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Impact of Climate and Land Use Changes on the Flood Vulnerability of the Brahmaputra Basin

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ABSTRACT

A physically based macro-scale distributed hydrological model (DHM), which works on the concept of hydrological similarity classes (HSCs), has been calibrated validated and then used to assess the possible future changes in the flood characteristics and flood vulnerability of the Brahmaputra basin, India, due to climate and land use changes. Future projected meteorological data from a regional climate model (RCM) simulation (PRECIS) and the *'Best Guess'* land use change scenarios were used to obtain the changes in spatio-temporal distribution of flood generation and its propagation through the Brahmaputra river and its tributaries. This spatio-temporal distribution of flood regime changes has been analyzed to assess the flood vulnerability of the basin.

This study reveals that the projected climate change would affect the flood vulnerability more significantly than the land use / land cover changes. Alteration of paddy agriculture fields would significantly change the flood characteristics in the valley. The projected climate change can increase the peak flow of Brahmaputra by about 28%, the same has been found to be increased by a maximum of about 9% for land use/ land cover changes. Similarly the other flood characteristics like flood inundation period, monsoonal yield, time to peak, maximum lift and number of waves in a season have been found to be more vulnerable to be affected by the projected climate change scenarios and these changes increase towards the downstream areas of the basin. Longer duration of waves with higher discharges are expected to inundate more areas, increasing the flood vulnerable area, in future causing serious socio-economic and ecological changes in the basin. Hydrological impacts of changing land use/ land cover have been found to be more dominating in the drier years compared to the wet years.

Keywords: *Climate change, Land use, Flood, Brahmaputra basin.*

1. INTRODUCTION

Temperature of the planet has shown an increasing trend particularly since 1920s. Though still now there are different opinions about enough convincing proof to attribute the global warming to the greenhouse gases, a number of warm years in recent period have found to outshine the expected range of natural variability (Hadley centre, 1997) and thus the accountability passes to the human activities. Climate change resulting from increasing greenhouse gas concentrations in the atmosphere is likely to shift the spatial and temporal distribution of water resources in river basins (Kundzewicz et al., 2007). This change can be further intensified by the land use/ land cover changes of the basin. The spatial and temporal changes in runoff regime may increase flood vulnerability in a river basin.

The changes in runoff characteristics resulting from climate change depend on individual catchment characteristics. In particular, basin geology and elevation are primary variables to control the response, in the form of change in timing and magnitude of basin runoff, to climate change; but change in land use / land cover can further augment the changes. Understanding changes in spatial and temporal variations of runoff in an explicit way is important for flood management and flood mitigation plan in a large river basin. Trends in fluvial flooding are more difficult to detect, as changes in factors such as land use, reservoirs and drainage or flood alleviation schemes would simultaneously act to change the flood regime in addition to the changes due to the climate. But at the same time estimation of the changes in the trends of fluvial flooding is extremely important considering the fact that a majority of the economic activities and livelihood of the people are centered around the floodplain areas of the large river basins particularly in India.

Possible future flood scenarios can be obtained through a hydrological model using the future projected meteorological data from a climate model. General circulation models (GCM) are frequently used for this purpose. However the coarse resolution of GCM leads to an inadequate spatial distribution of the meteorological variables required for a distributed hydrological model (DHM). Regional climate models (RCM) have been used in recent times to obtain the required resolution (Kay et al., 2006; Wang et. al., 2006). Even though sometimes the resolution of a RCM is not fine enough and creates some biasness in the spatial distribution of meteorological variables. Different hydrological models were used to convert different meteorological model output scenarios into hydrological response to study the future possible changes of flood scenarios due to climate change in several countries and regions (Chang and Jung, 2010; Reynard et al., 2001; Arora and Boer, 2001; Kay et al., 2006; Mirza, 2002; Cameron et al., 2000; Wang et. al., 2006). However the future changes of characteristics of the flood waves were not addressed with its due importance.

Prediction of the possible future changes in the characteristics of flood waves and the lift of flood waves (Karmaker and Dutta, 2010), which are the primary control of the flood vulnerability, is a challenging task and needs a distributed hydrological model which works on the different hydrological processes in a distributed manner with fine enough spatial and temporal resolution. In the present study a physically based macro-scale distributed modeling approach has been envisaged. High resolution meteorological (rainfall and temperature) data from a regional climate model and the *'Best Guess'* (Reynard et al., 2001) land use scenarios have been used to estimate the future spatio-temporal distribution of hydro- meteorological variables over the basin.

2. STUDY AREA: BRAHMAPUTRA RIVER BASIN

The Brahmaputra with a drainage area of 580,000 km^2, of which 194,000 km^2 is in India, carries an annual runoff of 537.2 km^3 (Sarma, 2004). It has a huge impact on the socio-economic activities as well as the hydrology of the region. Originating from plateau of Tibet, known as Tsangpo, it enters India at an elevation of 660 m and flows in a southern course and then turns to a western course through the alluvial plains of Assam for about 710 km., and enters the deltaic planes of Bangladesh to deplete to the Bay of Bengal (Fig. 1). The valley spreads about 640 km long with its width variation from 64 to 90 km. The valley consists of flood plain area, hilly terrain and the river Brahmaputra along with its tributaries. In its flood plain area, the most dominated land-use is paddy agriculture whereas a mix of grassland and forest seen in its hilly area. It is also reported that there are more than 2500 wetlands spreading across the valley. Another its hydrologic condition is the presence of shallow ground aquifer, which fluctuates highly with the change of its surface hydrology (Goswami 1998). In addition of the above unique hydrologic behaviours, a complex integrated system of hillslope-floodplain-channel flow describes the valley hydrologically (Wainwright and Mulligan, 2004).

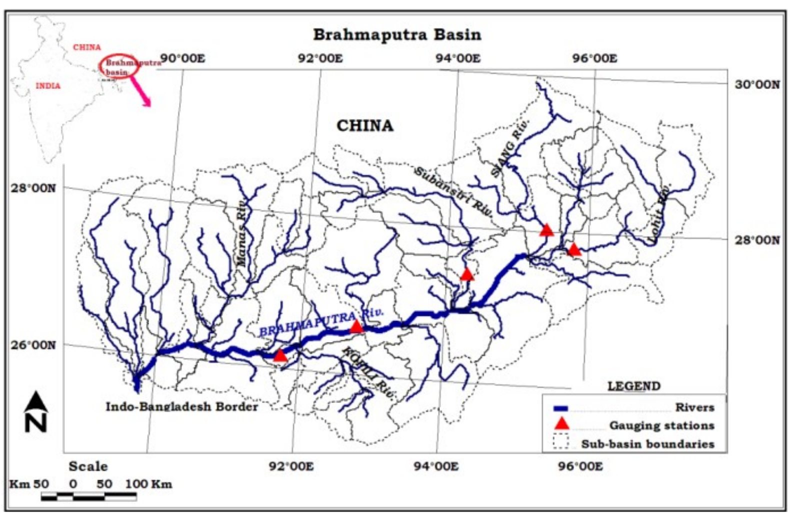

Figure 1. Study area: Brahmaputra river basin with its drainage network

Meteorological data of the study area shows that the area undergoes high intensity storm events, due to the monsoonal wind, frequently during four summer months from June to September. Clusters of successive several days with high rainfall can be observed during the monsoon season (Soja and Starkel, 2007). In the Brahmaputra valley, 66–85% of annual rainfall occurs during the monsoon and 20–30% occurs during the pre-monsoon season while the percentage of annual rainfall occurring in the winter season is negligible (Sarma, 2005).

Analysis of flood characteristics of river Brahmaputra reveals that the intense monsoonal rainfall, within a very short period, responses in the form of flood waves due to its fast hydrological response and large contributing area with dense drainage network. In addition to the normal monsoonal response the river Brahmaputra experiences 4 to 5 major flood waves, on average, annually during the monsoon months (Datta and Singh, 2004; Karmaker and Dutta, 2010). Analysis of historical stage records shows the percentage of occurrence of flood in the month of June, July, August and September as 25%, 35%, 37%, and 3% respectively (Datta and Singh, 2004).

3. HYDROLOGICAL MODEL

Rice Irrigation System Evaluation (RISE) model (Dutta and Zade, 2003), a distributed physically based macro-scale hydrological model in which the hydrologic processes has been conceptualized to work on different distinct hydrological similarity classes (HSC) for a paddy-agriculture dominated watershed in subtropical regions, has been used to translate the projected meteorological and land use changes into hydrological responses. A detailed mathematical formulation of the hydrological processes used in the model can be obtained from Mishra et al., 2008. The type and sources of the input data and the calibration parameters used in the hydrological model are listed in Table-1. The hydrological model was callibrated and validated for the study area based on the observed rainfall distribution over the study area and stage level record at two gauging stations along the Brahmaputra river located at Tezpur and Guwahati (Ghosh and Dutta, 2009). This calibrated model has been used for the assesment of the changes in the flood vulnerability of the Brahmaputra basin.

Table 1. Input data, model parameters and their sources

Parameter type	Name	Source
Static	Topography and Basin Characteristics	Asia Hydro1k database, USGS
	Soil type distribution	NBSS&LUP, India
	Soil parameters	NBSS&LUP, India
	Land use classes	Ionia Glob Cover Portal, ESA
	Average surface storage in paddy field (*h*)	Calibration parameter
	Degree of impermeability of hardpan formation (*r*)	Calibration parameter
	Minimum storing depth in micropores	Calibration parameter
Dynamic	Exponential transmissivity decay function (*m*)	Calibration parameter
	Natural logarithm of transmissivity of just saturated soil profile (lnT_0)	Calibration parameter
	Initial saturated topographic index (*TI*)	Asia Hydro1k database, USGS
	Variable advection, diffusion constants (*a, b, a ,ß*)	Computed model parameters
Time Series	Daily observed stage record	Brahmaputra-board, India
	Rainfall distribution (Validation period:1978-2003)	IMD, Pune, India
	Future rainfall and temperature data	IITM, Pune, India

For the simulations a uniform grid size of 1000 m and a simulation time step of 24 hour were adopted. The time resolution of 24 hour was found to be sufficient for capturing time scales of important hydrological events, as the flood wave takes around 5.3 days to travel through the study area (Datta and Singh, 2004). In order to eliminate the possible deviations due to the initial conditions, simulation was started well before the monsoonal season.

4. PROJECTED SCENARIOS OF CLIMATE AND LAND USE CHANGE:

The impact of land use / land cover changes on the flood vulnerability of the Brahmaputra basin has been assessed by using the *'best guess'* (Reynard et al., 2001) future land use scenarios. Three major land use/ land cover, found vulnerable for the changes, were considered in this study viz. forest with soil macroporosity, *Jhum* cultivation and other fallow land with less soil macroporosity and paddy agricultural system with surface detention capacity. The "*best guess*" changes in land use /land cover considered for the present study are-

Case I: Forest to Jhum cultivation/other fallow land

Case II: Forest to paddy agriculture

Case III: Paddy agriculture to fallow land.

The random spatial changes have been generated in PCI-Geomatica (Law & Kelton, 2000) and superimposed with the existing land use/ land cover. The ranges of the changes considered for this study are 2.5%, 5% and 10%.

Future projected meteorological (rainfall and temperature) data was obtained from the output of a regional climate model (PRECIS) simulation for A2 scenario (SRES-98 emission scenarios after IPCC) at Indian Institute of Tropical Meteorology (IITM) Pune, India (Rupa Kumar et al., 2006). This dataset, consisting of two sets of rainfall and temperature data, having the spatial resolution of 0.44^0 X 0.44^0 was used to simulate the required flood characteristics through the distributed hydrological model (DHM).

5. RESULTS AND DISCUSSION

5.1 Effect of land use and land cover changes

Presence of paddy fields in the basin area has been found to be most sensitive to change the hydrological regime and the flood characteristics of the basin. For extreme wet conditions like in the year 1988, it has been observed that case-II scenarios were most sensitive to increase the monsoonal yield. About 14% change in the monsoonal yield has been observed at the gauging station of Guwahati for about 10% change in forest to paddy agriculture. This change was even higher at the tributaries. However no significant impacts have been observed for case-I type of land use changes. Case-III scenarios actually reduced the monsoonal yield by a maximum of about 4%.

Changes in peak flow at Brahmaputra due to the land use changes have been found to be lesser than the changes in annual yield. The peak flow at Guwahati was increased by a maximum of about 5% for case-II scenario; while for the other two cases no significant impacts have been observed. The tributaries had shown a higher change in its peak flow for case-II scenarios as well.

These changes have been found to be more dominating for the moderate wet years like in case of the year 1992. About 17% increase in monsoonal yield at Guwahati has been observed for the year 1992. The changes in tributary level were rather higher and a maximum value of 22% has been found for the river Subansiri. At Guwahati almost 9% increase in peak flow has been observed for the same Case-II scenarios; for Subansiri this was found to be as high as 15%. Case-III scenario reduced the monsoonal yield and peak discharge as well. These variations were found to be significantly high in case of the upstream gauging stations and the tributaries. This indicates that the hydrological impact of land use land cover changes are more scale dependent for the drier monsoon years.

In Fig. 2 the temporal variation of the deviations of the daily discharge from the original discharge (Q_s) of the base year for the extreme three scenarios is illustrated for an extreme wet year of 1988 and a moderate wet year of 1992. About 6000 m^3/s increase in the discharge can be observed at Guwahati.

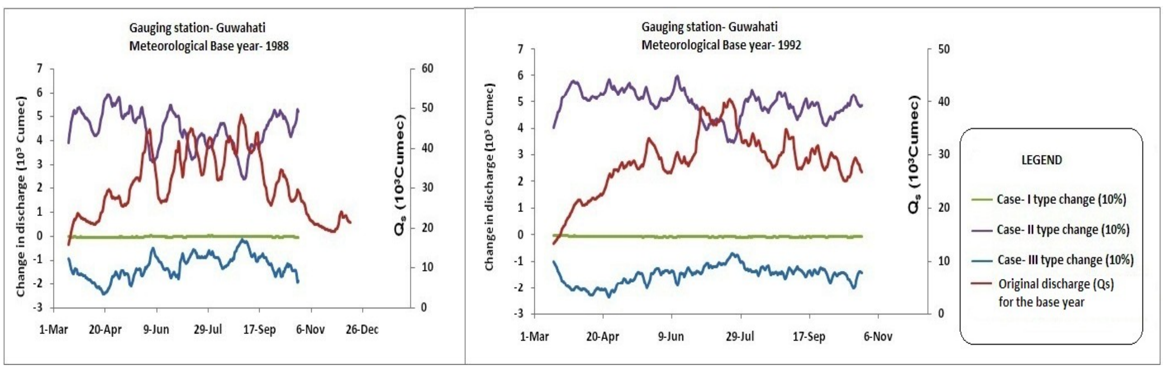

Figure 2. Changes in daily discharge series in Brahmaputra river due to land use changes

5.2 Effect of Climate change

5.2.1 Changes in annual peak flow

The projected annual peak flow due to the projected climate change is presented in Fig. 3. Comparison of 30 years of simulation result gives a consistent indication that the peak monsoonal flow would increase by 2070s compared to the baseline period of 1970s. The increase in the median value of 30 years monsoonal peak flow series has been found to be 7.42% at Tezpur in upper part of the middle reach of the Brahmaputra. At the gauging station of Guwahati in middle reach of the river Brahmaputra, increase in the median value of the 30 years monsoonal peak flow series was found to be 26.82% and at Dhubri in the lower reach of the river Brahmaputra near Indo-Bangladesh border this increment was found to be 28.46%. Thus it can be concluded that as the river propagates towards the downstream, vulnerability due to monsoonal floods is going to increase towards the end of this century. This change in the tributaries has been found to be rather abrupt and fluctuates significantly with meteorological variables and basin characteristics.

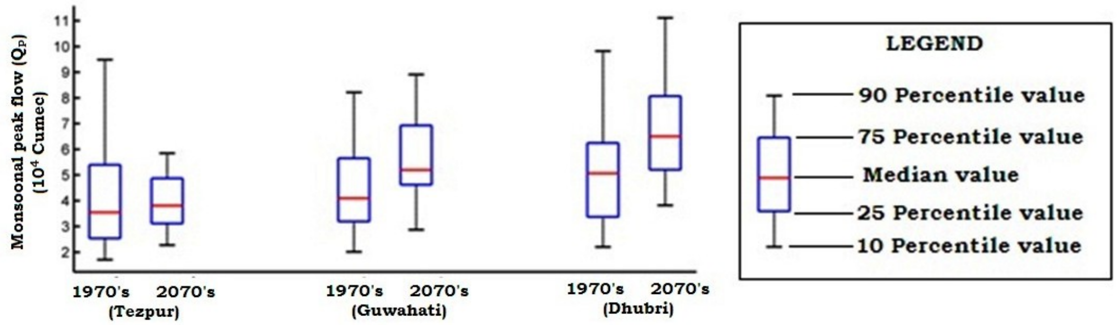

Figure 3. Changes in the monsoonal peak flow series due to projected climate change

5.2.2 Changes in flood wave characteristics

Flood characteristics have shown significant changes in response to the projected climate change. While the number of flood events per year has decreased for the monsoonal period of the year, the peak discharge and flood lift has increased significantly. This finding can be clearly correlated with the facts that- increase in the frequency of extreme events and a decrease in the frequency of moderate events are going to characterize the rainfall events in future (Goswami et al., 2006).

The duration of the flood wave and flood inundation i.e. time taken from the initiation of the flood wave to its attenuation (T_d) is another important aspect for the assessment of flood vulnerability in view of its consequences on the socio-economic activities of the valley. The duration of the flood waves during the monsoonal period has been found to be increased (Fig. 4). The median value of the duration of the waves for all the flood waves in thirty years simulation period has shown an increment from 15.4 days for the baseline period to about 20.3 days towards the end of this century for all three gauging stations along the Bramhaputra reaches. However the time to peak (T_p) for the monsoonal flood events has not shown any significant change, though some extreme events have been observed for this period as depicted in Fig. 5. Similar pattern in the changes of the flood characteristics has been observed for the major tributaries of the Brahmaputra basin. However the vulnerability to be affected by the climate change has been found to be scale dependent and is significantly lower for the tributaries.

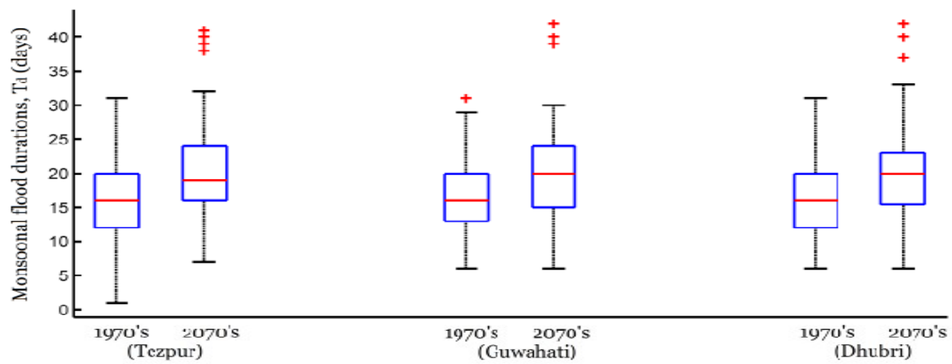

Figure 4. Changes of monsoonal flood duration due to the projected climate change

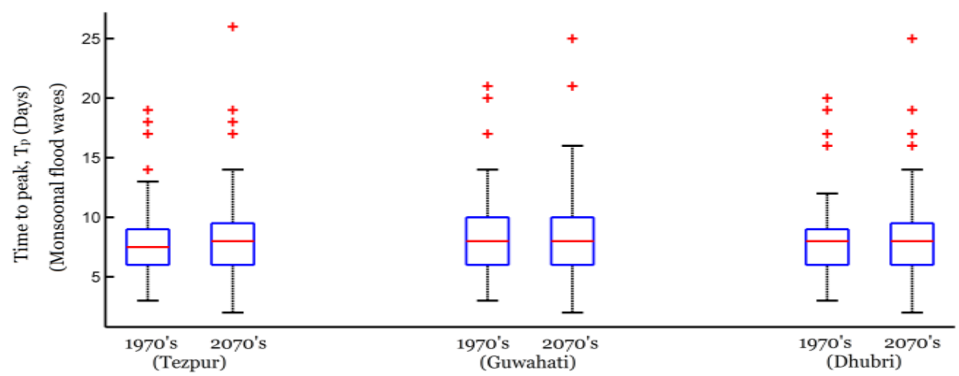

Figure 5. Changes of time to peak of monsoonal waves due to the projected climate change

5.2.3 Changes in flood at tributary level

Simulation result suggests that peak annual discharge of all the major tributaries are likely to increase in response to the projected climate change as shown in Fig. 6. Though the relative increment in peak discharge is higher in the tributaries the absolute value of increment suggests lesser flood vulnerability compared to the Brahmaputra. Greater fluctuations of the discharges in the tributaries can be attributed to the fast hydrological responses of the smaller catchment area. The same trend has been observed for the mean annual flow for the major tributaries of the Brahmaputra, however river Sankosh and Dhansiri have actually shown a decrease in mean annual flow (Fig. 7).

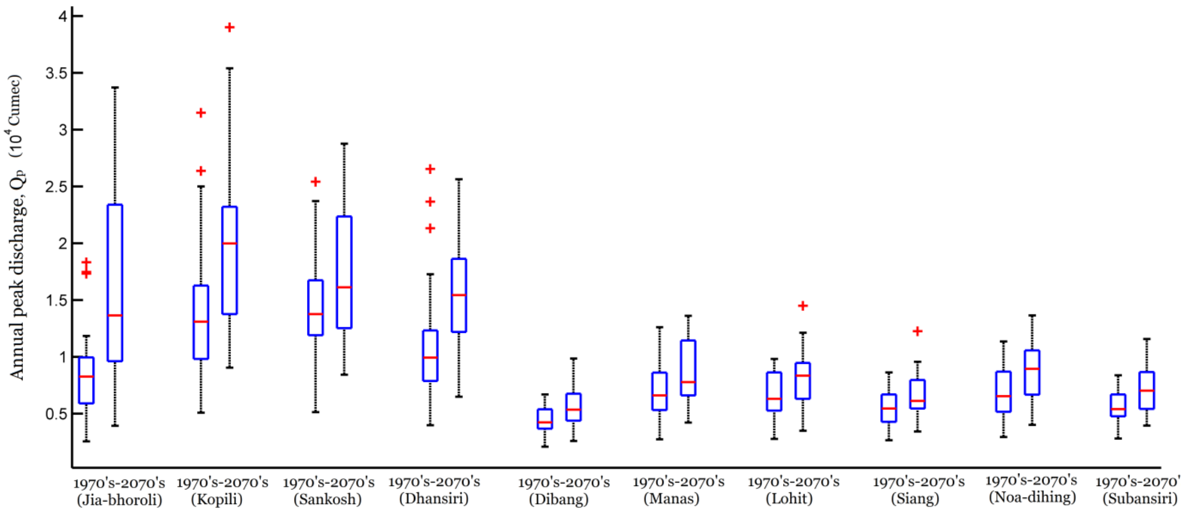

Figure 6: Changes in annual peak discharge of the major tributaries of Brahmaputra

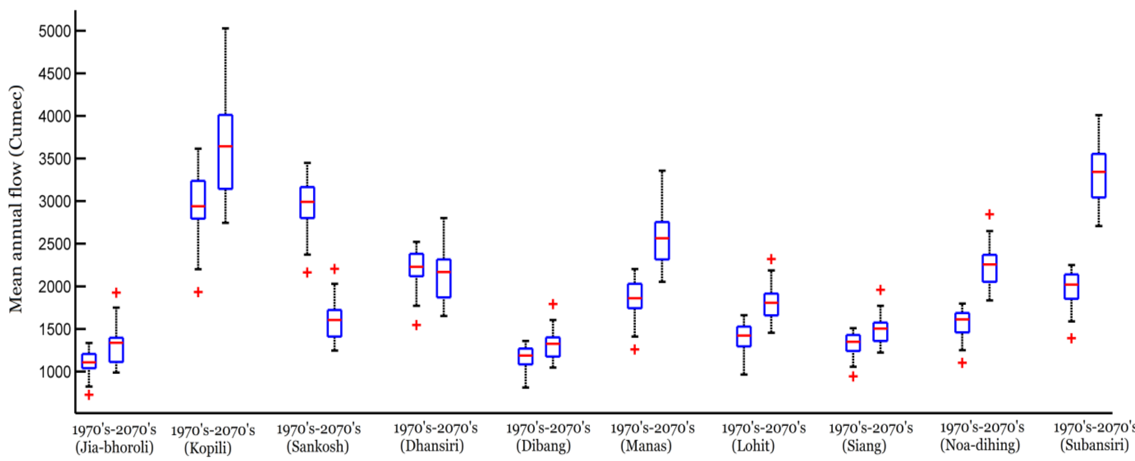

Figure 7: Changes in mean annual discharge of the major tributaries of Brahmaputra

6. CONCLUSION

Climate and land use/ land cover changes can potentially alter the flood characteristics of a river basin. This study has assessed the flood vulnerability by assessing the potential changes in the flood characteristics of the Brahmaputra basin in long term scenario. A physically based macro-scale distributed hydrological model has been used to obtain the important flood wave characteristics. Output of a Regional Climate model simulation (PRECIS) and the *'Best*

Guess' land use change scenarios with their spatial variations have been used to carry out a long series of simulation to find out the general trend of the change.

Effect of climate change has been found to be more dominating for the study area than the effect of land use/ land cover changes. Paddy agricultural fields has been found to be the most sensitive land use class to affect the hydrological regime and flood characteristics of the basin. The projected climate change can increase the peak flow of Brahmaputra by about 28%, the same has been found to be increased by a maximum of about 9% for land use/ land cover changes. Similar way the other flood characteristics like flood inundation period, monsoonal yield, time to peak, maximum lift and number of waves in a season have been found to be more vulnerable to be affected by the projected climate change scenarios. These relative changes are found to be scale dependent and increase towards the hydrologically drier year. In general flood vulnerability has been found to increase towards the downstream area of the basin.

In the present study single projected meteorological scenario (A2 scenario; SRES-98 emission scenarios after IPCC) has been used to evaluate the effect of climate change. More general trend of the future hydrological changes and flood vulnerability can be assessed with the use of other projected meteorological scenarios and the trend analysis of the changes of present land use.

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