Assessment of the Climate Change Impact on the Flood Risk Change in Chenab River Basin

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ABSTRACT

This study was conducted to analyze the impact of climate change on the intensity and frequency of floods in the Chenab transboundary basin. Ground rain gauge and Global Satellite Mapping of Precipitation (GSMaP) data were used in the Rainfall-runoff-inundation model (RRI) for calibration and validation. Past (1981-2000) and future (2040-2059) climate rainfall data projected by General Circulation Models (GCMs) from the Coupled Model Inter-Comparison Project Phase 5 (CMIP5) were obtained from Data Integration and Analysis System (DIAS) after bias correction with Asian Precipitation Highly Resolved Observational Data Integration towards Evaluation of Water Resources (APHRODITE) for the selected GCMs. Representative Concentration Pathways 8.5 (RCP8.5) scenario was selected for this study. The discharge and inundation values in the projected climate were obtained through the simulation of the RRI model. We utilized 50 and 100 year return period of rainfall in the analysis of heavy flood events. We estimated loss of the harvest by the flood to assess the flood inundation effect on the agricultural yield. There is a large variability in the projection of rainfall, flood and inundation. The main cause of this uncertainty in the projected future found out to be the variations in the strength of projected meridional and zonal wind by selected GCMs. It is concluded that the future climate is expected to be very much uncertain and it is a big challenge for planning.

Key Words: Monsoon, General Circulation Models, Hydrological model, Climate Change, Inundation

INTRODUCTION

Chenab is the second largest of the five rivers, flowing through the plains of Punjab province in Pakistan (Fig. 1). It is a transboundary river with 65 percent of its catchment areas lying in Indian administrated part of Kashmir (Junaid *et al.,* 2018). The upper mountainous part of the catchment has the capability of the flash flood while lower part experiences riverine flood. The catchment area of the river in Pakistan is 41,656 km^2, and the average annual discharge is 1.52 million m^{3}s^{-1} (Shakeel & Razia, 2018). Heavy rainfall occurred during monsoon from mid of July to end of September which often resulted in a catastrophic flood. The floods impose a great amount of damage to socio-economic conditions. Wang *et al.,* (2011), while analyzing the abnormally high precipitation event of 2010 in upper Indus basin, stated that the heavy rainfall events are the combined effect of the circulation changes in local destabilization due to warming and moistening of lower atmosphere, which are the result of internal and external variations. Cyclonic anomalies combined with enhanced instability due to the increase in warming of the surface and moisture supply, could trigger intense precipitation. Imran *et al.,* (2013) found that there is a significant increasing trend in the frequency of peak rainfall events during the

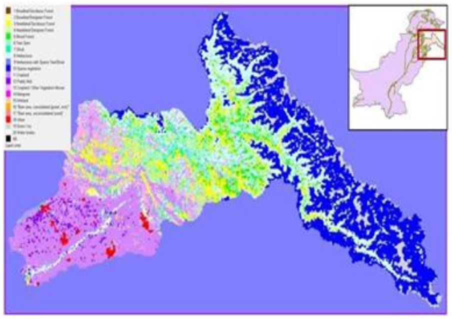

Figure 1: Location of study area

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last week of July to the first week of August and frequency of peak precipitation events is highest in month of August in the northeast Pakistan. Bokhari *et al.*, (2017) while studying the impact of climate change in Chenab river basin, found the variations in the monthly, annual, and seasonal rainfall were non-uniform. They concluded that due to the climate change, precipitation showed large variations in the future projections especially in the wettest month. There is a high probability of a decrease in the frequency of heavy precipitation events and an increase in the number of dry days. This will results in intensive wet spells after a long span of the dry period, which will increase the risk of flooding (Ikram *et al.*, 2016).

THEORY AND METHODOLOGY

The methodology (Fig.2) includes the parameter tuning of hydrological model using ground gauge and satellite rainfall data, obtaining past and future rainfall data from selected GCMs, bias correction of GCM data, analysis of the past and future rainfall, discharge and inundation variations, return period calculation of the extreme rainfall event and risk assessment to agriculture sector.

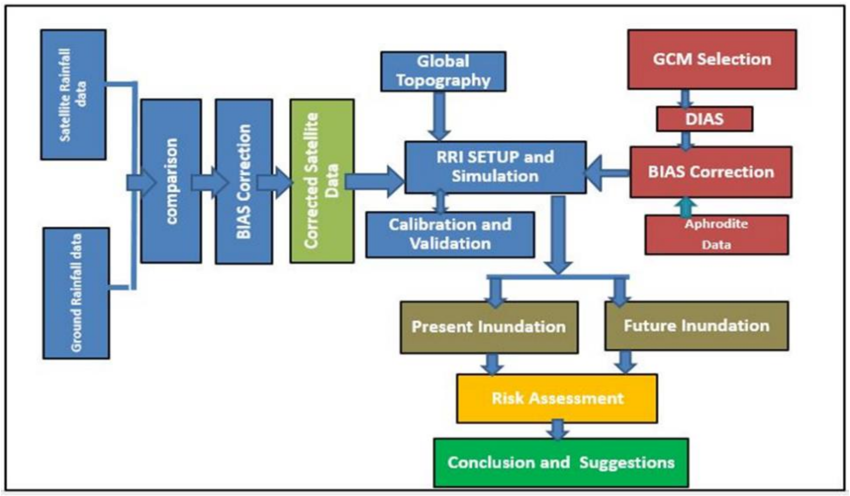


Figure 2: Methodology of the study

(i) Bias Correction of Global Satellite Mapping and Precipitation (GSMaP) Data

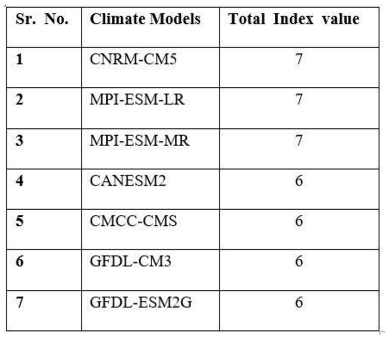
As we found a significant bias in GSMaP rainfall in the target area, we made regression analysis between ground rain gauge and GSMaP data set. The obtained correction factor was applied to the GSMaP data to correct bias to be used for the Chenab basin area.

(ii) Parameter tuning of Hydrological Model

To calibrate the hydrological model, high flood event of September 2014 in the Chenab river basin was selected. The model was operated for both ground gauge and satellite-based rainfall data. In case of rain gauge data, the simulated peak is very close to the recorded peak discharge value but slightly underestimated for GSMaP data. We validated the model with 2016 flood event. It showed almost same accuracy as for the calibration.

(iii) Selection of GCMs through Data Integration and Analysis System (DIAS)

Table 1: Selected GCMs



Sr. No.	Climate Models	Total Index value
1	CNRM-CM5	7
2	MPI-ESM-LR	7
3	MPI-ESM-MR	7
4	CANESM2	6
5	CMCC-CMS	6
6	GFDL-CM3	6
7	GFDL-ESM2G	6

By using the DIAS system, suitable GCMs for the study region were selected from CMIP5. Historical period 1981-2000 and near future period 2040-2059 with RCP8.5 scenario were selected to analyze the climate change effect for this study. To select the historical and future monthly data set, performance of GCMs for the selected study area was evaluated. Seven meteorological parameters; precipitation, air temperature, outgoing longwave radiation, sea level pressure, zonal wind, meridional wind and sea surface temperature, were examined on the basis of Spatial-correlation and RMSE index., GCMs with highest total index value were selected. Seven GCMs were selected in this study (Table 1).

(iv) Bias Correction of GCM Data

The biases of rainfall data of the selected GCMs were corrected through online DIAS tool with respect to APHRODITE data as long term in-situ data is not available for the study area. After bias correction, corrected past (1981-2000) and future (2040-2059) data sets were obtained.

(v) Discharge and Inundation Analysis

The corrected past and future rainfall data of the selected GCMs were provided in RRI hydrological model to simulate the projected discharge and inundation values. A comparison between the past and the projected future results of discharge and inundation was made through Geographic Information System (GIS) tool.

(vi) Frequency Analysis

Frequency analysis was done using Log-Normal distribution on the basis of past (1981-2000) and future (2040-2059) rainfall data. Annual maximum series (AMS) was developed for the whole range of climate data set and extreme rainfall values for 50 and 100 year return period were calculated.

(vii) Risk Assessment

On the basis of projected flood inundation extent and depth, risk assessment was conducted. Inundated area of various depths significant for the damage to the crop was computed and used to calculate the projected loss to the agriculture sector. A comparison was made between the past and future projected values of loss.

DATA

(i) Rainfall Data (Ground Rain Gauge, Satellite and APHRODITE Data Set)

Ground raingauge data obtained from Pakistan Meteorological Department (PMD) was used in this study. This basin is transboundary, so all the stations of the PMD are located in the lower plain part of the basin only. To address the issue of scarcity of data, GSMaP-NRT daily data of 0.25^{o} resolution was used. As study area is a transboundary basin and *in situ* data is not available for most parts of the basin. To overcome this issue, APHRODITE data was used as the baseline data for the period 1981-2000.

(ii) Discharge Data

Daily Discharge data for the monsoon period at Qadirabad Barrage was obtained from Flood Forecasting Division (FFD) of PMD. The data for the year 2014 was used for the calibration of the RRI model, whereas validation was done on the basis of 2016 discharge data.

(iii) Topographic Data

Topographic data of USGS HydroSHEDS, which is a global data set provided by the United States Geological Survey (USGS), is used in this study. Data for the target river basin was clipped and by using the RRI Model package, Digital Elevation Model (DEM) 30 second was used in this study and river parameters were adjusted to be suitable for model simulation.

(iv) General Circulation Models (GCMs)

For the purpose of climate change impact analysis on the river basin, General Circulation Models (GCMs) were used. Precipitation data generated by these models through DIAS was utilized for the analysis of past (1981-2000) and projected future climatic trends in RCP8.5 scenario for the period (2040-2059) of the near future.

RESULTS AND DISCUSSIONS

(i) Rainfall Analysis of GCMs

There were large variations in the projection of different GCMs (Fig. 3, 4). Four GCMs out of seven, CNRM-CM5, MPI-ESM-MR, GFDL-CM3, and GFDL-ESM2G showed an increasing trend towards heavy rainfall events while three GCMs MPI-ESM-LR, CAN-ESM2, and CMCC-CMS showed a trend towards decrease. The amount of variation also differed a lot from one model to another and deviations were more in case of heavy precipitation but for lower values, differences were not much significant. MPI-ESM-MR projected the highest value of the increase while the CMCC-CMS projected the largest decrease for the future climate (2040-2059).

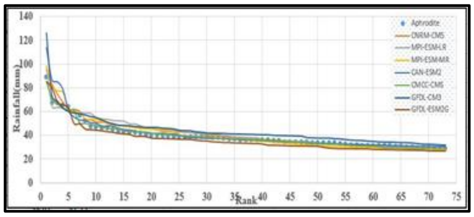


Figure 3: Rainfall comparison past (1981-2000)

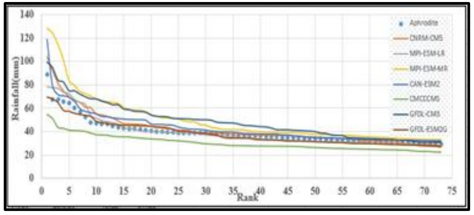


Figure 4: Rainfall comparison future (2040-2059)

(ii) Discharge Analysis by GCMs Rainfall

The rainfall data obtained from GCMs was used in the RRI model to simulate the discharge for past and future climate (Fig. 5, 6). Five GCMs, CNRM-CM5, MPI-ESM-MR, CAN-ESM2, GFDL-CM3, and GFDL-ESM2G showed a trend towards the increase in the peak discharge values while other two MPI-ESM-LR and CMCC-CMS projected a decrease. MPI-ESM-MR showed the highest increasing trend while CMCC-CMS showed the largest decrease.

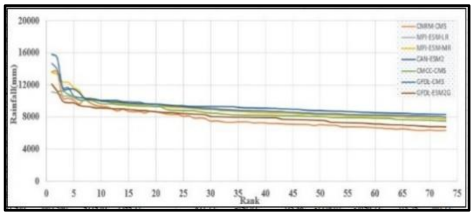


Figure 5: Discharge comparison past (1981-2000)

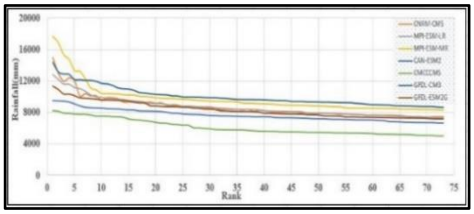


Figure 6: Discharge comparison future (2040-2059)

(iii) Inundation Analysis by GCMs Rainfall

Five GCMs CNRM-CM5, MPI-ESM-MR, CAN-ESM2, GFDL-CM3 and GFDL-ESM2G projected an increase in the future maximum inundation depth values while two models MPI-ESM-LR and CMCC-CMS depicted a decrease (Fig. 7, 8). The highest increase was projected for MPI-ESM-MR, which was consistent with the highest projected rainfall and discharge values. CMCC-CMS projected the largest value of decrease. Total inundated area, inundation depth, and duration, a combination of all these factors determined the severity of a flood.

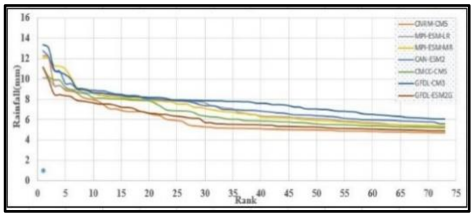


Figure 7: Inundation comparison past (1981-2000)

(iv) Frequency Analysis

Frequency analysis (Table 2) was performed to estimate the most probable future behavior of extreme rainfall events and hence floods and inundation magnitude over a specific return period through RRI simulation. Six days annual maximum rainfall was used to find out the probability of future extreme events. 50 year and 100 years return periods were selected for frequency analysis because of significance for planning purposes. There was a lot of variability in the return period extreme values of rainfall among the selected models. On the basis of a selected hyetograph corresponding to the past heavy flood events, a hyetograph for the specific return period was designed by applying a conversion factor.

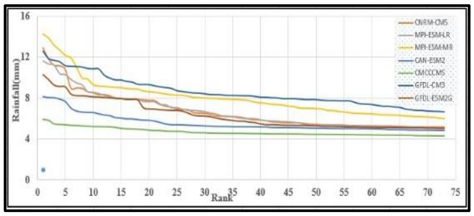


Figure 8: Inundation comparison future (2040-2059)

(v) Variation in Inundation under the Influence of Climate Change

For the 50 years return period (RP), four GCMs; CNRM-CM5, MPI-ESM-MR, GFDL-CM3, and GFDL-ESMG projected an increase in maximum inundation with MPI-ESM-MR depicted the largest increase (Fig.9). Three GCMs; MPI-ESM-LR, CAN-ESM2 and CMCC-CMS showed a decreasing trend with CMCC-CMS showed largest decrease (Fig.10). In the case of the 100 year return period, three GCMs, CNRM-CM5, MPI-ESM-MR, and GFDL-CM3 showed an increasing trend with GFDL-CM3 projected largest increase (Fig.11) whereas four GCMs; MPI-ESM-LR, CAN-ESM2 and CMCC-CMS and GFDL-ESM2G showed a decreasing trend for future climate. GCM CMCC-CMS projected the highest value of decrease (Fig. 12).

Table 2: Return period of rainfall

Sr. No.	Climate Models/ Return Period	Past Climate		Future Climate	
		50 year	100 year	50 year	100 year
1	CNRM-CM5	236	264	249	280
2	MPI-ESM-LR	276	311	246	279
3	MPI-ESM-MR	269	304	321	364
4	CAN-ESM2	273	310	210	235
5	CMCC-CMS	208	232	183	205
6	GFDL-CM3	271	302	309	346
7	GFDL-ESM2G	228	256	230	255

(vi) Climate Change Uncertainty Analysis

Underlying reason for uncertainty in the projected climate was investigated by analyzing various meteorological parameters. Meridional wind depicted the most dominant reason for the increasing or decreasing precipitation in future climate (Fig.13). All those GCMs projected increase in precipitation also projected the strengthening of the southern component of meridional wind simultaneously, which was actually the southwesterly monsoon current. The strong zonal component of wind over the sea was also found responsible for deriving the monsoon wind from the sea to the land and it was a prominent feature in the GCMs which projected increase in rainfall (Fig. 14).

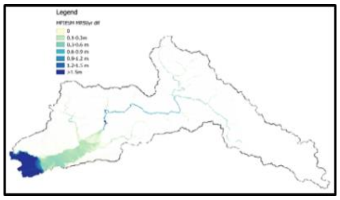


Figure 9: MPI-ESM-MR, 50year RP

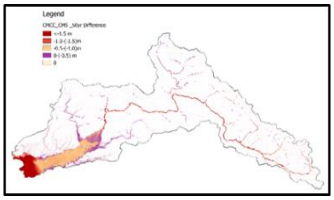


Figure 10: CMCC-CMS, 50year RP

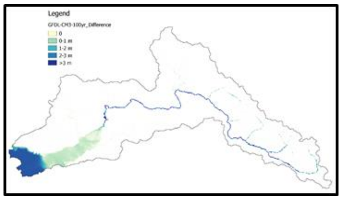


Figure 11: GFDL-CM3, 100year RP

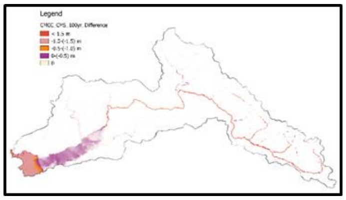


Figure 12: CMCC-CMS, 100year RP

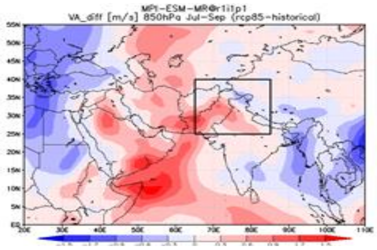


Figure 13: MPI-ESM-MR, Meridional wind

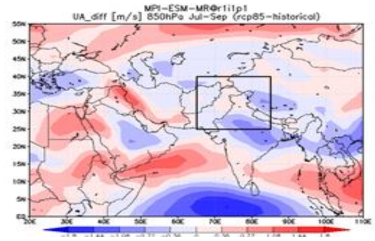


Figure 14: MPI-ESM-MR, Zonal wind

(vii) Risk Assessment to Agriculture Sector

On the basis of projected inundation depth and duration, the loss to agriculture was computed. From the comparison of loss between the future and the past climate for 50 and 100 years return

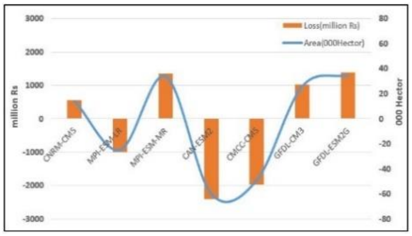


Figure 15: Projected loss for 50 year RP

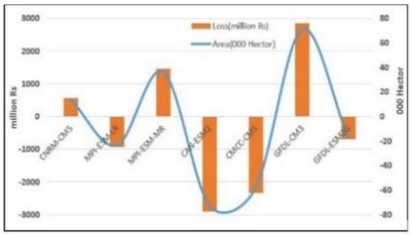


Figure 16: Projected loss for 100year RP

period, large variation in the estimated loss values were obtained (Fig. 15, 16). The loss could be very high in some years or comparatively moderate in others, but still the value of the loss was quite significant.

CONCLUSION AND RECOMMENDATIONS

Floods are the biggest natural disasters in Pakistan and cause a great amount of damage to the socio-economic conditions of the country. An analysis of a number of hydrological and climatological factors concludes that future is projected to be more uncertain. Under the influence of climate change, the intensity and frequency of heavy floods will also be changed. Some years are expected to have quite heavy rainfall, and hence big floods with large inundation will occur, while some years are expected to be relatively drier. The estimation of the damage value in the future is also much uncertain. During certain years, heavy floods can destroy infrastructure and agriculture land and exert great pressure on the socioeconomic conditions of the country but the frequency of these fatal events is also unpredictable. The future climate is projected to be quite uncertain, and planners should make preparation for the worst. There is still a lot of room for improvement. Quality and quantity of meteorological data should be improved. To minimize agriculture loss due to flooding, the cropping practice should be modified. For crops more vulnerable to flood damage, sowing time should be shifted to early sowing so that the crop can attain maturity and harvested before the flood period.

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