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Assessment of precipitation and river runoff change on the Ganges, Brahmaputra and Meghna River basins due to climate change and adaptation measures by structural means

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Abstract

Meteorological Research Institute (MRI) and Japan Meteorological Agency jointly developed a super-high resolution GCMs (MRI-AGCM3.1S and MRI-AGCM3.2S), whose horizontal resolution is about 20km. These GCMs can represent well defined local precipitation. Daily precipitation for present (1980-2004), near-future (2015-2039), and future (2075-2099) periods are used after bias correction. Daily discharge is produced by using BTOP model with bias-corrected precipitation. From this study, it is found that water will be abundant in both near-future and future climates but in near-future climate, changing is not so much. In general, the results show increasing trend in more area of GBM basin in the near-future and future climates. Annual mean precipitation and discharge tend to increase in the near-future and future periods. Peak flow may much more severe especially in future climate. Therefore, present design height of levee will not be sufficient and need to heighten to control future flood.

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Keywords: Climate change, GBM basin, MRI-AGCM3.1S and 3.2S, BTOP model, levee height.

1. Introduction

The composite Ganges-Brahmaputra-Meghna (GBM) basin is the 13thlargest river basin in the world, and the 3rd largest freshwater outlet (Jain 2007). The annual average flow of GBM is 1.4x10^{12} m^{3} and the peak discharge of GBM is 1.6x10^{5}m^{3}/s. It is characterized topographically in three areas: the Hindukush Himalaya, the Ganges Delta and the Peninsular Basin of central India. The Ganges and Brahmaputra join in Bangladesh after that flow under the name Padma. The flow finally meets with Meghna river and empties into the Bay of Bengal by the taking the name Meghna. The total catchment area of GBM river system is

$1.72x10^6$ km^2 of which 64% lies in India, 8.6% lies in Nepal, 2.7% lies in Bhutan, 17.7% lies in China and 7% lies within Bangladesh (JRC 2012). The GBM river networks and river basins are shown in Figure 1. The GBM Delta is the largest and most populated delta in the world. It is one of the extreme vulnerable to climate changes because it is subject to the combined effects of glacier melt, extreme monsoon rainfall and sea level rise.

Fig. 1. Basin area of the Ganges (orange)-Brahmaputra (violet)- Meghna (green) river.

In past, a great number of studies from different points of views have been carried out on impact assessment on climate change on GBM basin. (IPCC 2007) indicates that monsoon rainfall will increase in south Asia. Rainfall is projected to be higher as well as more irregular frequency. As a result intensity of floods and droughts are likely to increase. Monsoon flood will be more devastating due to increase of monsoon precipitation and sea level rise. It may cause more damage to crops and properties as well as threaten to human life if adaptation measures are not taken. However, the horizontal resolution of Global Circulation Models (GCMs), used in IPCC AR4 and all others previous studies, is much coarser to represent local atmospheric phenomena. MRI-AGCM3.1S and MRI-AGCM3.2S which are about 20km horizontal resolution can represent well define local precipitation. These GCMs have great advantage of spatial scale, because there is no regional climate model is required to downscaling (Kim et al. 2009).

2. Theory and methodology

2.1 MRI-AGCM3.1S and 3.2S and BTOP model

By using higher resolution models, it is possible to simulate large-scale phenomena and regionally localized phenomena associated with small scale orography. In this context, the Meteorological Research Institute (MRI) and Japan Meteorological Agency (JMA) jointly developed super high resolution atmospheric GCMs, MRI-AGCM3.1S (Mizuta et al., 2006) and MRI-AGCM3.2S (Mizuta et al., 2011) with a 20-km resolution. Block-wise TOPMODEL (BTOP) model is the extension of TOPMODEL of distributed hydrological model for large basin simulations. Here this model considers the catchment is an aggregate of heterogeneous land areas has been developed for hill slope hydrology, not for macro-scale basin hydrology. All of the basic equations of the original TOPMODEL are kept similar but the variables and parameters of TOPMODEL are re-defined in BTOP model (Takeuchi et al. 2007).

2.2 Assessment of precipitation

To see distributional change, calculations are performed for each grid cell. To determine the annual mean precipitation for each river, first basin area of each river is detected to take the reference outlet points; Ganges at Hardinge Bridge, Brahmaputra at Bahadurabad, and Meghna at Bhairab Bazar. Figure 2 shows the GBM river main stream networks with three observed stations and Figure 3 shows the basin area for three different rivers.

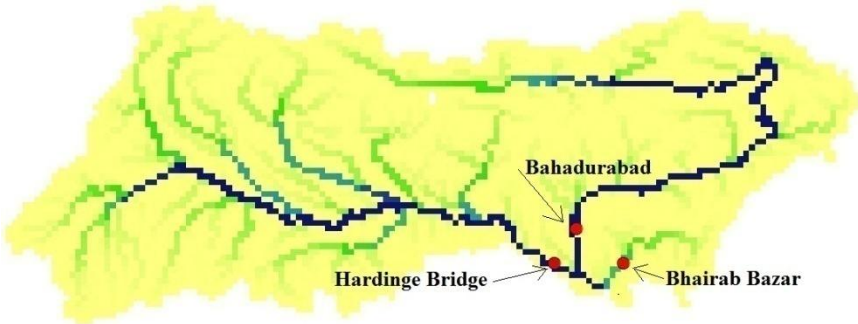

Fig. 2. Main channel networks in GBM basin (Red points are observed stations).

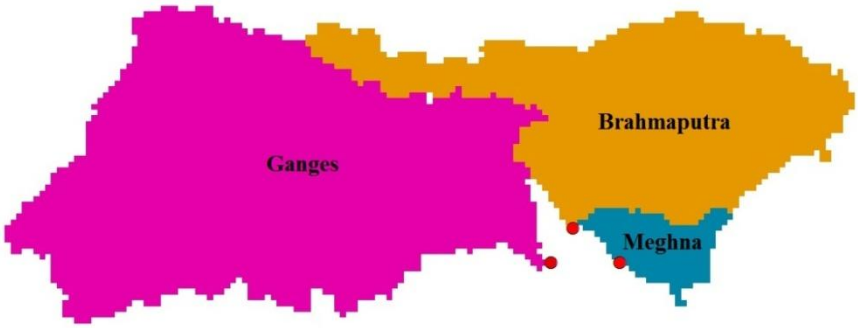

Fig. 3. Basin area of Ganges: Pink, Brahmaputra: Orange and Meghna: Blue

2.3 *Assessment of discharge*

Annual mean discharge changes in the near future and future climates are compared with that in the present climate. For peak discharge analysis, Gumbel distribution is used. Data of three periods are plotted in one Gumbel probability paper to compare peak flood changing by using statistical software "R". To determine the scale parameter and location parameter, L-moment method is used. Minimum discharge is analyzed by Weibull distribution. Goodness-of-fit test is performed by probability plot correlation coefficient test according to (Stedinger et al. 1993).

2.4 *Adaptation measures by structural means*

Design height of levee should be change in future to adapt climate change effect. Logarithmic stage-discharge relationships or rating curves are developed from observed data. Extrapolation of the rating curve is used to determine the levee height for projected discharge. Relative change of discharge in near-future and future compared to present period are determined for specific return period. For that return period, observed discharge is calculated, and changing discharge is determined for near-future and future. By using rating curve, water levels in near-future and future climates can be determined respectively.

3. Data

In this study, two versions of daily precipitation dataset, MRI-AGCM3.1S and 3.2S are used after bias correction (Inomata et al. 2011) for three time periods; present (1980-2004), near-future (2015-2039) and future (2075-2099) climates. A prototype of gridded daily rain gauge dataset, which is developed in JMA/MRI succeeding to APHRODITE project (Yatagai et al.

2009), is used as a reference data of the bias correction. Daily discharges for different climates are simulated using BTOP model (Takeuchi et al. 2007) with bias-corrected daily precipitation. The BTOP model is used with optimizing parameters for GBM basin. Observed discharge and water level data are collected from Bangladesh Water Development Board (BWDB). These data are at the three outlets of the three rivers of GBM basin.

4. Results and discussion

4.1 Assessment of precipitation

The precipitation data that are used in this study, the MRI-AGCM3.1S and 3.2S are well bias corrected. Figure 4 shows the mean annual precipitation in present climate in observation and bias-corrected GCM simulations.

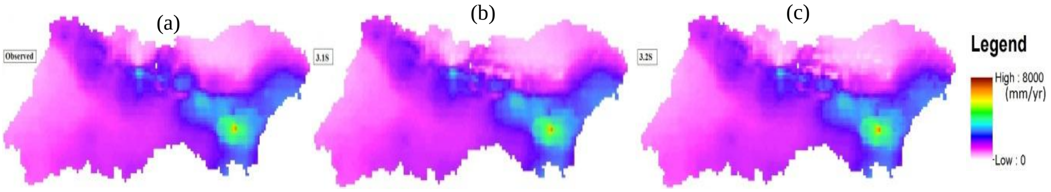

Fig. 4. Annual mean precipitations in present climate (a) observation and bias corrected (b) MRI-AGCM 3.1S and (c) MRI-AGCM 3.2S simulations

To see distributional change in precipitations, the mean annual precipitation changes are calculated for each cell for entire basin. Figure 5 and 6 show the percentage change in annual mean precipitation in near future and future periods respectively. Both versions show about 68% area of entire basin increasing in near-future precipitation and about 32% area decreasing. Precipitation of about 52-62% area will increase 0-10%and 30% area will decrease 0-10% in near-future period. In future period, most of the basin area (about 94%) shows the increasing trend. About 32-38% area shows 0-10% increasing and about 74-80% area shows 0-20% increasing.

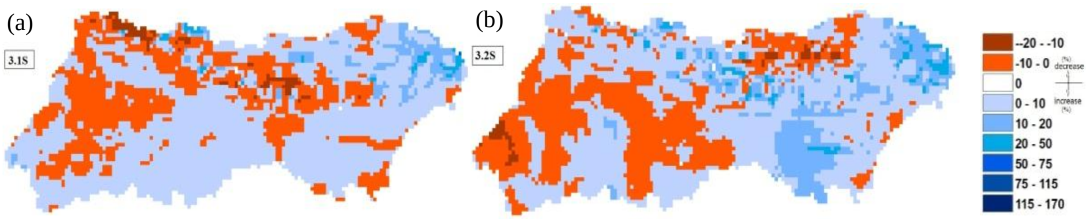

Fig. 5. Rate of change of mean annual precipitation between present and near future climates in bias-corrected (a) MRI-AGCM 3.1S and (b) MRI-AGCM 3.2S simulations

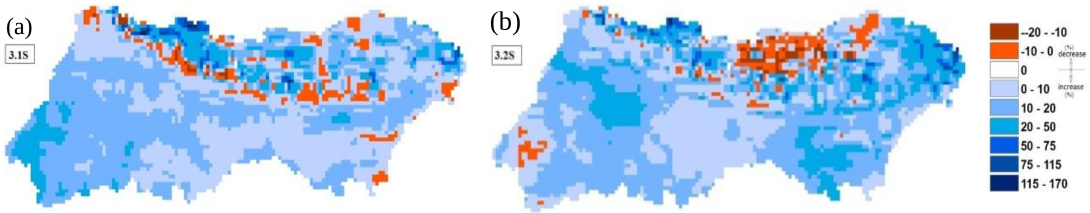

Fig. 6. Rate of change of mean annual precipitation between present and future climates in bias-corrected (a) MRI-AGCM 3.1S and (b) MRI-AGCM 3.2S simulations

It is seen from both versions of data, annual mean precipitation will increase in every river in near future and future period. In Ganges River, annual mean precipitation is likely to increase 1-2% in near-future period and 11-12% in future period. In Brahmaputra River it will increase 4-7% in near future and 11-16% in future climates. In Meghna River, it will increase 2-8% in near-future period and 6-17% in future period. Figure 7 shows the annual mean precipitation in each river basin.

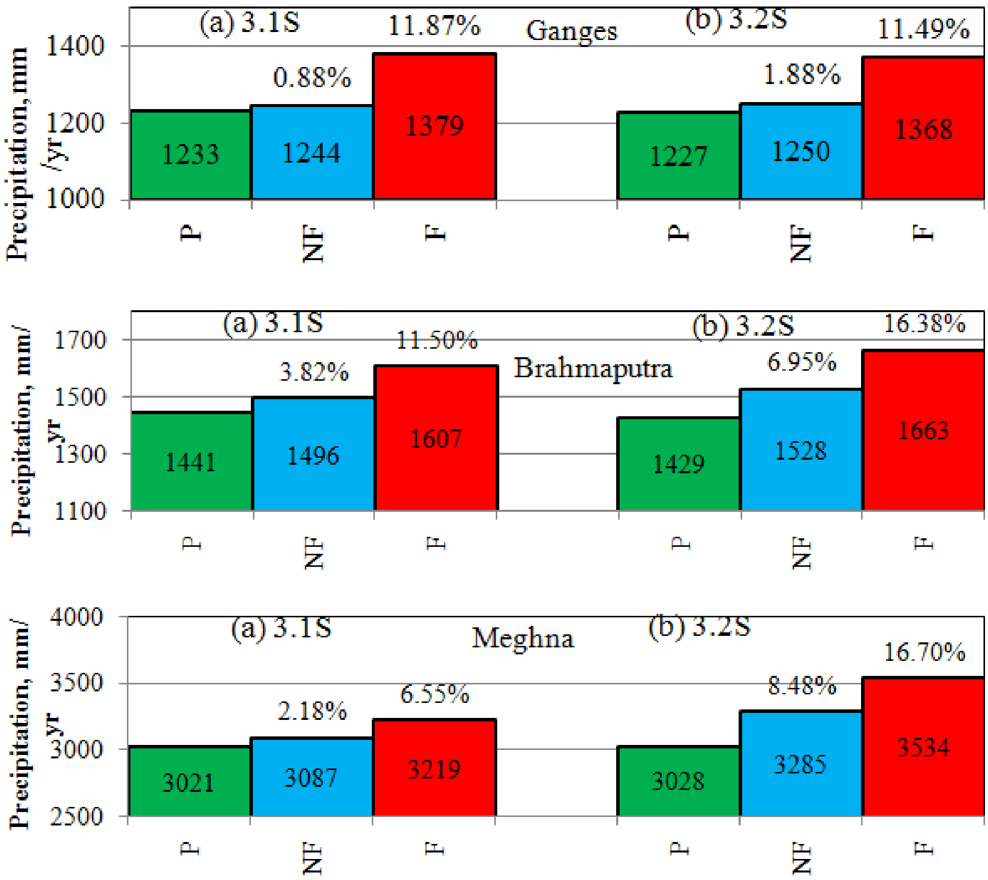

Fig. 7. Mean annual precipitation in present, near future and future climates with bias-corrected (a) MRI-AGCM 3.1S and (b) MRI-AGCM 3.2S simulations.

4.2 *Assessment of discharge*

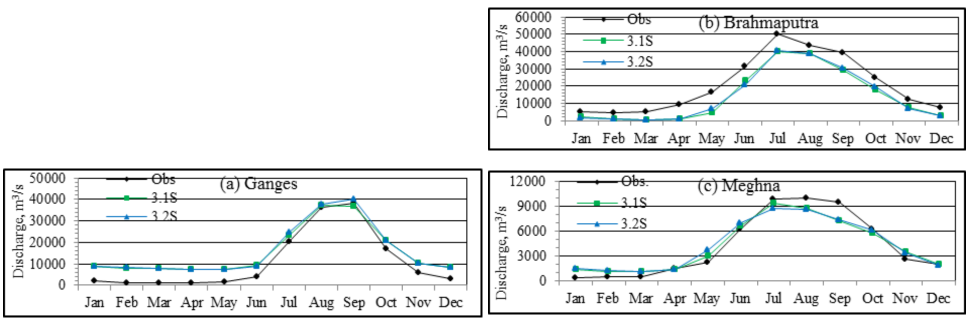

Fig. 8. Comparison of monthly mean discharge in present climate between observed and BTOP simulations.

In Ganges River, annual mean discharge will increase 2-4% in near-future and 21-24% in future period. Annual mean discharge in Brahmaputra River will increase 7-11% in near-future and in future period, it will increase 20-26%. In Meghna River, it will increase 3-13% in near-future period and10-24% in future period. Figure 9 shows the annual mean discharge for different periods in each river basin.

Both versions show peak discharge increasing significantly in near-future and future climates. But that with MRI-AGCM3.2S dataset shows much more increasing. The curves further go apart from present period when return period increased. Comparisons of annual maximum discharge for different period on Gumbel probability paper are shown in Figure10. Mean annual peak discharge will increase so much especially in future period. In future climate, mean annual peak discharge will increase 27%-34%, 35%-55% and 19%-26% in Ganges, Brahmaputra and Meghna rivers respectively. Table 1 shows the details change of mean annual peak discharge.

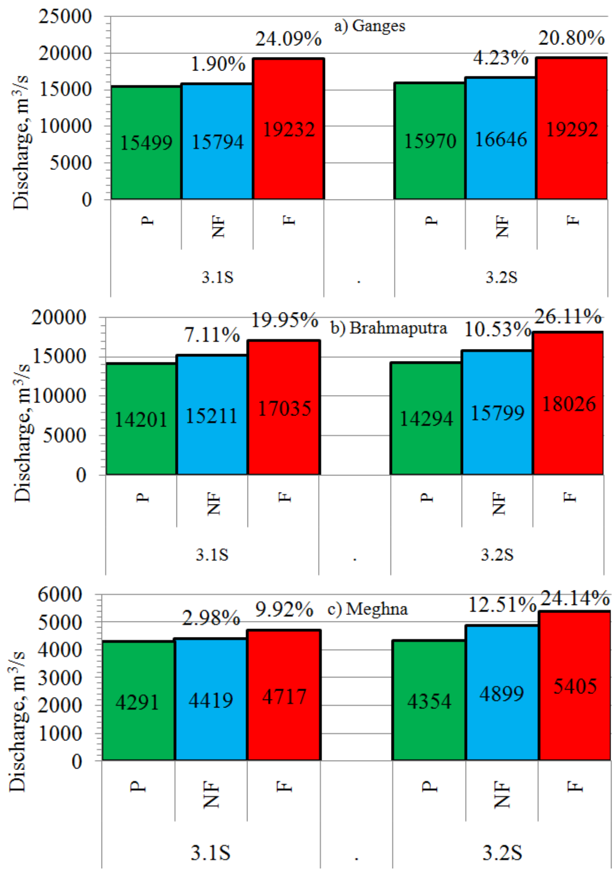

Fig. 9. Comparison of annual mean discharge in a) Ganges b) Brahmaputra and c) Meghna River.

Annual minimum discharge also will increase especially in future climate. So in this study, minimum discharge analysis is not given importance. Table 2 shows the details of mean annual minimum discharge in different time period.

Table 1
Changing of mean annual peak discharge

River	MRI-AGCM	Mean peak discharge (m^3/s)			Change (%)	
		P	NF	F	NF	F
Ganges	3.1S	55723	53686	74662	-4	34
	3.2S	64936	70416	82706	8	27
Brahmaputra	3.1S	55207	62103	74632	12	35
	3.2S	53102	62410	82443	17	55
Meghna	3.1S	11201	11477	13322	2	19
	3.2S	15134	16275	19026	7	26

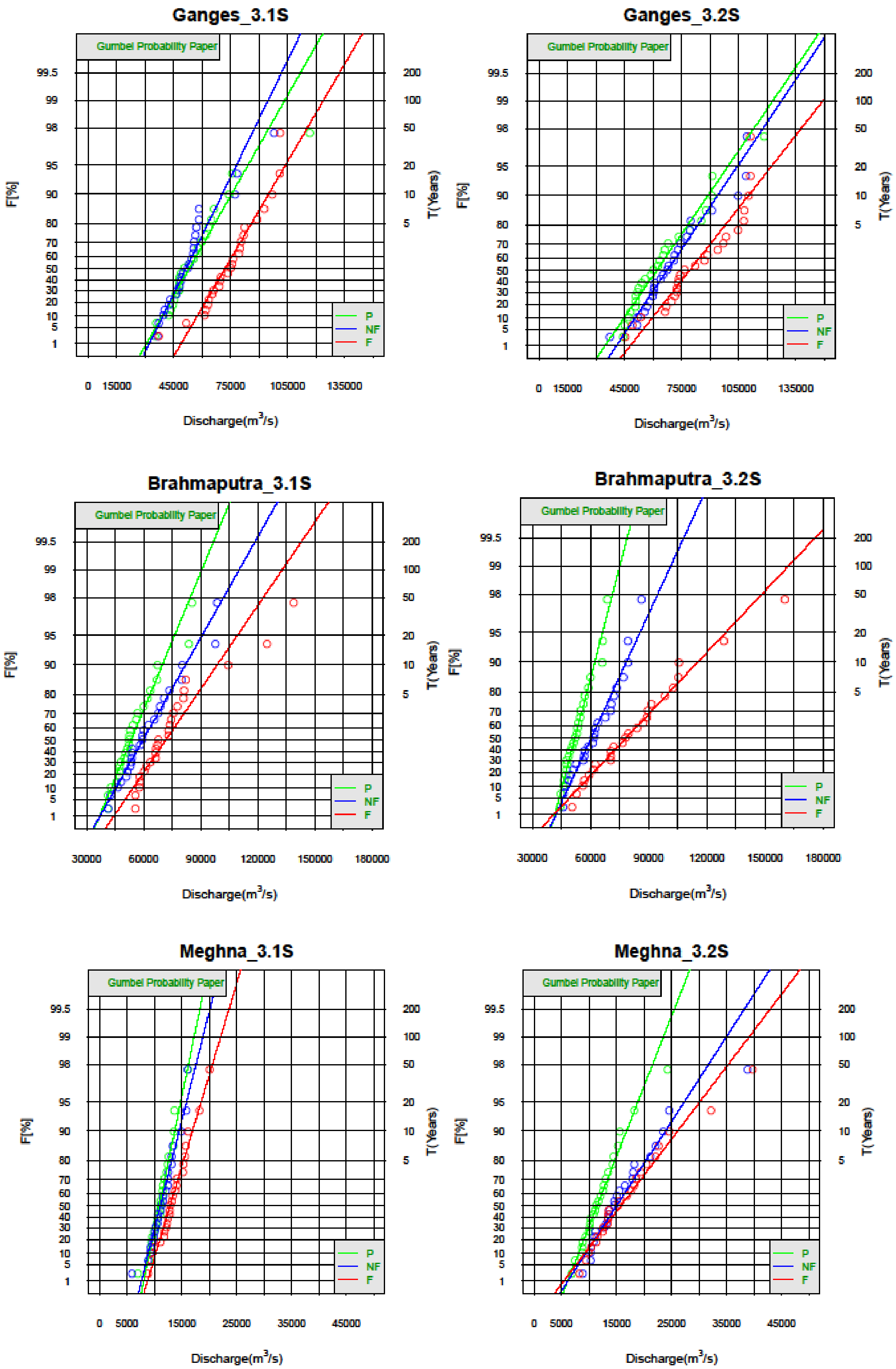

Fig. 10. Comparison of peak discharge on Gumbel probability paper.

Table 2
Changing of mean annual minimum discharge

River	MRI-AGCM	Mean annual minimum discharge (m^3/s)			Change (%)	
		P	NF	F	NF	F
Ganges	3.1S	6983	6948	7810	0	12
	3.2S	7038	7280	7780	3	10
Brahmaputra	3.1S	587	555	598	-5	2
	3.2S	558	627	717	12	28
Meghna	3.1S	1025	1020	1070	0	4
	3.2S	1034	1094	1139	6	10

4.3 Adaptation measures by structural means

Rating curves are fitted for the years; 1998 for Ganges and 1988 for Brahmaputra and Meghna rivers. Rating curves are shown in Figure 11. To protect 25 years flood, levee should be heighten or construct with extra height about 14cm, 49-74cm and 27-149cm on Ganges, Brahmaputra and Meghna River to face climate change effect at the near-future climate, respectively. In future climate, levee should be heighten or construct with extra height about 61cm, 74-199cm and 88-194cm on Ganges, Brahmaputra and Meghna river to control 25 year flood, respectively.

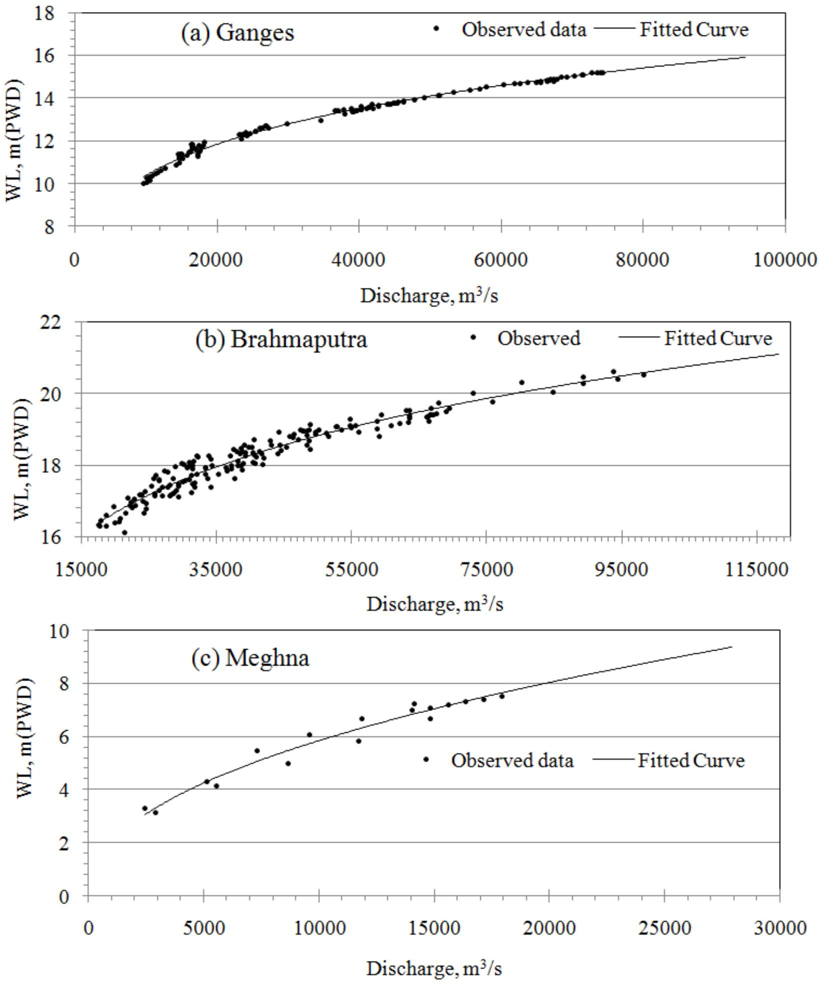

Fig. 11. Rating curve for (a) Ganges, (b) Brahmaputra and (c) Meghna River

5. Conclusion

From all types of analysis of MRI-AGCM3.1S and 3.2S precipitations and discharge output of BTOP model, it can be seen that water will be abundant in both time periods, near future and future climates but in near future changing is not so much. In future climate, it may become much more severe. In general, the results show the increasing trend in more area and some area also shown decreasing trend in the near future and future climates. Annual means of rainfall and discharge are also likely to increase in the near future and future periods but maximum flow may much more severe. Minimum flow also is likely to increase in the future climate. Present design level of flood control embankment or levee will not be sufficient to control flood in future basically the end of 21stcentury. Design height of levee should be higher than present design height to adapt the future climate change.

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