cases (2012, 2015, 2016 and 2017). It can be assumed that TRMM data will be closer to ground rainfall in Indian portion also. That is why, TRMM_gauge data were selected for calibration and validation of the RRI model.

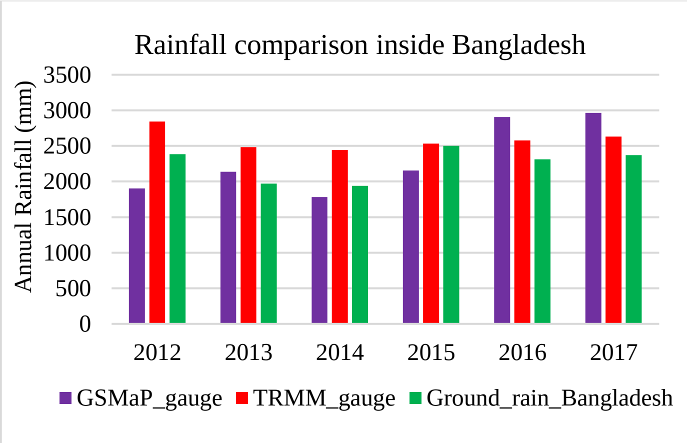

Figure 5. Comparison of GSMaP and TRMM data.

(ii) **Model Preparation** :

The RRI-snow model was calibrated for monsoon period (June to September) of 2015 and validated for 2016 and 2017. Some parameters were kept changing until the simulated discharge match better with the observed discharge. A general bias-correction method was also applied to TRMM_gauge data. Basin averaged monthly correction factor was calculated for Bangladesh portion and it was used as a multiplying factor for the whole basin. The result was improved after applying this bias-correction. The simulated discharges come closer to the observed discharges after applying correction but still there is some difference with peak discharges which is neglected for this study. Figure 6 and Figure 7 show the final calibration and validation result for RRI-snow model.

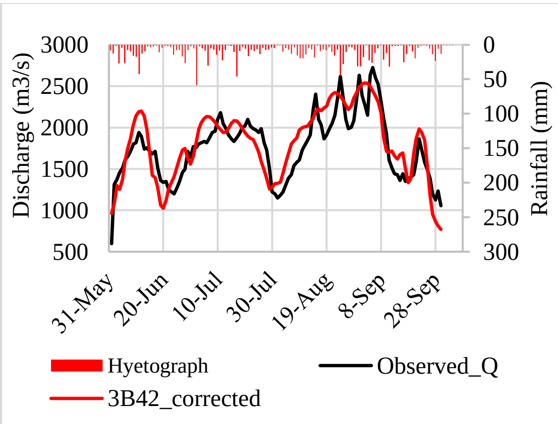

Figure 6. RRI model calibration for 2015

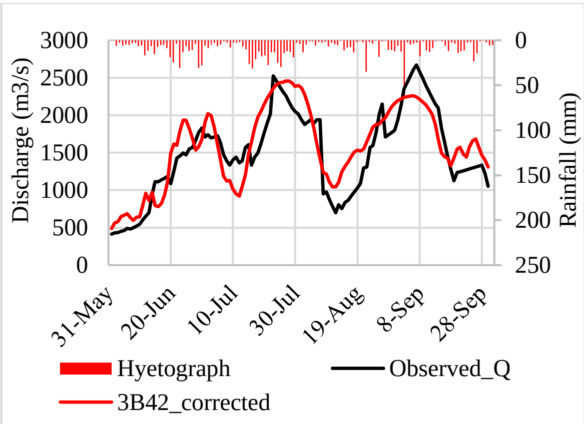

Figure 7. RRI model Validation for 2017

Inundation Validation: As data were not available to validate surface inundation, simulated water levels were validated with observed water levels at two stations. Then surface inundation inside Bangladesh was compared to the inundation obtained from MODIS image by Modified Land Surface Water Index (MLSWI) to distinguish floodwaters from cloud and mixed areas (Kwak *et al*., 2014).

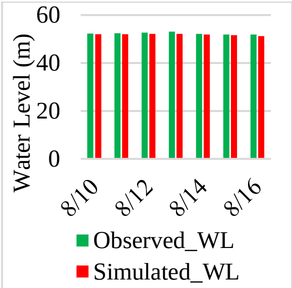

Figure 8: WL at Dalia

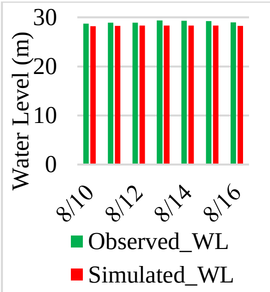

Figure 9.WL at Kaunia

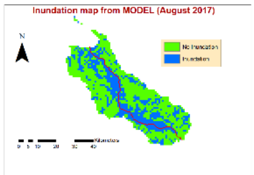

Figure 10. MODEL

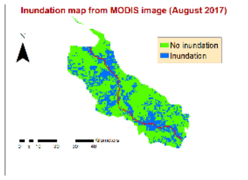

Figure 11. MODIS

(iii) **Climate Change Impact Assessment** :

Six GCMs namely ACCESS1.3, CNRM-CM5, CESM1 (BGC), CMCC-CMS, Can-ESM2 and GFDL-ESM2G were selected by DIAS and then bias-correction was done by APHRODITE data. Extreme daily rainfall and basin average monthly rainfall were calculated for past and future climate. Then the calibrated RRI model was run with GCM rainfall to obtain discharge for past (1981-2000) and future climate (2046-2065). All the models show higher extreme daily rainfall, monthly rainfall and extreme daily discharges for future climate condition indicating the possibility of larger floods in future.

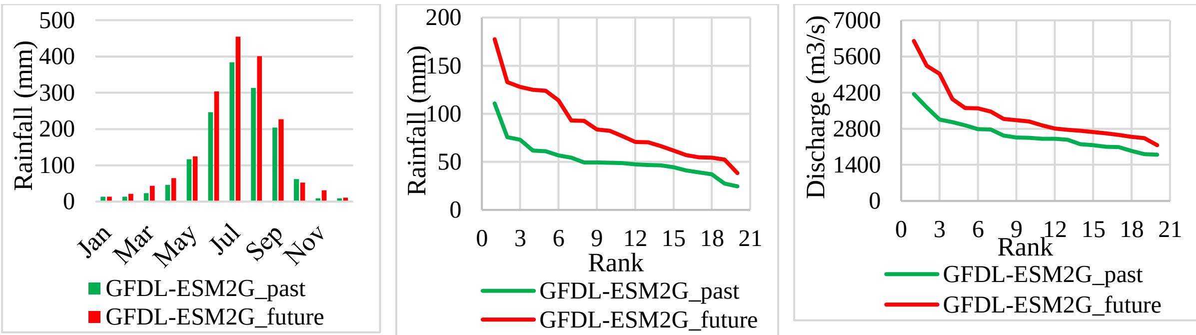

Figure 12. Average monthly rainfall, extreme daily rainfall and daily discharges for GFDL-ESM2G

(iv) **Frequency Analysis** :

The extreme daily rainfall for different return period were obtained from Gumbel distribution plotted by Cunnane method. The result of frequency analysis is shown in Table 2.

Table 2. 50 year and 100 year return period rainfall maxima by climate models (Gumbel distribution)

Models	Current climate 7-day rainfall in mm		Future climate 7-day rainfall in mm	
	50 year RP	100 year RP	50 year RP	100 year RP
ACCESS1.3	305	333	367	396
CNRM-CM5	344	377	365	394
CESM1 (BGC)	357	389	423	464
CMCC-CMS	351	387	435	482
Can-ESM2	371	409	577	634
GFDL-ESM2G	388	430	641	715

It is observed that rainfall corresponding to 50 year and 100 year return period flood for future climate are higher than that of current climate condition. Inundation maps were produced by 'hpeak' ascii file generated by the RRI model. Among all models, Can-ESM2 and GFDL-ESM2G model give highest inundation and significant area is inundated by more than 3.0 meter depth as given by future climate condition (Figure 13). Channel improvement by dredging and levee improvement by bank revetment work could be possible countermeasures against probable future floods.

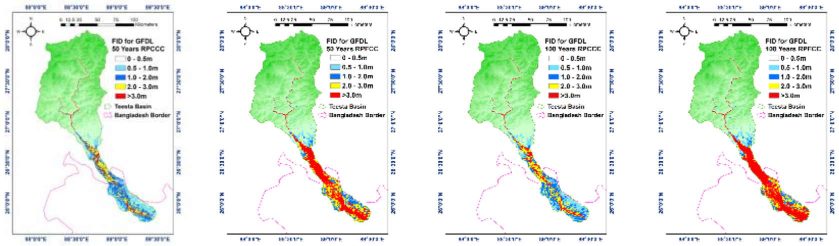

Figure 13. Inundation maps for 50 year & 100 year return period flood given by GFDL-ESM2G model for current & future climate conditon.

CONCLUSIONS AND RECOMMENDATION

The study focused on the impact of climate change on flooding in the Teesta River basin. From analysis of GCM rainfall data it was observed that the annual average monthly rainfall, annual maximum daily rainfall and annual maximum discharges for future climate are higher than that of present climate. From inundation analysis, it was observed that overall inundated area inside Bangladesh might increase from 78% at present to 91% in future for 50 year return period flood and 85% at present to 94% in future for 100 year return period flood. Moreover, the percentage of inundated area with greater than 3.0 meter depth might be increased by 11% for 50 year return period flood and 17% for 100 year return period flood. This might cause greater damage to land, infrastructures, households and other properties. So, proper precautions and countermeasures need to be taken to cope with probable extreme future floods. River dredging together with bank revetment work could be feasible countermeasures to cope with probable large floods in near future. For future studies, the result could be checked by using transboundary ground rainfall data, applying dynamic downscaling to GCM and surface inundation could be validated by actual surface inundation data.

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