

## Research Article

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# The Impacts of Climate Change on Maximum Daily Discharge in the Payab Jamash Watershed, Iran

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**Abstract:** One of the most crucial consequences of climate change involves the alteration of the hydrologic cycle and river flow regime of watersheds. This study was an endeavor to investigate the contributions of climate change to maximum daily discharge (MDD). To this end, the MDD simulation was carried out through implementing the IHACRES precipitation-runoff model in the Payyab Jamash watershed for the 21st century (2016-2100). Subsequently, the observed precipitation and temperature data of the weather stations (1980-2011) as well as 4 multi-model outputs of Global Climate Models (GCMs) under the maximum and minimum Representative Concentration Pathways (RCPs) (2016-2100) were utilized. In order to downscale the output of GCMs, Bias Correction (BC) statistical method was applied. The projections for the 21st century indicated a reduction in Maximum Daily Precipitation (MDP) in comparison with the historic period in the study area. The average projected MDP for the future period was 9 mm/day and 5 mm/day under 2.6 and 8.5 RCPs (4.6% and 2.6% decrease compared with the historical period), respectively. Moreover, the temperature increased in Jamash Watershed based on 2.6 and 8.5 RCPs by 1°C and 2°C (3.7% and 7.4% increase compared with the historical period), respectively. The findings of flow simulation for the future period indicated a decrease in MDD due to the diminished MDP in the study area. The amount of this decrease under RCP8.5 was not remarkable ( $0.75 \text{ m}^3/\text{s}$ ), whereas its value for RCP2.6 was calculated as  $40 \text{ m}^3/\text{s}$  (respectively, 0.11% and 5.88% decrease compared with the historical period).

**Keywords:** Climate change, Hydrology cycle, maximum daily discharge (MDD), RCP, Bias Correction (BC)

## 1 Introduction

The various impacts of climate change have been taken into account as a challenging issue in many parts of the world and has attracted much attention to itself in the recent decades [1, 2].

One of the ramifications of climate change is concerned with the alterations in the hydrological cycle and river flow regime in the watersheds [3]. The changes in the temperature and precipitation prompted by the increase in the greenhouse gases, engender the alteration of the hydrologic cycle, particularly in the arid and semi-arid areas [4]. It should be noted that arid and semi-arid areas are more susceptible to climate change in comparison to humid areas [5].

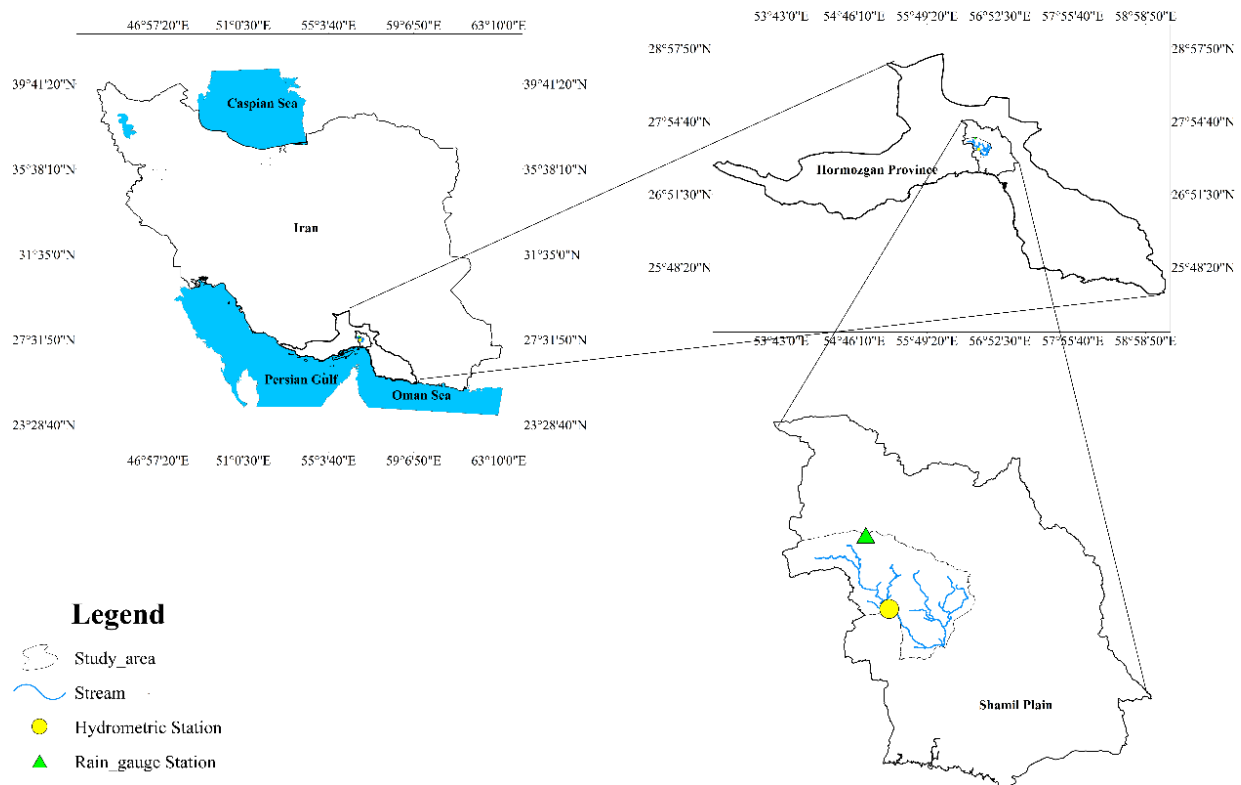
In recent years, this subject has been discussed for diverse watersheds in the world. Many investigations have assessed the impact of climate change on the hydrologic behavior of the watersheds. Their findings have indicated that the hydrologic regime of different areas is affected by the alterations in the climatic conditions [6–10].

According to the Intergovernmental Panel on Climate Change (IPCC) reports, over the past decades the occurrence probability of extreme climatic events has increased worldwide [11]. Since the increase of such probability can lead to devastating hydrological changes, mainly in terms of magnitude and frequency of floods and droughts, the study of climatic extremes has been widely emphasized throughout the world [12–15]. The findings of these studies indicate regional variations in the projected rainfall and temperature [16–20]. Therefore, MDD would increase and decrease regionally, and consequently, the effect of precipitation and temperature on MDD would become complex [21–26].

The application of a hydrologic model through implementing the outputs of the GCMs is the most efficient method to investigate the effects of climate change on runoffs [27]. Maurer [9] and Christensen and Lettenmaier [28] have investigated the effect of climate change on the water resources in the USA through the implementation of the outputs of 11 Atmosphere–Ocean Global Circulation Models (AOGCMs) in the Variable In-

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**Figure 1:** The location of Jamash watershed, Hormozgan Province, Iran

filtration Capacity (VIC) hydrologic model [9, 28]. Their results showed that, in their study areas, the river flow is influenced by the temperature, thereby indicating that temperature enhancement in the future will lead to runoff reduction. In a similar work, Zhang *et al.*, indicated that the temperature and precipitation would increase in the Yellow River basin, and noted that the precipitation changes have larger fractional contribution to stream-flow changes than temperature changes [29]. In other researches, through implementing the Soil and Water Assessment Tool (SWAT), it was determined that the hydrologic cycles of the watersheds, especially the seasonal ones, are very susceptible to climate change [30].

The first outputs of the Coupled Model Intercomparison Project 5 (CMIP5) were released in 2011 [31]. In 2013, some papers citing the outputs of the CMIP5 series of models were published. In addition, in the Assessment Report Fifth (AR5), the outputs of the CMIP5 series were taken into account under new scenarios known as the Representative Concentration Pathways (RCPs) [32].

Afterwards, the studies on climate change focused on these series of models. In these studies, the effects of climate change on the hydrologic cycle was investigated through employing the CMIP5 series under different RCPs [27, 33–38].

The Jamash River is an important river in Hormozgan Province, Iran. It is generally seasonal and also huge floods occur when there is precipitation. A huge part of these floods flow into the alluvial fans of the rivers, which are made up of permeable and coarse materials resulting in groundwater recharge. Since the climate change impact is intricate and also the precipitation and temperature play a different regional role, the emphasis is made on MDD changes in Jamash River in a warming climate.

## 2 Materials and Methods

### 2.1 Study Area

The Payab Jamash watershed is located between  $56^{\circ} 57' 25''$  and  $56^{\circ} 57' 30''$  northern latitudes, and between  $27^{\circ} 32' 50''$  and  $27^{\circ} 16' 16''$  eastern longitudes with an area of  $1,039 \text{ km}^2$  at the eastern part of the Bandar-e-Abbas, Hormozgan Province, Iran (Figure 1). The elevation ranges from 170 m to 3,042 m with an average value of 775 m. Regarding the climatic conditions, this area is categorized as warm and arid; it has warm and long summers (8 months) and temperate winters. The average temperature in this area is  $26.32^{\circ}\text{C}$ . With regard to the precipitation frequency,



**Figure 2:** Flood in Jamash watershed 14-02-2017

**Table 1:** Summary of implemented models in studying the climatic parameters in Jamash watershed

| Spatial resolution   | Modelling center | Country   | Model         |
|----------------------|------------------|-----------|---------------|
| $1.25 \times 0.94$   | NCAR             | USA       | CCSM4         |
| $1.875 \times 1.875$ | MPI-M            | Germany   | MPI-ESM-MR    |
| $2.812 \times 2.79$  | BNU              | China     | BNU-ESM       |
| $1.875 \times 1.875$ | CSIRO-QCCCE      | Australia | CSIRO-Mk3.6.0 |

the study area includes two seasons of dry and humid conditions, respectively. The humid season includes April, December, January, February, and March, receiving more than 90 percent of the annual precipitation. The investigation of the annual precipitation during 1984–2011 shows that the highest amount of precipitation was recorded as 607 mm in 1995, whereas the lowest amount of precipitation was observed in 2008 at 23 mm. The average annual precipitation has been recorded at 230 mm in the study area.

With regard to the characteristics of the Payab Jamash watershed and its climate, the Jamash River is categorized as a seasonal river considering its flow regime according to the classification methods, and due to the huge floods that occur in this river (Figure 2).

## 2.2 Data used

The two data series used in the present study are as follows:

1. The daily temperature and precipitation data recorded at the Sarkha weather station, and the daily discharge from the Sarmoghsem Hydrometry station 1984–2011, both of which are located in Payab Jamash watershed.

2. The precipitation and temperature outputs of the four climate models (Table 1) during 1980–2005 and 2006–2100 under the two scenarios of RCP2.6 and RCP8.6 (<https://esgf-node.llnl.gov/projects/cmip5/>).

## 2.3 Hydraulic model

The IHACRES precipitation–runoff model that represents a conceptual-metric binary model was used for transforming the precipitation to runoff. This model, in addition to having the simplicity of the metric models, tries to represent more details of the interior processes of a metric model. The main reason for selecting this model is its efficiency despite its simple structure [39].

The inputs of this model are precipitation, runoff, and a third parameter, which helps to show the effects of evaporation; the temperature or potential evaporation could be regarded as the third parameter (temperature was used for this purpose). The time-step ranged from one minute to a month. In each run of the model, the time-steps of the precipitation and runoff should be the same. In addition, the time-step of the third parameter should be the same as that of the precipitation and temperature [40].

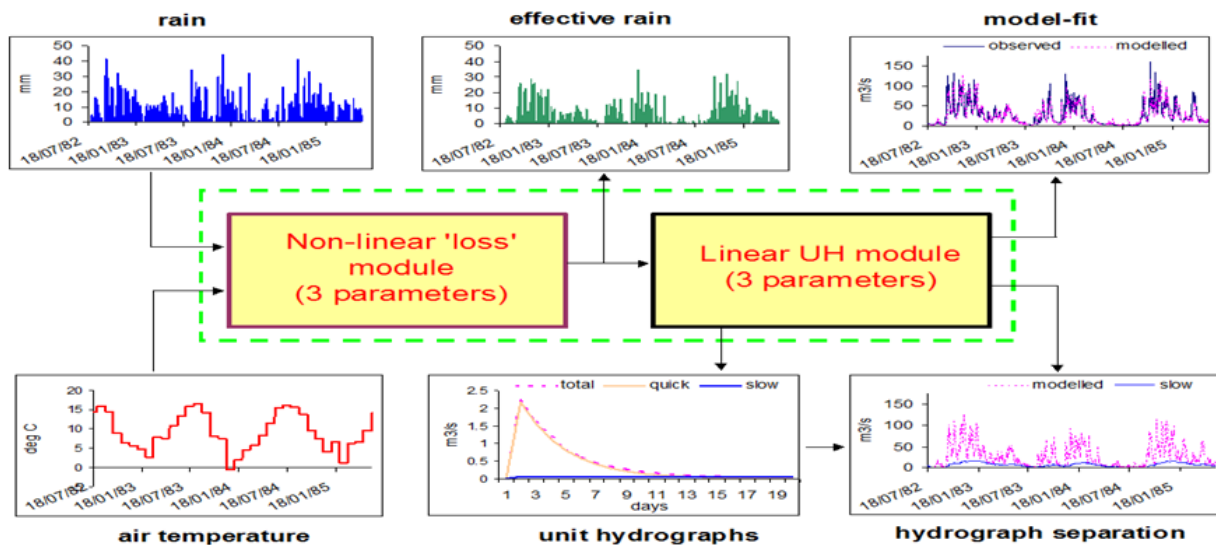
## 2.4 Downscaling

The empirical methods are categorized as statistical methods of downscaling [42]. Bios Correction (BC) is one of the empirical methods [38]. This method assumes that the difference between the observed data and the outputs of the climate models is constant and will be the same in the future [43]. This model can be implemented as follows:

$$X'_O = T_{BC}(X'_M), T_{BC} : \text{calibrated on } X_M \text{ and } X_O \quad (1)$$

Here, the climatic variable during the baseline period is denoted as  $X_O$  and its future projection as  $X'_O$ ; the climate model simulations of this variable are given as  $X_M$  and  $X'_M$  for the baseline and future periods, respectively, and  $T_{BC}$  is the statistical transformation function for the BC method.

Different methods have been presented for calculating the  $T_{BC}$ . In this research, two methods, namely, Mean-based (MB) and Variance-based (VB) methods were used for downscaling the temperature and precipitation data, respectively.



**Figure 3:** Precipitation–runoff simulation using the IHACRES accompanied by the linear and nonlinear modules in the represented method by [41].

#### 2.4.1 Mean-based (MB) method

Initially, the ratio between the average of the observed data and the average of the climate models' output is calculated. Subsequently, the output of the climate models is multiplied by this ratio to produce the downscaled data for the future projections. The equation of the MB method is as follows [44, 45]:

$$\hat{X}_O = \hat{X}_M + \mu_O - \mu_M \quad (2)$$

where  $\hat{X}_O$ , and  $\hat{X}_M$  are the same as Equation 1,  $\mu_O$  is the average of the observed data in the calibration period, and  $\mu_M$  shows the average of the climate models' output in the calibration period.

#### 2.4.2 Variance based (VB) method

In this method, in order to obtain the difference ratio between the observed data and the climate models' outputs, the variance, average, and output of the climate models are implemented. The VB can only be used for precipitation and is calculated as [46, 47]:

$$\hat{X}_O = \frac{(\hat{X}_M - \mu_M)}{\sigma_M} \times \sigma_O + \mu_O \quad (3)$$

where  $\hat{X}_O$ ,  $\hat{X}_M$ ,  $\mu_O$ , and  $\mu_M$  are the same as in aforementioned equations,  $\sigma_O$  shows the standard deviation of the observation, and  $\sigma_M$  shows the standard deviation of the

climate models' output for both calibration periods. To evaluate the efficiency of the downscaling method, mean square error (MRE) was implemented. The MRE can be calculated as follows:

$$MRE = \frac{ABS(X' - X^O)_G}{ABS(X - X^O)_G} \quad (4)$$

where  $X'$  is the downscaled data,  $X^O$  is the observed data, and  $X^{Raw}$  shows the raw data of the GCM. An MRE value close to zero depicts the likeness between the downscaled data and the observed values, and an MRE value of equal to or more than 1 shows the likeness between the downscaled data and the raw data produced by the climate models [47].

**Table 2:** The MRE values of downscaling in each model

| Model       | MRE           |             |
|-------------|---------------|-------------|
|             | Precipitation | Temperature |
| BNU-ESM     | 0.5           | 0.05        |
| CCSM4       | 0.47          | 0.057       |
| CSIRO-Mk3.6 | 0.46          | 0.03        |
| MPI-ESM-MR  | 0.36          | 0.03        |

The highest and lowest values of the MRE in the downscaled precipitation data are associated with the BNU-ESM and MPI-ESM-MR models, where the MRE values are 0.5 and 0.36, respectively, indicating the better efficacy of the MPI-ESM-MR. For temperature downscaling, it can be seen

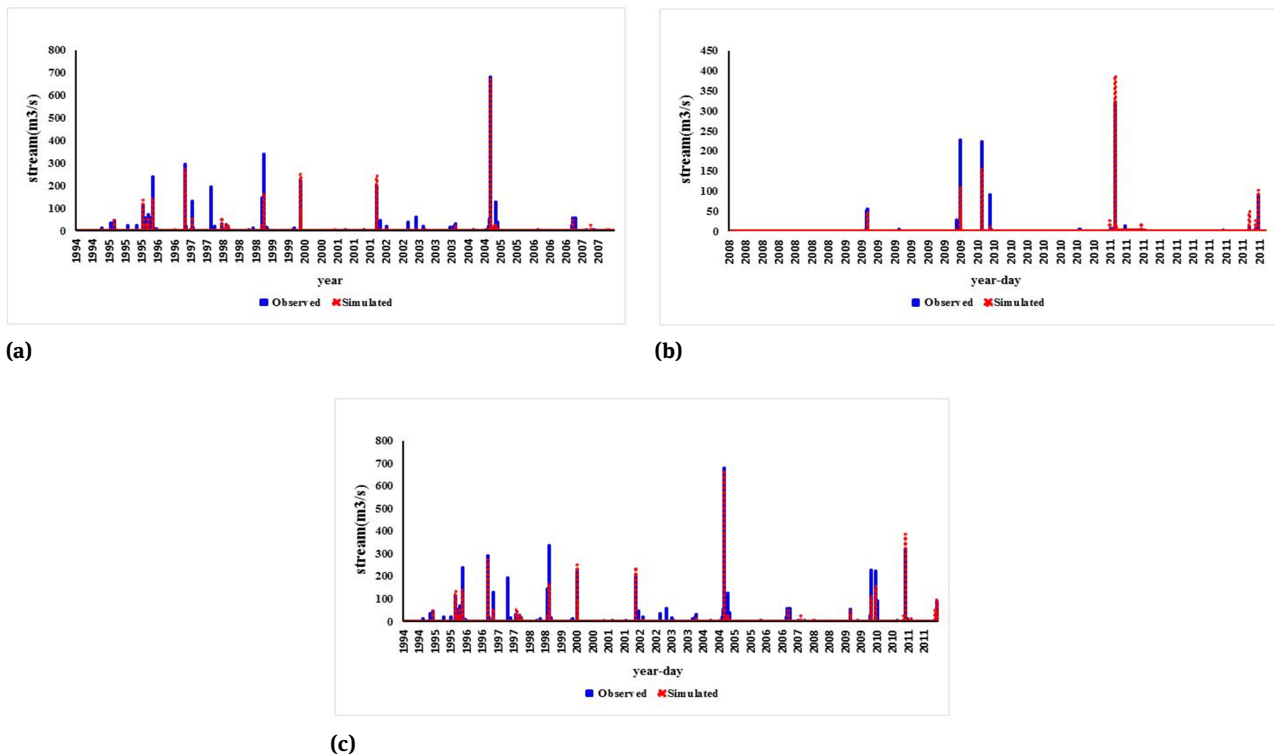


Figure 4: Simulated discharge in Sarmoghsem Hydrometry station for (a) calibration period, (b) validation period, and (c) whole period

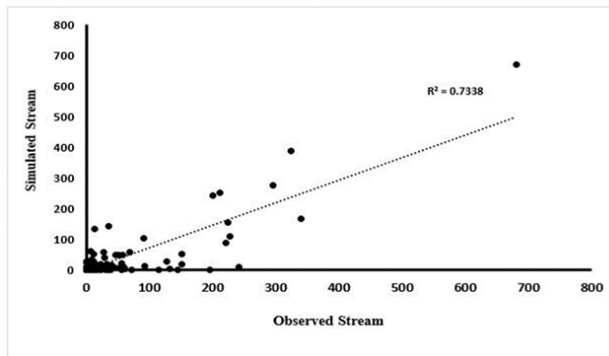


Figure 5: Scatter plot of observed and simulated discharge value

that CSIRO-Mk3.6 and MPI-ESM-M had the weakest performance with the MRE value of 0.03, whereas the CCSM4 had the best efficiency with the MRE value of 0.057.

### 3 Results

It needs to be clarified that in order to calibrate and validate the precipitation–runoff model, the data and observations from the two periods, i.e. 1994–2007 (80%) and 2008–2011 (20%) of the temperature, precipitation, and

discharge of the stations, were implemented. To evaluate the performance of the IHACRES, the two indices of  $R^2$  were used—one for the correlation between the observed and simulated flows, and the second for the flow pattern variations using a higher weight for the maximum flow.

Regarding the  $R$  squared and  $R2\_sqrt$  of the calibration and validation periods, it can be concluded that the IHACRES model has successfully simulated the MDD in the Payab Jamash watershed.

The scatter plot of the observed and simulated discharge values by the IHACRES model has been represented in Figure 5. The  $R^2$  was calculated as 0.73.

#### 3.1 precipitation and Temperature downscaling for the future period

Figures 6 and 7 show the simulated precipitation and temperature until the end of the 21st century for the Payab Jamash watershed using the BNU-ESM, CCSM4, CSIRO-Mk3.6, and MPI-ESM-MR under the minimum and maximum RCP scenarios.

Table 3: Summary of the outputs of the observed and climate models for the reference period

| Model         | Precipitation |         | Temperature |       |
|---------------|---------------|---------|-------------|-------|
|               | Maximum       | Minimum | Maximum     | Mean  |
| CCSM4         | 187           | 1       | 42.47       | 26.90 |
| MPI-ESM-MR    | 137           | 6.2     | 34.14       | 26.92 |
| BNU-ESM       | 145           | 1       | 42          | 26.92 |
| CSIRO-Mk3.6.0 | 116           | 0       | 38.3        | 27.06 |
| Average Model | 146           | 2       | 39          | 26.95 |
| Observed      | 195*          | 10.85   | 38.6        | 26.92 |

\*Note: The maximum recorded precipitation is 311 mm / d, which is a historic data with significant difference with the data afterwards (195 mm / d). Subsequently, the maximum recorded precipitation is 195 mm / day, repeated at least twice during the observation period.

Table 4: The results of calibration and validation for the Sarmoghsem Hydrometry station

| Validation period |         |           | Calibration period |         |           |
|-------------------|---------|-----------|--------------------|---------|-----------|
| Monthly R2        | R2_sqrt | R Squared | Monthly R2         | R2_sqrt | R Squared |
| 0.81              | 0.64    | 0.76      | 0.76               | 0.6     | 0.72      |

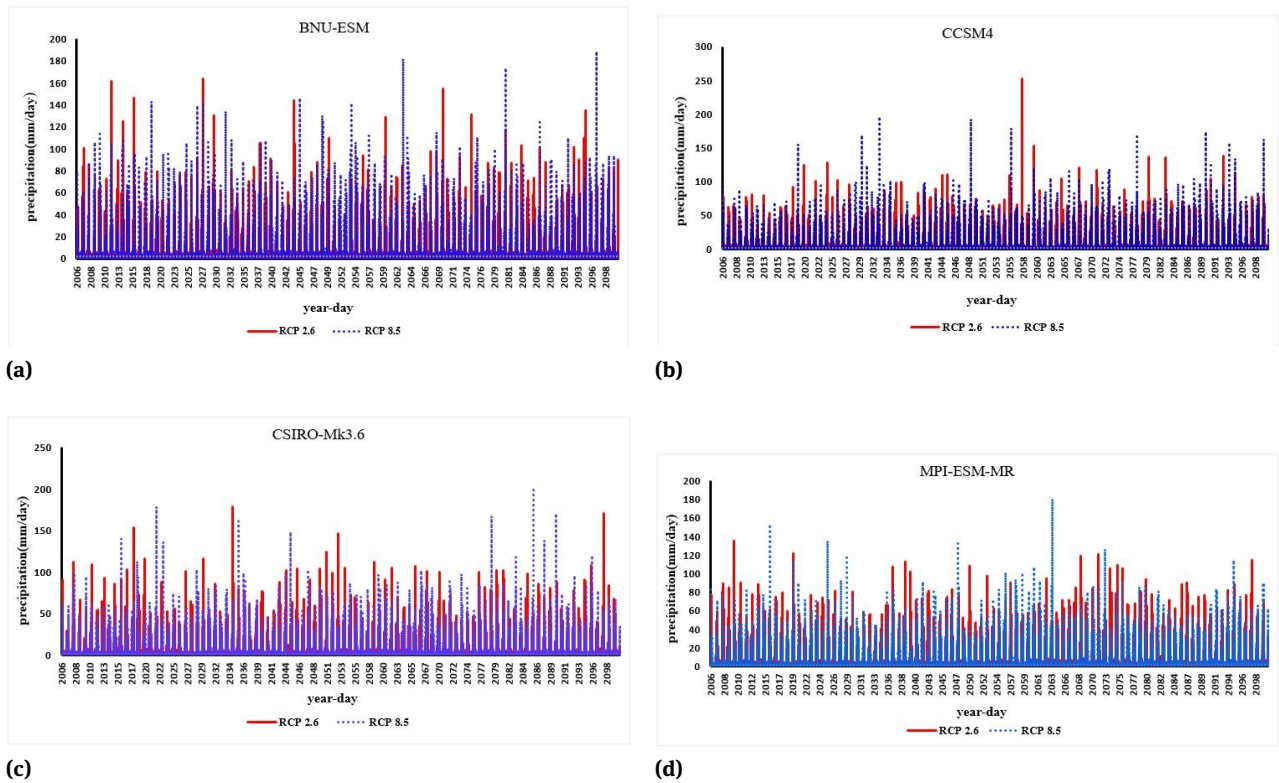


Figure 6: Simulated precipitation for 2016-2100 period in Sarkha weather station

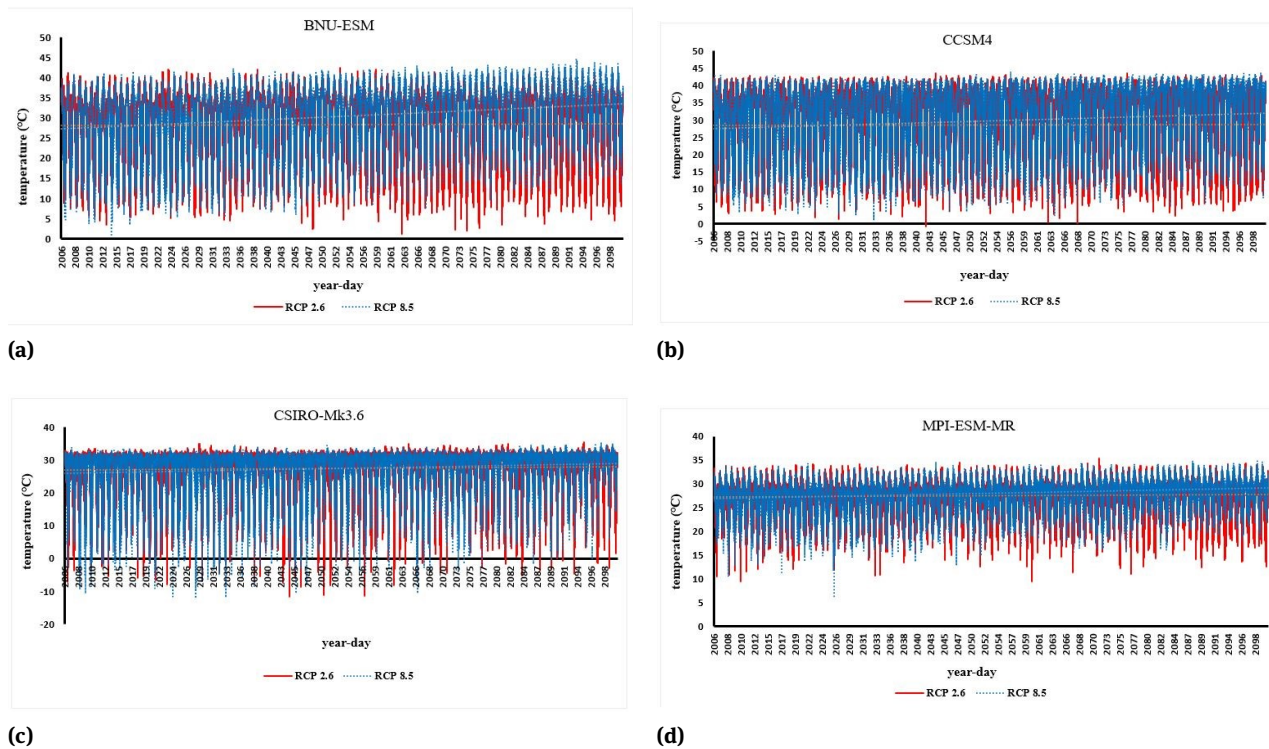


Figure 7: Simulated temperature for 2016–2100 period in Sarkha weather station

Table 5: Summary of the simulated daily precipitation and temperature for 2016–2100 in the Sarkha weather station

| Model/ factor          | Precipitation |        | Temperature |        |         |        |        |        |
|------------------------|---------------|--------|-------------|--------|---------|--------|--------|--------|
|                        | Maximum       |        | Minimum     |        | Maximum |        | Mean   |        |
|                        | RCP2.6        | RCP8.5 | RCP2.6      | RCP8.5 | RCP2.6  | RCP8.5 | RCP2.6 | RCP8.5 |
| CCSM4                  | 269           | 193    | −0.6        | 0.9    | 43.5    | 43.09  | 28.46  | 29.76  |
| MPI-ESM-MR             | 135           | 180    | 9.38        | 6      | 35.33   | 34.85  | 27.51  | 28     |
| BNU-ESM                | 164           | 189    | 1.5         | 1      | 42.5    | 44.70  | 28.43  | 30.43  |
| CSIRO-Mk3.6.0          | 179           | 201    | −11         | −12    | 35.35   | 35.27  | 27.44  | 27.46  |
| Average Model          | 186           | 190    | 0           | −1     | 39.1    | 39.5   | 27.9   | 28.9   |
| Observed               | 195           |        | 10.85       |        | 38.6    |        | 26.92  |        |
| Average Model baseline | 146           |        | 2           |        | 39      |        | 26.95  |        |

### 3.1.1 Precipitation

The comparison of the projected MDP under the RCP2.6 with the RCP8.5 through the utilization of the different models indicates a similar trend in the two models of BNU-ESM and CSIRO-MK3.6 in such a manner that in the beginning of the century, the MDP under the two RCPs are equal, whereas while approaching the end of the century, the MDP predicted by the RCP8.5 is more than the MDP predicted by the RCP2.6. This trend is similar in the CCSM4 and MPI-ESM-MR in such a manner that the predicted precipitation values for the entire century under the RCP2.6

are lower than the values predicted under the RCP8.5. However, there was one exceptional case in the CCSM4, in all the models, where the predicted MDP under the RCP2.6 is lower than RCP8.5 (Table 5). The highest projected MDP was obtained from the CCSM4 under the RCP2.6 with a value of 269 mm/D, whereas the lowest MDP value was obtained from the MPI-ESM-MR under the RCP2.6 with a value of 135 mm/D.

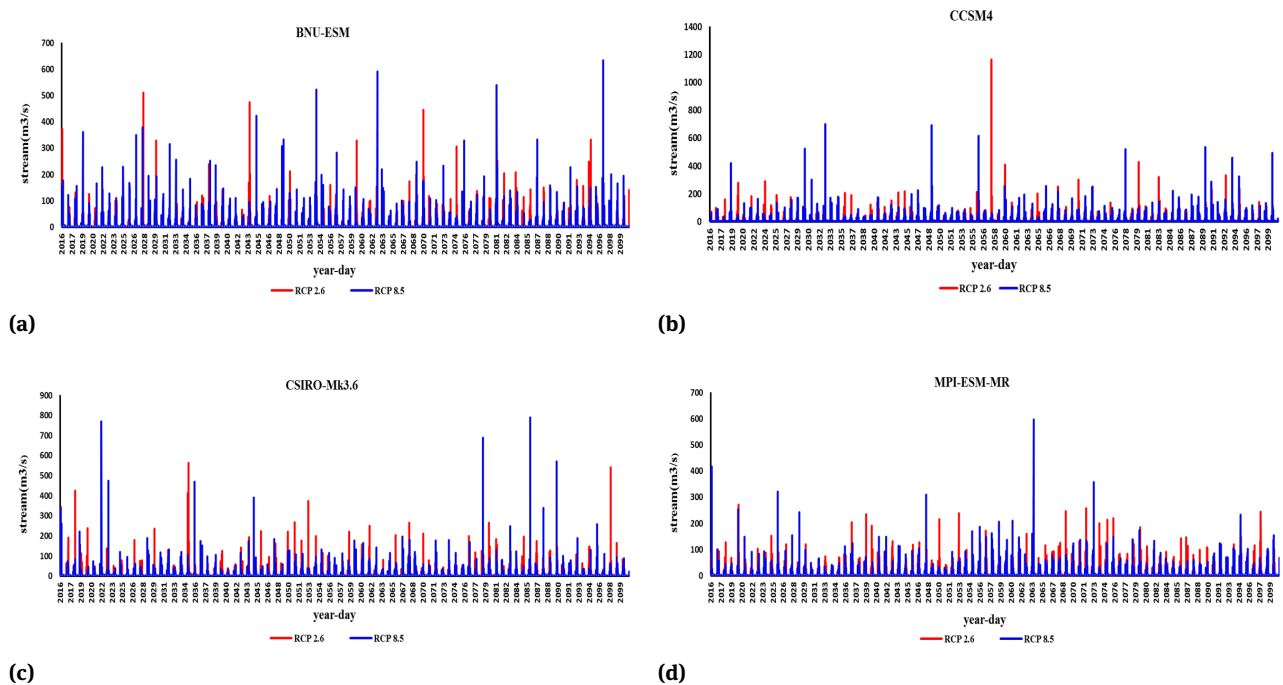


Figure 8: Simulated MDDs in 2006-2100 in Sarmoghsem Hydrometry station

### 3.1.2 Temperature

The projected temperatures obtained from all the climate models in this study under the minimum and maximum RCPs for the 21<sup>st</sup> century show a similar trend in such a way that the temperature increases while approaching the turn of the century. The highest value of the temperature variability was related to the CSIRO-MK3.6, whereas the lowest temperature variability was related to the MPI-ESM-MR model. The maximum predicted temperature was obtained from the BNU-ESM under RCP8.5 with a value of 44.7°C, while the minimum predicted temperature was obtained from the CSIRO-MK3.6 under the RCP8.5 with a value of -12°C. The highest long-term average daily temperature was obtained from the BMU-ESM under the RCP8.5 with a value of 30.43°C and the lowest long-term average daily temperature was calculated by the CSIRO-MK3.6 under the RCP2.6 with a value of 27.44°C. The average of the simulated temperatures under the RCP8.5 was more than the corresponding value under the RCP2.6 for all the models.

Table 6: Statistical summary of the simulated MDDs

| Model         | MDD    |        |
|---------------|--------|--------|
|               | RCP2.6 | RCP8.5 |
| CCSM4         | 1160   | 700    |
| MPI-ESM-MR    | 328    | 597    |
| BNU-ESM       | 510    | 633    |
| CSIRO-Mk3.6.0 | 562    | 787    |
| Average Model | 640    | 679.25 |
| Baseline      | 680*   |        |

Maximum recorded flow data in this station was 1200 m<sup>3</sup>/s that considering its ++ difference with the next discharge (*i.e.* 680 m<sup>3</sup>/s), this was regarded as a historical data. The discharge 680 m<sup>3</sup>/s was the second highest discharge which occurred twice.

### 3.2 Results of the flow simulation in the future period

Figure 8 shows the results of the daily runoff simulation for the Payab Jamash watershed in the 21<sup>st</sup> century using the climate models such as the BNU-ESM, CCSM4, CSIRO-MK3.6, and MPI-ESM-MR under the minimum and maximum scenarios.

The simulated daily discharge obtained through implementing the outputs of the climate models in the Payab

Jamash watershed was in conjunction with the projected precipitation. While the average simulated MDD of models based on RCP8.5 is very close to the baseline, the average MDD is reduced based on RCP2.6. The simulated MDDs under the RCP2.6, except for one case in the case of the CCSM4 model, are lower than those under the RCP8.5 (Table 6). The highest simulated MDD was obtained by the CCSM4 model under the RCP2.6 with a value of 1160 m<sup>3</sup>/s and the lowest MDD was related to MPI-ESM-MR under the RCP2.6 with a value of 328 m<sup>3</sup>/s. The highest simulated MDD based on the CCSM4 model probably is due to model uncertainties because, in a warmer climate, more intense hydrologic behavior is expected.

## 4 Conclusion

This study investigated the MDD till the end of the 21<sup>st</sup> century. For the study, four climate models were implemented to project the precipitation and temperature, and meanwhile, the IHACRES was utilized to simulate the runoff. Regarding the distribution type of the daily data, the BC method was selected for downscaling the GCM outputs [39]. The value of the mean relative error for the results of the downscaling indicates its acceptable performance.

The climate models predict the climatic variables for the future considering the RCPs, which are the indicators of the greenhouse gases emissions. The increase in the greenhouse gases emissions results in the increase in the temperature all over the world, though, in the case of precipitation, in some places, it increases, whereas in other places it decreases [3].

The results of this study, conducted by using various climate models, indicated an increase in the temperature and a decrease in the average maximum precipitation for the 21<sup>st</sup> century under both RCPs. In all the climate models, the average of the predicted temperatures under the RCP8.5 was more than its value under the RCP2.6. The average of the maximum precipitation values predicted by the climate models under the RCP2.6 was 186 mm/D, whereas its value under that in the case of RCP8.5 was 190 mm/D.

Since Jamash is a seasonal river, its flow regime is also seasonal and it is highly influenced by the maximum precipitation. The findings from the predicted precipitation indicated a decrease in the maximum precipitation and an increase in the temperature values under both RCPs; therefore, the flow simulation for the future also showed a decrease in the MDD compared with the historical period. With regard to the precipitation amounts under the two

RCPs of minimum and maximum, the magnitude of MDD decrement predicted for these two RCPs were different. The amount of decrease in the average MDD projected under the RCP2.6 compared to the historical period was more than its peer under the RCP8.5. Reducing the runoff and the MDD. One of the perceptible systems of the study area is the thermodynamic Asian Monsoon that probably under extreme RCP8.5 is going to be stronger, consequently, intensifying the MDP of the study area in summer, though it needs more research and investigation.

Reducing the MDD and increasing temporal changes made it necessary to pay more attention to water reservoir, ecosystems, drought, flood spreading, and soil erosion management of the study area.

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