Climate Change Runoff Modeling using MIKE 11 in Temperate Himalayan Region, India

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Abstract

The aim of the present study was to simulate the rainfall-runoff process under changing climate using MIKE 11 rainfall-runoff model of the river Jhelum flowing through Srinagar city. The model was calibrated for the years 2006-2009 and validated for the year 2010-2013. The maximum discharge during the simulation period was found to be 746.745 m^3/s. The MIKE 11 statistical results between observed and simulated discharge for the calibration period showed Nash-Sutcliffe Efficiency (N_{SE}) equal to 0.907, the Coefficient of Determination (R^2) equal to 0.954 and Volume Difference (D_v%) equal to 17.8% respectively. For the validation years of 2010-2013, the obtained N_{SE} was 0.963, the R^2 obtained was 0.892 and Dv% obtained was 13.2% respectively. The simulated results were used for climate change detection using IPCC's SRA1B and SRA2 scenario with the increase of 2.8º C temperature. In the SRA1B scenario, the maximum discharge was found to be 856.399 m^3/s and in the SRA2 scenario, the maximum discharge was found to be 950.745 m^3/s. The climate change detection shows that there is a great difference on carrying capacity and distinct increase in runoff when the temperature rises by 2.8º C and since the drainage capacity of river Jhelum has reduced, therefore, flood threats will increase. This research demonstrates the utility of the established model for runoff prediction in Srinagar, which can be used as an application for basin-scale integrated water resource management and production. Thus, the model can be successfully used for hydrological simulations in temperate catchments for effective water resource planning and management.

1 Introduction

Water is the utmost valuable natural resource for human & animal life [1] and plays a key role in the maturation of plants [2]. Water resources play an important role as a catalyst for the economical development of a nation. Consequently, it is mandatory to develop, conserve, utilize and economically utilize this crucial resource on an integrated basis so as to achieve the ever-growing demand for agriculture, industry, domestic use and generation of electricity. Quick urbanization carries the gigantic negative impact to inland surface water (lakes, streams and wetlands). Urbanization causes river contamination and the contaminated waterway in invert limits the practical improvement of local economy of quick urbanization. Water quality has decayed in most of the significant streams inconsequence of urbanization, industrialization and populace development along waterways. Seasonal variation of stream flows has also experienced exceptional changes.

Wetlands engulf 6% of the world's land surface and bear about 12% of the global carbon pool, which is a vital part of the global carbon cycle [3–4].The changes due to hydrological influences on wetlands have certainly been more sensational than other effects. Hydrologic changes have enormous and prompt implications for the physical state of a wetland, like the depth, duration, and recurrence of immersion of the wetland. Unlimited control over the presence and characteristics of a wetland can be attributed to the changes in hydrology brought on by urbanization. The surface overflow is likely to increase wetland inflow velocities, which will disrupt wetland biota and scour wetland substrates. Expanded storm water runoff controls in wetlands change the reaction times, depths, and period of water containment at the water level [5–6].

Due to urbanization, the expansion of artificial surfaces induces an expansion of flood recurrence due to low penetration and reduction of stream obstruction. Furthermore, the hydro meteorological changes driven by urbanization and the resulting effects of extraordinary precipitation are being created. In the last twenty years, a lot of research has shown a close link between urban regions and surrounding microclimates. The influence of the "urban heat island" (UHI) is currently ingrained, with urban areas having higher temperatures than the surrounding areas. UHI can increase the precipitation in the region of the urban areas. In the areas downwind of urban centers, multiple studies have found a rise in precipitation, with rises as high as 25% at times [7–8].

Therefore, a need to manage water resources properly and hydrological modeling is the most common way. In the sense of flood control, drought and irrigation under climate change and urbanization, hydrological modeling is important for better water resource management, but is very difficult due to the variability of streamflows. The hydrological models are usually designed on the basis of rainfall-runoff and snowmelt-runoff and in majority of cases models primarily follow either of the two mentioned algorithms. Runoff simulation helps to gain a deeper understanding of hydrological dynamics and how modifications influence the hydrological cycle [9]. Runoff models anticipate what happens in water environments due to changes in existing surfaces, vegetation and meteorological events. The Runoff model is essentially a collection of equations that help to determine the amount of rainfall that becomes runoff as a result of various parameters used to characterize a watershed [10]. The Danish Hydraulic Institute (DHI) is one of the world's leading developers of software for integrating time series data related to water supplies into modeling. MIKE 11 stands for top-quality river modeling that encompasses more application areas than any other available river modeling kit. Whether the projects deal with floods, navigation, water quality, forecasting, sediment transport, a mix of these or other aspects of river engineering, MIKE 11 handles it. Options for researching river bank overflow and catchment hydrology are also included in MIKE 11.

Madsen [11] applied MIKE 11 NAM model following automatic calibration strategy. He used an automated method of optimization based on a shuffled algorithm of complex evolution. The scheme optimizes four separate calibration targets for numerical performance measures: overall water balance, hydrograph overall shape, peak flows, and low flows. An automated optimization process can therefore be implemented to solve the problems of multi-objective calibration. Shamsudin and Hashim [12] substantiated MIKE 11 NAM model for rainfall-runoff simulation in Layang River in Malaysia. With approximate values of 20.94 m^3/s and 18.93 m^3/s sequentially, the simulated peak flow occurred in 1992 and 1995. Optimum values were presented for the model parameters obtained during the calibration process. On the Efficiency Index (EI) and Root Mean Square Error (RMSE), the reliability of MIKE11 NAM was assessed. The EI and RMSE obtained during this research are respectively 0.75 and 0.08. Doulgeris *et al.* [13] substantiated MIKE 11 NAM model Strymonas river catchment in Greece. Optimal calibration was done using meteorological and discharge data, using three different model setups. Hafezparast *et al*

[13] applied the auto calibrated MIKE 11 NAM model in the Sarisoo River Basin on the North West of Iran. Using measured stream flow data; the model was calibrated and then tested for three years. Based on the Nash-Sutcliffe coefficient and Root Mean Square Error, the reliability of MIKE 11 NAM was evaluated. The R^2 obtained during the analysis was 0.74. Ashutosh *et al.* [15] evaluated the MIKE 11 NAM model for Vanyakpur catchment, Chattisgarh, India. The model was calibrated and validated using measured stream flow data from 2001 to2004, and then from 2005 to 2007. To provide a satisfactory estimate, the calibration and validation procedures were carried out. The simulated runoff reached its highest point in August (1681.63 cumecs) and its lowest point in April (84.14 cumecs). For simulation, the optimum values of nine NAM model parameters obtained during the calibration procedure were used. The Nash-Sutcliffe coefficient, correlation coefficient (R^2), and root mean square error were used to assess the MIKE 11 NAM's reliability (RMSE). Model calibration and validation R^2 values were found to be 0.79 and 0.75, respectively. Kumar *et al.* [16] evaluated the MIKE 11 NAM rainfall-runoff model for the Arpa river basin in Chattisgarh, India. The calibration and validation results show that this model is capable to define the rainfall runoff process of the basin and thus predicting daily runoff. Teshome *et al.* [17].verified the MIKE 11 NAM model for simulating streamflow in Madhya Pradesh, India. In the study, the model performed quite well during calibration and validation period. The model performance was found to be satisfactory based on coefficient of determination and efficiency index. Bami *et al.* [18] used MIKE NAM rainfall runoff model in daily flow simulations in Goband catchment, Hamedan. Flow rate data from three hydrometric stations in the Gonbad catchment were used to calibrate and validate the NAM model. Percent bias (PBIAS) and the coefficient of determination (Nash-Sutcliffe coefficient) were used to assess the model's efficiency. During calibration, NSEs of 0.80, 0.89, and 080 were obtained, while NSEs of 0.81, 0.87, and 0.71 were obtained for the Nemooneh sub catchment, Shahed sub catchment, and Gonbad catchment, respectively, during the validation phase. For the Nemooneh sub catchment, Shahed sub catchment, and Gonbad catchment, respectively, percent biases of -0.6, 1.5, and 6.3 were obtained during calibration, and − 2.7, 7.6, and − 4.2 were obtained during validation. Aredo *et al.* [21] used (MIKE 11) model in Shaya catchment, Ethiopia to model the rainfall-runoff process. Thus, in this study, MIKE 11 was used to simulate the hydrological response of the River Jhelum which flows through Srinagar. The rainfall runoff was simulated for the Ram Munshi Bagh catchment and the corresponding climate change analysis was also carried out to study the impact of changing climate on the discharge and accumulated runoff in the said catchment.

2 Study Area

The present study was conducted at Ram Munshi Bagh catchment located in Srinagar city, which is centrally located in the Kashmir region. It is located between 34 ° 0 'N to 34 °15' N latitude and 74 ° 45 'E to 75 °0' E longitude. It has a catchment area of 5490 km^2. It is located (Jhelum basin) lies between 32°58'42" to 35°08'02" north latitude and 73°23'32" to 75°35'57" east longitude. The channel has a total length of 44 km and functions only when the discharge in the river rises above the danger mark. The detail of location is illustrated in Fig. 1.

3 Mike 11 Rainfall-runoff

The rainfall runoff editor in MIKE 11 provides the following functions:

- Input and editing of rainfall runoff computational parameters.
- Specification of time series on time series page within the RR editor.
- Calculation of catchment rainfall.

There are various RR modules available in MIKE 11. For the present study, urban time/area method was used for rainfall runoff computation which is given in Fig. 2.

3.1 Urban Time/Area Method

The runoff computation method of urban time/area offers a hydrograph with a user-specified concentration time and is sufficient for large urban catchments and rural catchments. It is designated as a Model A Urban Runoff. The runoff is governed here by the initial loss, the size of the contributing area and the continuous loss of the hydrograph. The runoff hygrograph's form is controlled by the time of concentration and the time-area curve. A mathematical definition of the catchment reaction speed and the shape of the catchment are described by these two parameters.

3.2 Parameters of Urban Runoff Model

The impermeable region reflects the reduced area of catchment that leads to surface runoff.

Time of Concentration

Concentration time determines the time needed for the flow of water to the point of outflow from the most distant part of the watershed. Kirchip gave one of the empirical relationships used in measuring the time of concentration [20] given as
$t_o = 0.0195L^{0.77} S^{-0.382}$ (1)

Where

t_o is overland flow time in minutes

S is the slope

L is the maximum distance of travel of water along the watercourse (m)

Initial Loss

Initial loss is characterized as the depth of precipitation that is essential to start the runoff process. It is one-off loss, comprising the wetting and filling of depressions.

Reduction Factor

The reduction factor of runoff accounts for water losses caused by evapotranspiration, the contributing region being imperfectly impervious.

Time/Area Curve

The type of the catchment layout is accounted for and the choice of the available T/A curve to be used in the calculation is calculated. There are three types of usable T/A curves:

- Rectangular Catchment
- Divergent catchment, which is widest at outlet
- Convergent catchment, which is widest at its head

3.4 Input Data

The required inputs for MIKE 11 model applied in this study are daily precipitation and daily discharge. The daily discharge data for the year 2006–2013 was collected from Irrigation and Flood Control Department, Srinagar. The daily precipitation data was collected from Meteorological Department, Srinagar. This knowledge was needed for the model calibration and validation and subsequent climate change scenario predictions. Data for hydrological year 2006–2009 was used for calibration of the model and the data while the data 2010–2013 were used for validation of the model.

3.5 Model Parameters

The input parameters for MIKE 11 include: Time of Concentration, Initial Loss, Reduction Factor, Time Area Curve Number, Impervious Area, and Model Type.

3.6 Assessment of Model Accuracy

Three statistical indicators have been used to test the model accuracy criteria which are as follows: Nash-Sutcliffe Efficiency (N_{SE}), Coefficient of Determination (R^2) and Deviation volume (Dv %).

3.6.1 Nash Sutcliffe Efficiency Coefficient

The Nash-Sutcliffe Efficiency (NSE) is a standardized statistical measure that specifies the relative extent of the residual variance compared to the data variance measured [21]. The NSE is determined as follows:

$$\mathrm{NSE} = 1 - \frac{\sum_{\mathrm{i}=1}^{\mathrm{n}} \left(\mathrm{Obs_i} - \mathrm{Sim_i}\right)}{\sum_{\mathrm{i}=1}^{\mathrm{n}} \left(\mathrm{Obs_i} - \overline{\mathrm{Obs}}\right)}$$

2

Where:

Obs_i is the observation value

Sim_i is the forecast value

$\overline{Obs}$ is the average of observation values

3.6.2 Coefficient of Determination (R^2)

The correlation of R^2 determines how well the regression model fits the results. The coefficient of determination, R^2, is identical to the coefficient of correlation, R. The formula of the correlation coefficient will tell you how effective a linear relationship is between two variables. R^2 is the square of the coefficient of correlation. You need to calculate the Pearson correlation and then square it in order to calculate R^2. The coefficient of determination is computed as follows:

$$\mathrm{R} \ = \frac{\sum_{i=1}^{n}(\mathrm{Obs_i} - \bar{\mathrm{O}}\mathrm{b_s})(\mathrm{Sim_i} - \bar{\mathrm{S}}\mathrm{im_i})}{\sqrt{\sum_{i=1}^{n}(\mathrm{Obs_i} - \bar{\mathrm{O}}\mathrm{b_s})}\ \sqrt{\sum_{i=1}^{n}(\mathrm{Sim_i} - \bar{\mathrm{S}}\mathrm{im_i})}^{2}}$$

3

Where:

Obs_i is the observation value

Sim_i is the forecast value

$\bar{S}im_i$ is the average of forecast values

$\overline{Obs}$ is the average of observation values

3.6.3 Percent Volume Difference (D_v)

Perhaps the simplest goodness-fit criterion is the variance of runoff volumes Dv, also known as the percentage bias. The variance of runoff volumes is equal to zero for a perfect model. The smaller the value of variance runoff volumes, the better the model’s efficiency. The percent volume difference can be computed as follows:

$$\mathrm{D_v}\backslash\% = \frac{\sum_{i=1}^{n}(\mathrm{S_i} - \mathrm{O_i})}{\sum_{i=1}^{n}\mathrm{O_i}} \times 100$$

4

Where:

O_i is the observed value

S_i is the simulated value

3.7 Climate Change Impact Detection

In the current study, the climate change analysis was conducted on the basis of the delta change factor approach using the MIKE climate change tool. Using MIKE tools, it is possible to create climate change scenarios. Workability depends on the work mentioned in the Fourth Assessment Report by the Intergovernmental Panel for Climate Change (IPCC-AR4). The climate change forecasts are taken directly from the work of the IPCC, and thus no climate model is used in the MIKE program.

In the so-called delta change factor process, estimates of climate variables are built. Factors of delta change indicate how much a certain variable will shift with respect to a baseline period (reference). According to the geographical position and the projection year, the MIKE climate change scenario tool modifies the time series of precipitation, temperature and possible evapotranspiration. The change factors are derived from the climate model projections for multiple emission scenarios.

Air temperature, precipitation, as well as air temperature and precipitation anomalies are GCM results recorded by the IPCC, which are defined as deviations from the reference values taken as an average over the years 1961–1990. These forecasts of anomalies are in the form of absolute shifts. The data is temporally and spatially varied. Using grid values, the former is shielded, while the latter is defined by an average per month value.

A number of emission scenarios which have been used as an input to GCMs have been identified by the IPCC. MIKE software contains findings of popular scenarios. The two scenarios that the IPCC has described are:

- **SRA1B**: The A1 storyline portrays a future world with very fast economic development, a world population that will peak in the middle of the century and then decrease and modern and very effective technology will be rapidly implemented. The overall production of energy sources would be balanced in this storyline. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three groups are distinguished by their technological emphasis and the A1B group defines a balance across all sources. Balanced here is defined as not relying too heavily on one particular energy source.
- **SRA2**: The A2 storyline portrays a world with a growing population that will be heterogeneous. Economic development will be regionally driven, but relative to the other storylines, it will be rather slower.

Any subset of GCMs and emission scenarios can be made feasible by MIKE software. If more than one GCM is used, factors of delta change will be taken as the average over the selected GCMs.

Air Temperature

Air temperature anomalies are given as delta-change grid values, i.e., the values reflect absolute deviations from the reference values. In the MIKE model, at any geo-referenced location represented by latitude and longitude coordinate set, the temperature delta change values are taken. This bilinear interpolation is done from the grid values to the determined position in order to achieve this. In addition to estimating the values of any future year, the data is interpolated between the layers linearly.

Precipitation

Within a modeling area, precipitation amounts can differ dramatically. This variation is on a sub-scale that the coarse grid used by the GCMs does not represent. The delta change values have been translated to relative changes within each of the grid cells to compensate for the sub scale variance. This is achieved by using the absolute change in precipitation and the absolute precipitation given for the potential precipitation scenario as:

$$\Delta\, \text{precipitation}_{\text{relative}} = \frac{\text{precipitation}_{\text{scenario}}}{\text{precipitation}_{\text{scenario}} - \Delta \text{precipitation}}$$

A relative change is not fair if the reference precipitation is equal to zero, and thus the relative precipitation is set equal to 1. In addition, if the reference precipitation is very low, the relative change can become very high and an upper limit on the relative change of 5 is therefore imposed.

The MIKE climate change tool duplicates the current configuration and then modifies the time series of climate data, selected GCMs and emission scenarios according to a given future year. In order to determine the potential consequences of climate change, the original time series are then replaced by certain time series in the model reflecting the climate change scenario. The time series adjustment is carried out as follows: a set of 12 change factors is estimated on the basis of the following: latitude and longitude, GCM chosen, year of prediction and emission scenario.

If the time series is temperature, inside the time series, the adjustment factors should be applied to the individual values. The change factors should be multiplied within the time series with the individual values whether the time series is precipitation or possible evapotranspiration.

Therefore, we used described the future climate change scenarios by using the delta change factors of temperature and precipitation using the MIKE climate change tool. The following scenarios have been used for climate change analysis:

- The output of SRA1B and SRA2 scenario was considered (mean temperature and precipitation was changed based on delta change factor method).

4 Results

MIKE 11 simulated the hydrological response of the River Jhelum which flows through Srinagar. The rainfall runoff was simulated for the Ram Munshi Bagh catchment. It is very important to calibrate the model first and for that purpose, the initial values of the model must be set. It is a tedious task to set the initial parameters if sufficient data is not available. Due to the lack of data, the initial parameters were thus calibrated from the range of the values provided in the reference manuals of MIKE 11.

4.1 MIKE 11 Hydrological Simulation

Daily runoff simulations of the year 2006–2009 were carried out after calibrating the model for the said years. For model validation, the years 2010–2013 were chosen. For modeling of runoff, the model requires six input parameters and two variables including the daily precipitation and daily discharge.

4.2 Model Calibration

Model calibration is essential and appropriate for measuring the model's output and for seeing how similar the simulated values are to the values observed. In order to get the best match between the simulated and observed values, the model requires tuning. This is possible through the calibration process. Through the discharge measuring station at Ram Munshi Bagh, Srinagar, the data observed was collected. For the year 2006–2009, model results were obtained. Table 1 summarizes the various model parameters. Table 2 summarizes the calibrated model parameters.

Table 1
Range of MIKE 11 Parameters (MIKE 11 Manual, 2008)

Parameters	**Range**
Time of Concentration	No Range
Initial Loss	0.6-1 mm
Reduction Factor	0.9-1
Time Area Curve Number	1–3
Impervious Area	0-100 percent
Model Type	A-B

Table 2
MIKE 11 Final Parameters for Rainfall Runoff Model

Parameters	**Calibrated Values**
Time of Concentration	25 minutes
Initial Loss	0.6 mm
Reduction Factor	0.9
Time Area Curve Number	2
Impervious Area	80 percent
Model Type	A

The comparison between the observed discharge and the simulated discharge for the calibration period are summarized in the Table 3. It is very evident from the table that the maximum runoff was observed in the year 2006 and the minimum runoff was observed in the year 2008.The calibrated results of simulated runoff and observed runoff are presented in Fig. 3 for the year 2006–2009.

Table 3
Simulation results of maximum runoff for the calibration run for the year 2006–2009

	Hydrological Year	Observed Discharge (m^3/s)	Simulated Discharge (m^3/s)
Calibration Period	2006	706.483	684.215
	2007	537.7	484.128
	2008	263.19	244.93
	2009	355.83	300.184

4.3 Model Validation

After calibration, the model needs to be verified or validated. For this, the corresponding values of discharge and precipitation are to be changed but the parameters calibrated remain the same. The model was validated for the years 2010–2013. The validated results between the simulated values of the model and the observed values are summarized in the Table 4.

Table 4
Simulation results of maximum runoff for the validation run for the year 2010–2013

	Hydrological Year	Observed Discharge (m^3/s)	Simulated Discharge (m^3/s)
Validation Period	2010	736.23	498.993
	2011	706.483	454.698
	2012	746.745	414.778
	2013	537.7	389.189

It is shown in Table 4 that the observed and the simulated values for runoff are in close agreement and model performance is good. The validated results of simulated runoff and observed runoff are presented in Fig. 4 for the year 2010–2013.

4.4 Regression Analysis

The statistical method for evaluating the relation between a dependent variable and an independent variable is regression analysis. Regression analysis can result in graphs which may be either linear or non linear. When relationship between two variables is linear, it is called as linear regression. Regression analysis is used for finding equations that will fit the data. Regression equation thus obtained can be used to make predictions. One way of showing the relation between two numerical variables is the scatter plot. Coefficient of Determination (R^2) tells us how well the regression model fits the data. The higher the R^2 value, the better the fit is. The scatter plot of runoff for the calibration period and validation period, showing a strong agreement between observed and simulated values, is represented in Figs. 5–6.

4.5 Performance Indicators

Model performance was evaluated during calibration and validation periods using various indicators summarized in Table 5. The model simulates reasonably discharge in most conditions. The statistical indicators that were used to test the model accuracy criteria are as follows: Nash-Sutcliffe Efficiency (N_{SE}), Coefficient of Determination (R^2) and Deviation volume (Dv %). The results are presented in Table 5. The R^2 and Dv % and NSE values shown good agreement between model and simulated during calibration and validation periods. Model does not exhibit any bias towards the calibration period and validation period. The results show that the model has performed efficiently and can be used for predicting the runoff for future scenarios.

Table 5
Performance indicators for the calibration and validation period

Performance Indicator	Calibration Period (2006–2009)	Validation Period (2010–2013)
Nash-Sutcliffe Efficiency (N_{SE})	0.907	0.963
Coefficient of Determination (R^2)	0.954	0.892
Deviation Volume (Dv%)	17.8	13.2

4.6 Climate Change Run Using MIKE 11 Model

In the study model (MIKE 11) has been used to evaluate the runoff and accumulated runoff under changing climate. The current study makes use of the MIKE 11 model to simulate the discharge and accumulated runoff depicting a scenario of rising temperature. The delta change factors of precipitation in SRA1B scenario change on an average of delta change factors ranging from 0.8–1.4 while in SRA2 scenario, the delta change factors range from 0.6–1.3 (Fig. 7). The climate change scenario used was increased of 0.28º C per decade leading to overall temperature rise of 2.8 º C under SRA1B and SRA2 scenario (Fig. 8). When these delta change factors are multiplied with the precipitation, we will see that the lower precipitation values will become lower and where the precipitation is high, it will become higher. This means in the future, the precipitation will be of higher intensity but the number of days of precipitation will be lesser as compared to today. The delta change factors of temperature in SRA1B scenario change on an average of delta change factors ranging from 1–4 while in SRA2 scenario, the delta change factors range from 1–6. When these delta change factors are added to the temperature values, it will result in an increase in the both maximum and minimum temperature. This means in the future, the overall temperature will be high; there will be lesser colder days and more hot days.

The climate change impact under SRA1B scenario and SRA2 scenario is evaluated using simulation (validation) of the year 2013. Discharge simulated for the hydrological year 2013 is used as current discharge. The maximum discharge observed for the year 2013 was 746.23 m^3/s. The discharge simulated under increase in temperature is summarized in the Table 6.

Table 6
Climate change run of MIKE 11 with change in temperature

Simulated Discharge of year 2013 (m^3/s)	**IPCC Scenario**	**Simulated Discharge with 0.28º C per decade increase in temperature (m^3/s)**
746.23	SRA1B	856.399
	SRA2	950.745

It is evident from the Table 6 that with the overall rise in temperature by 2.8º C, the streamflow is expected to increase up to 950.745 m^3/s. If the trend of increasing temperature continues, then it will be become very difficult to manage the stream flow considering the current discharge at Ram Munshi Bagh catchment as shown in Fig. 9.

5. Discussion

The way a catchment responds when it is exposed to precipitation is a hydrological response. Hydrological response is important when it comes to inland surface waters. In case of heavy and torrential rains, the hydrological response of the catchment will be such that there is more runoff and thus the discharge and the corresponding gauge water level of inland surface waters will increase. Urbanization in the form of urban sprawl and climate change affects the hydrological response of a catchment by altering the precipitation intensity and the precipitation depth. These change the runoff generated from a catchment which has a direct impact on the stream flows and the corresponding gauge water level.

In the aforementioned study, the hydrological response of River Jhelum in which all of the inland surface waters of Srinagar drain was simulated. The parameter representing the hydrological response was runoff. The simulation was done using the MIKE 11 model for the present time conditions and was predicted for the future years based on the present trend of urban sprawl and consequent climate change. For efficient simulation and improving the model accuracy, calibration and validation of the model were performed. The calibration was performed for four years from 2006–2009 and validation was performed for the years 2010–2013.

The model parameters for runoff estimation during calibration were set in order to get the best possible results. The highest discharge at Ram Munshi Bagh station was found to be 706.438 m^3/s and the lowest was found to be 263.19 m^3/s during the calibration period. The simulated results were in close agreement with the observed values as is evident from the statistical indicators like Nash Sutcliffe Efficiency (NSE), Coefficient of Determination (R^2) and Deviation Volume (Dv%). The NSE for runoff was found to be 0.907, R^2 was found to be 0.954 and Dv% was found to be 17.8%. The statistical indicators suggest that the model performed efficiently for the calibration period and thus can be used for predicting scenarios and verification.

During validation, the parameters that were calibrated were kept unchanged in order to verify the model for the year 2010–2013. The statistical indicators showed that the model performed efficiently in the validation period too. The NSE for runoff was found to be 0.963, R^2 was found to be 0.892 and D_v% was found to be 13.2%. In the present time conditions, the hydrological response is not posing a serious threat to the urban living conditions and the environment as the discharge and gauge water level at Ram Munshi Bagh station present accepted values in accordance with the carrying capacity of the River Jhelum in Srinagar. The flood threat is vulnerable if the discharge goes beyond 710 m^3/s as due to the 2014 floods; the carrying capacity of River Jhelum in Srinagar fell below 710 m^3/s (Jhelum-Tawi Flood Recovery Project Report) and thus discharge above or near to it can pose a threat of flood which can become a catastrophe like the deluge of 2014. In order to see the combined effect of urban sprawl and climate change on the hydrological response, future predictions have been done from the year 2020–2100. The runoff, accumulated runoff and gauge water levels for the future time periods have been predicted too see how adverse the urban sprawl and climate change can make the hydrological response.

Keeping in view the future scenarios, the baseline was chosen from the year 2013. The future predictions were made on the basis of IPCC’s emission scenarios, i.e., SRA1B and SRA2. Firstly, the runoff was predicted from the baseline period which shows the maximum runoff as 746.48 m^3/s in the month of April to May. In the SRA1B scenario, the maximum discharge was found to be 856.399 m^3/s and in the SRA2 scenario, the maximum discharge was found to be 950.745 m^3/s.

It is quiet discernable from the results of future scenarios that the hydrological response of the River Jhelum flowing through Srinagar will change because of the urban sprawl and continuous climate change threat. The increase in runoff will have an adverse effect on the stream flow and thus flood threat will be inevitable.

6. Conclusion

The study demonstrates the utility of the established model for runoff prediction in Srinagar, which can be used as an application for basin-scale integrated water resource management and production. In this study, MIKE 11 was used for modeling of rainfall-runoff under changing climate. The results indicate that the model is efficient for simulating hydrologic response of the river. The climate change run shows that there is a great difference on carrying capacity, gauge water level and distinct increase in runoff when the temperature rises by 2.8º C and since the drainage capacity of river Jhelum has reduced, therefore, flood threats will increase. Using the locally available data, the MIKE 11 Urban Time/Area model accurately simulated the hydrological characteristics of the Srinagar catchment, including runoff and accumulated runoff. The simulated hydrographs matched the observed hydrographs very well. As a result, it can be used for hydrological simulations in temperate catchments for effective water resource planning and management.

Abbreviations

GCM	General Circulation Model
DC	Delta Change
WMO	World Meteorological Organization
DHI	Danish Hydraulic Institute
IPCC	Inter Governmental Panel on Climate Change
AR4	Fourth Assessment Report
SR	Special Report
RR	Rainfall-Runoff
N_{SE}	Nash-Sutcliffe Efficiency
Dv	Deviation Volume
RMSE	Root Mean Square Error

Declarations

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Author Declarations

1. Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by (Munjid Maryam, Rohitashw Kumar). The first draft of the manuscript was written by (Munjid Maryam) All authors read and approved the final manuscript.

2. Conflicts of interest/Competing interests : The authors declare they have no competing interests.

3. Funding : No funding was received for this study.

4. Ethics Declaration statement: Not applicable

5. Consent to Participate: Not applicable

6. Consent for publication : Not applicable

7. **Data availability**: Not available because of the policy of data providing agency

References

1. Clothier, B.E. (1990). Soil water sorptivity and conductivity. Remote Sens 5:281–291.
2. Kumar, R., Jat, M. K. & Shankar, V. (2012).Methods to estimate reference crop evapotranspiration - A review. Water Sci Technol 66(3): 525–35.
3. IPCC. (2001).Impacts, adaptation and vulnerability. Technical summary and summary for policymakers.
4. Paul, S., Jusel, K. & Alewell, C. (2006). Reduction processes in forest wetlands; tracking down heterogeneity of source/ link functions with combination of methods. Soil Biol Biochem 38: 1028–1039.
5. Hopkinson, C. & Day, J. (1980). Modeling the relationship between development and storm water and nutrient runoff. J Environ Manage 4: 315–324.
6. Ajibola, M., Adewale, B. & Ijasan, K. (2012). Effects of Urbanization on Lagos Wetlands. Int J B 3:17.
7. Huong, T. & Pathirana, A. (2013.) Urbanization and climate change impacts on future urban flooding in Can Tho city, Vietnam. Hydrol Earth Syst Sci 17<bvertical-align:super;>:</bvertical-align:super;>379–394.
8. Kumar, R., Huda, M. B., Maryam, M. and Lone M. A. (2022). Rainfall runoff modeling using MIKE 11 NAM of the Jhelum river in Kashmir Valley, India. MAUSAM, 73, 2, 365–372. DOI: https://doi.org/10.54302/mausam.v73i2.804
9. Xu, C. (2002). Mathematical models of small watershed hydrology and applications. Department of Earth Sciences, Hydrology, Uppsala University, 16:555–590.
10. Devi, G.K., Ganasri, B.P. & Dwarakish, G. S. (2015). A review on hydrological models. Aquat Procedia 4:1001–1007.
11. Madsen, H. (2000). Automatic calibration of a conceptual rainfall-runoff model using multiple objectives. J Hydrol 276–288.
12. Shamsudin, S. & Hashim, N. (2002). Rainfall runoff simulation using MIKE 11 NAM. Slovak J Civ Eng 15(2): 1–13.

13. Doulgeris, C., Georgiou, P., Papadimos, D.& Papamichail, D. (2010). Evaluating three different model setups in the MIKE 11 NAM model. Advances in the Research of Aquatic Environment 1: 241–249.
14. Hafezparast, M., Araghinejad, S., Fatemi, S. & Bressers, H. (2013). A conceptual rainfall-runoff model using the auto calibrated NAM modelsin the Sarisoo river. Hydrol Curr Res 4(1): 2157–7587.
15. Ashutosh, S, Singh, S.,, Nema, A.K., Singh, G. & Gangwar, A. (2014). Rainfall-Runoff Modeling using MIKE11 NAM Model for Vinayakpur Intercepted Catchment, Chhattisgarh. Indian J. Dryland Agric. Res. & Dev. 2014 29(2) : 01–07
16. Kumar, P., Lohani, A. K. & Nema, A.K. (2019). Rainfall runoff modeling using MIKE 11 NAM model. Curr World Environ 14(1): 27–36.
17. Teshome, F.T., Bayabil, H. K., Thakural, L. N.& Welidehanna, F. G. (2020). Verification of MIKE 11 NAM model for simulating streamflow. J Environ Prot 11(2):152–167.
18. Bami, Y.S., Porhemmat, J., Sedghi, H. & Jalalkamali, N. (2020).Performance Evaluation of Mike Nam Rainfall-Runoff (R-R) Model in Daily Flow Simulation (Case Study: Gonbad Catchment in Hamedan). Journal of Applied Engineering Sciences 10(1):1–6, DOI: 10.2478/jaes-2020-0001
19. Aredo, M.R., Hatiye, S.D. & Pingale, S.M. (2021). Modelling the rainfall runoff using MIKE 11 NA model in Shaya catchment, Ethiopia. Model Earth Syst.
20. Kirpich, Z.P. (1940). Time of concentration of small agricultural watersheds. Civil Engineering, 10(6), 362.
21. Nash, J. E. & Sutcliffe, J. V. (1970). River Flow Forecasting through Conceptual Models: Part I. A Discussion of Principles. Journal of Hydrology 10 (3): 282–90.
22. MIKE. (2008) –DHI MIKE 11 a modeling system for rivers and channels, User's Manual, Danish Hydraulic Institute, Horsholm, Denmark.

Figures

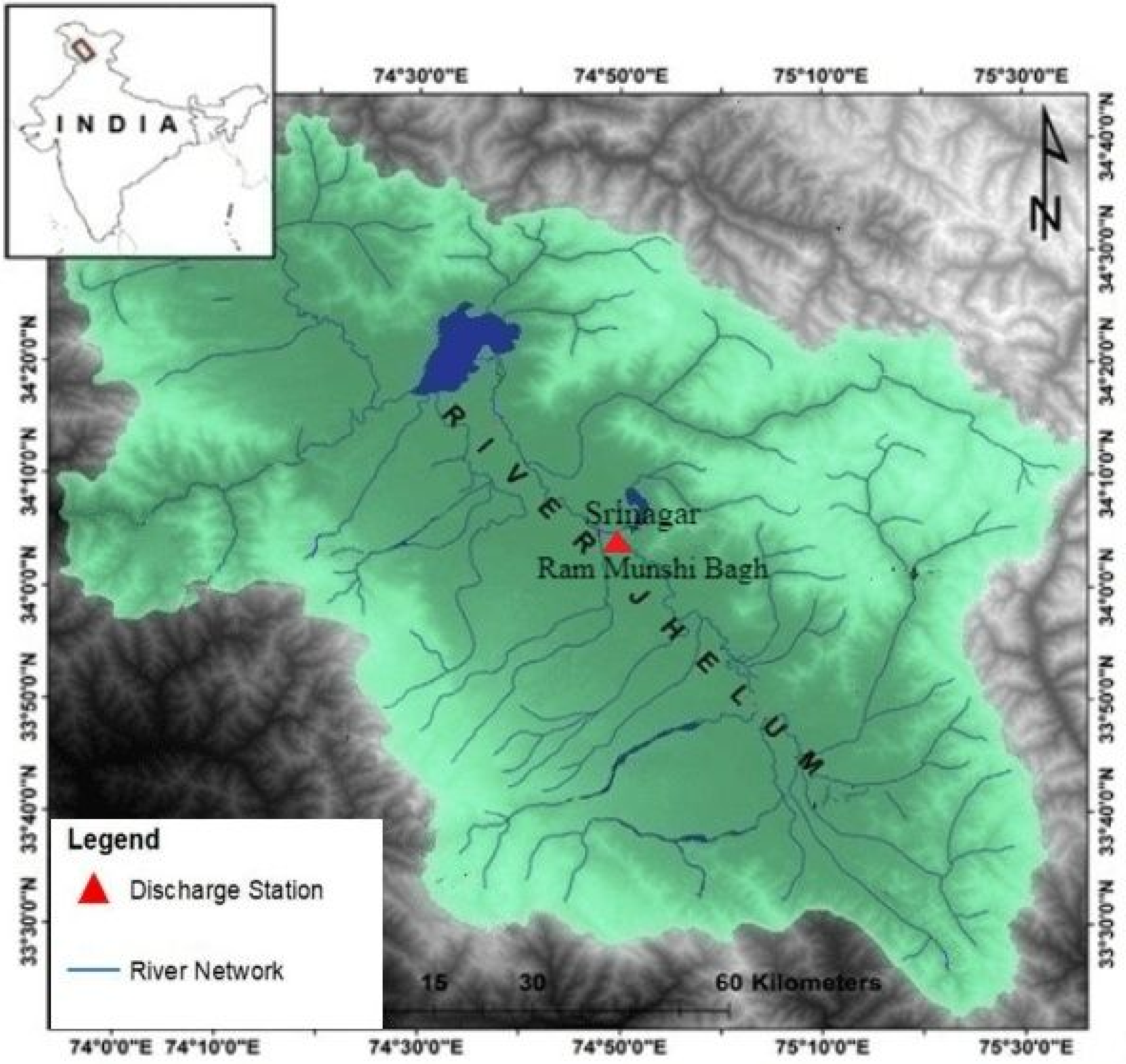

Figure 1

Location of the study area

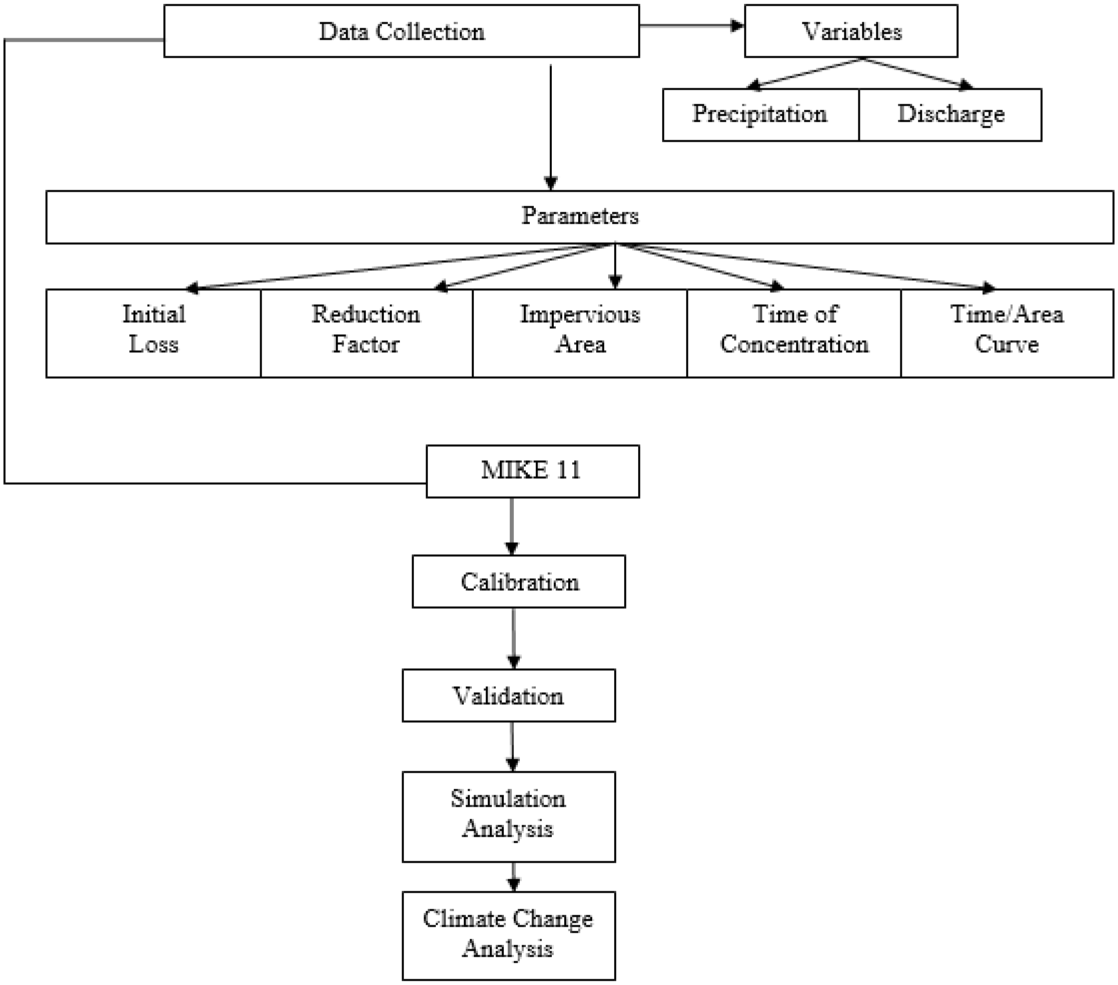

Figure 2

Work Flow of Research Using MIKE 11 Model

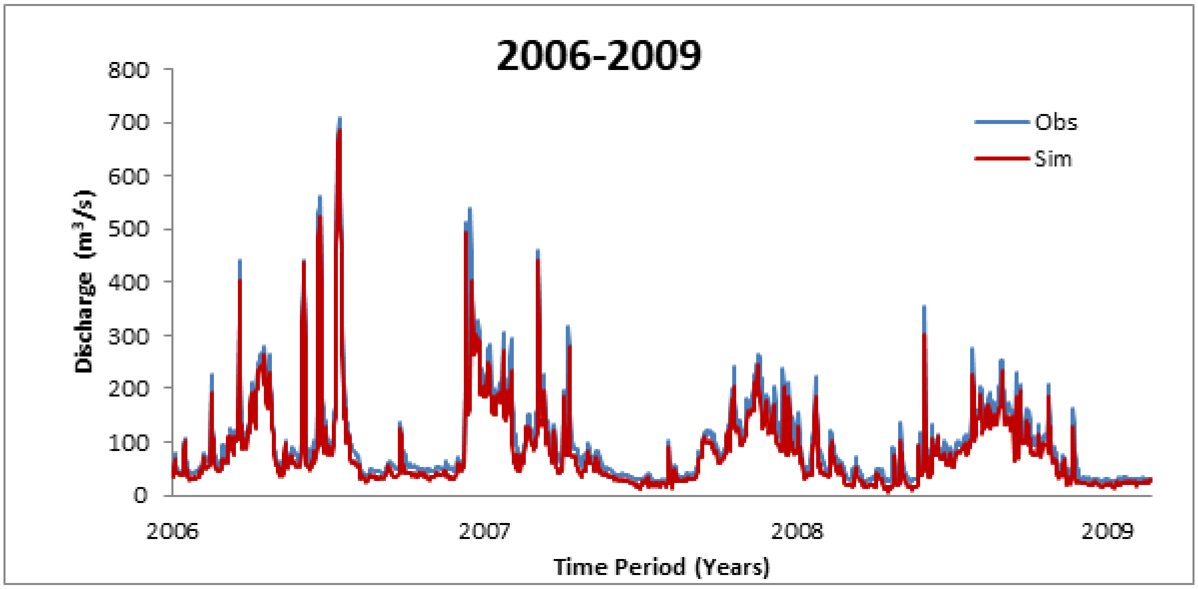

Figure 3

Model simulated and observed discharge for the year 2006-2009

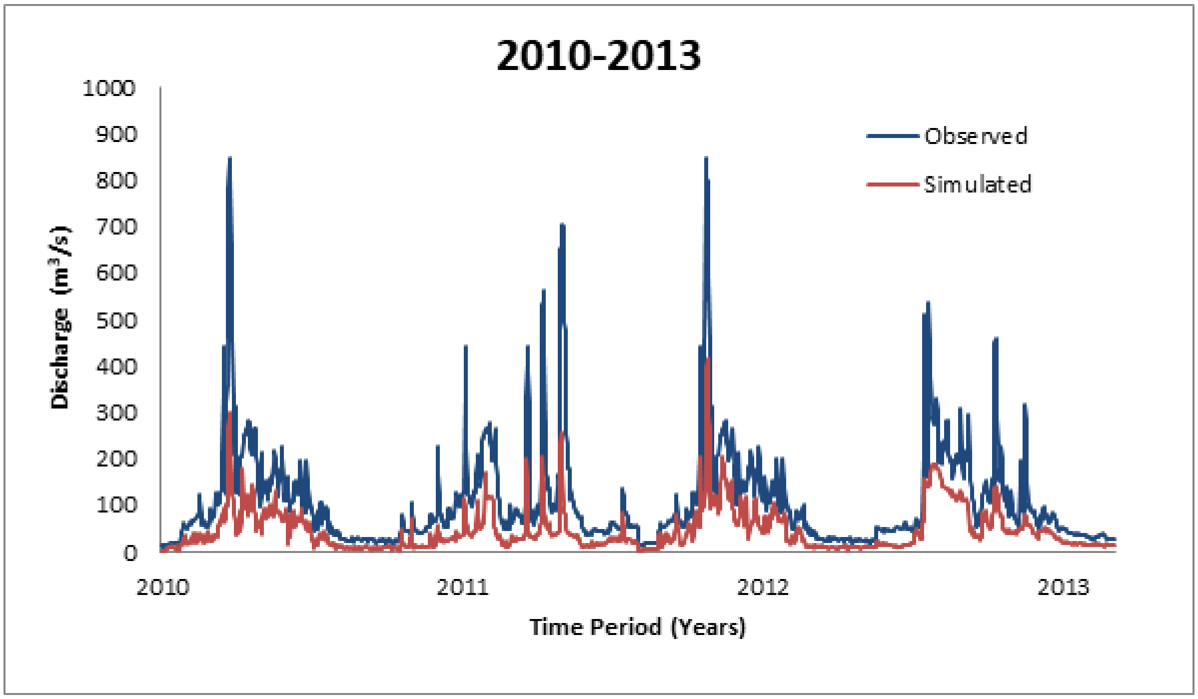

Figure 4

Observed and model simulated discharge for the year 2010-2013

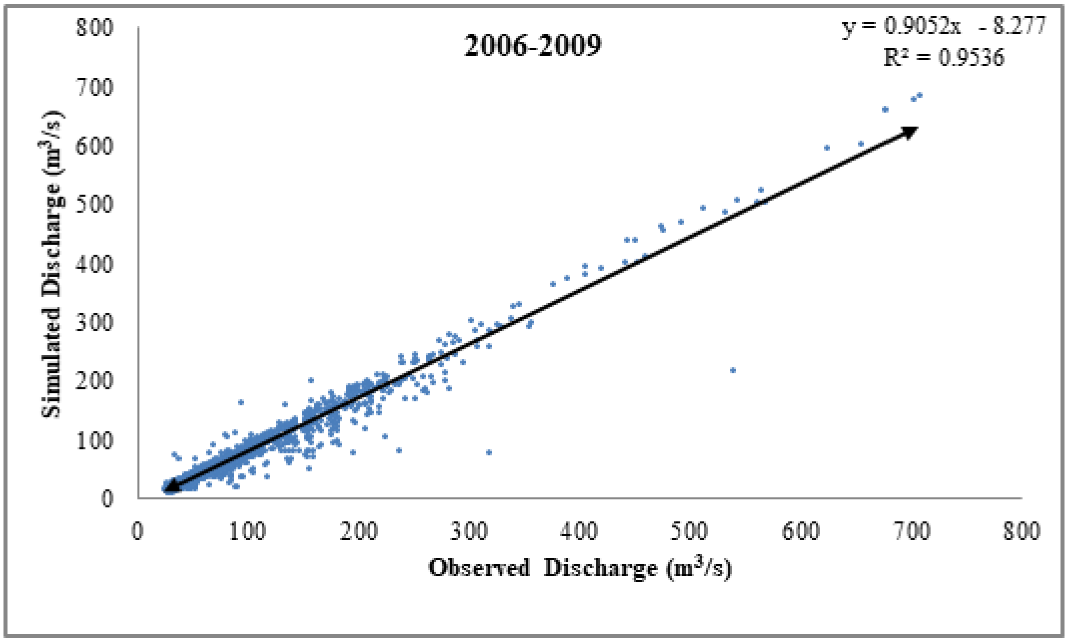

Figure 5

Scatter plot representing the simulated and observed runoff for the year 2006-09

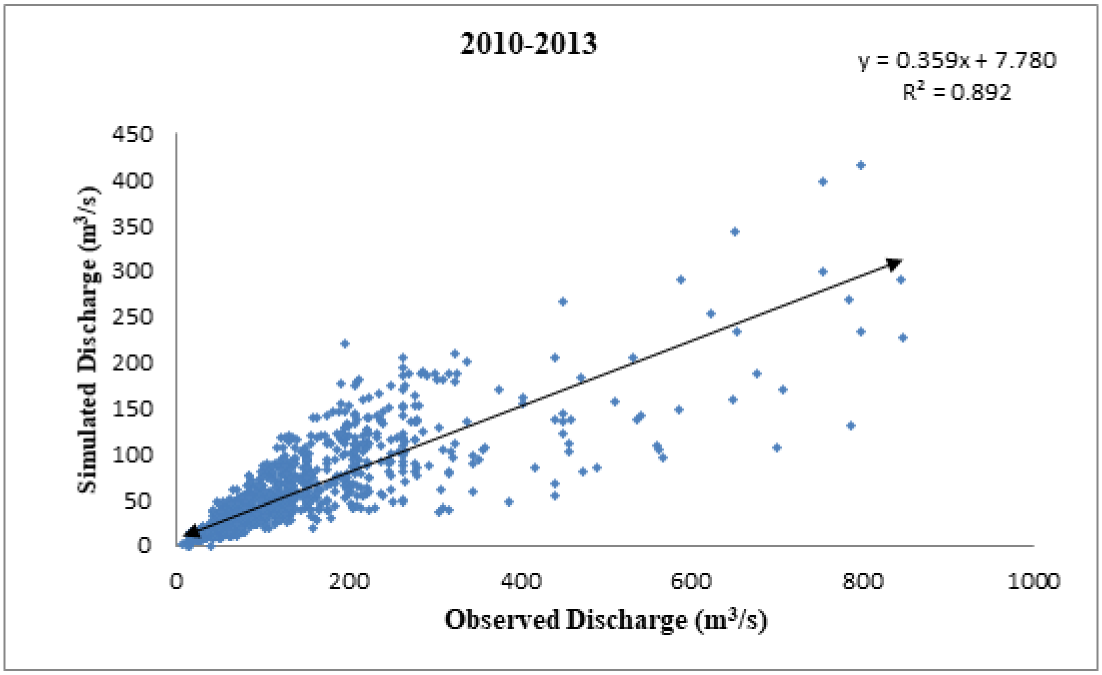

Figure 6

Scatter plot representing the simulated and observed runoff for the year 2010-2013

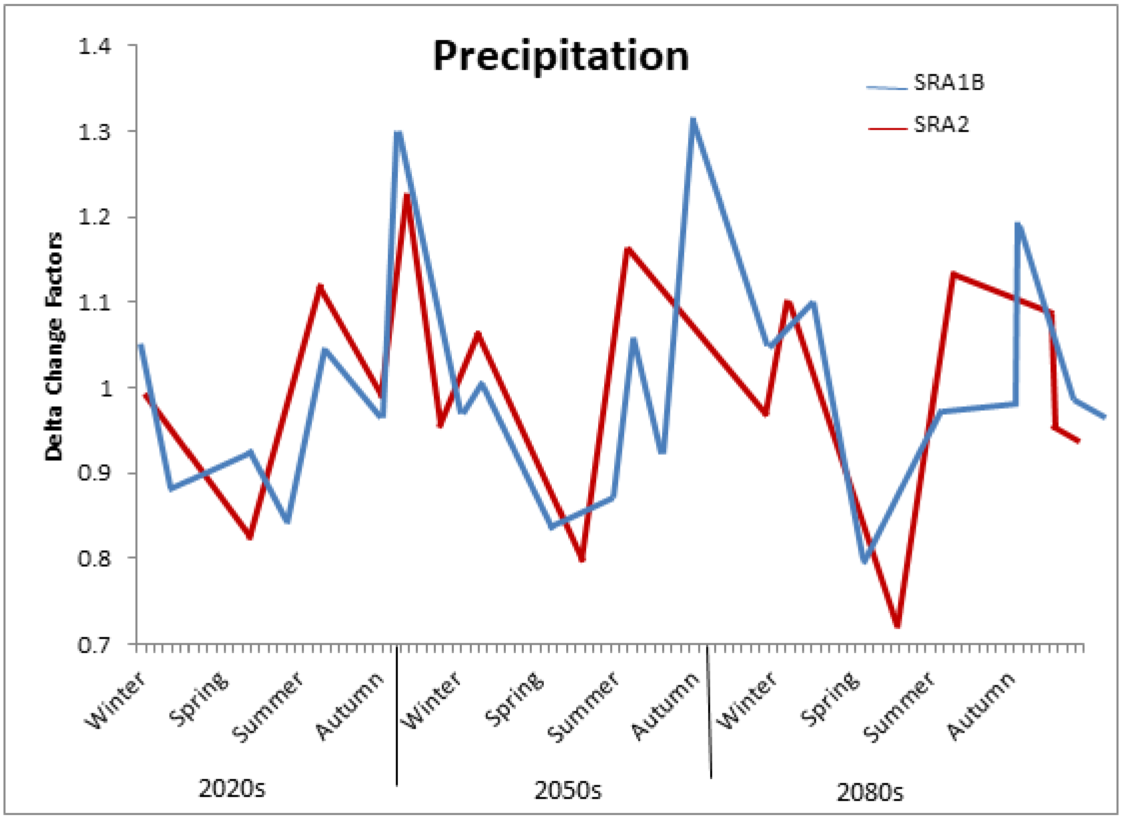

Figure 7

Changes in precipitation under IPCC SRA1B and SRA2 scenarios from 2020s to 2080s

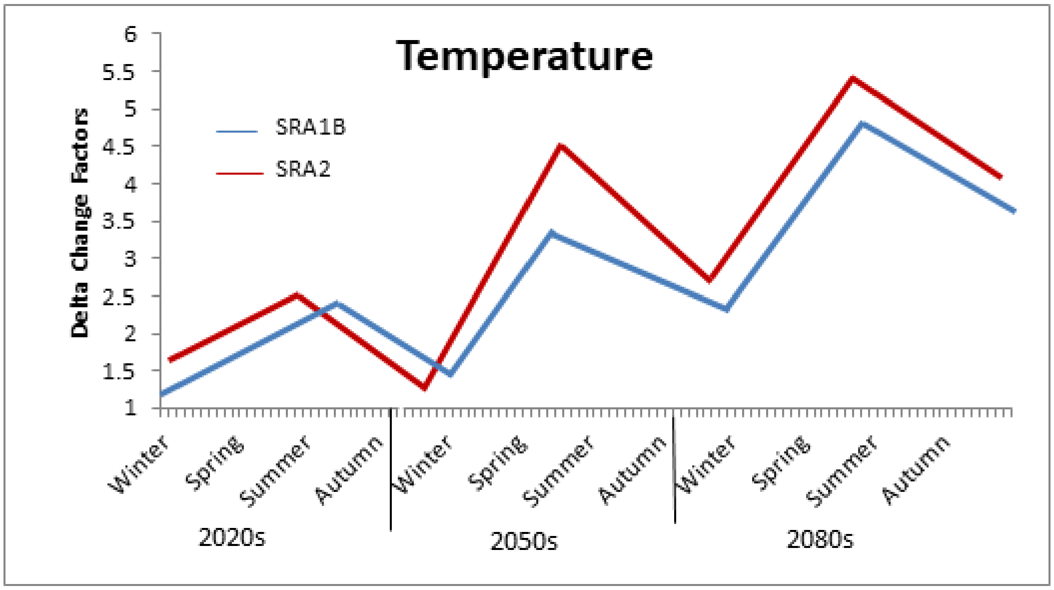

Figure 8

Temperature variation under IPCC SRA1B and SRA2 scenarios (2020s to 2080s)

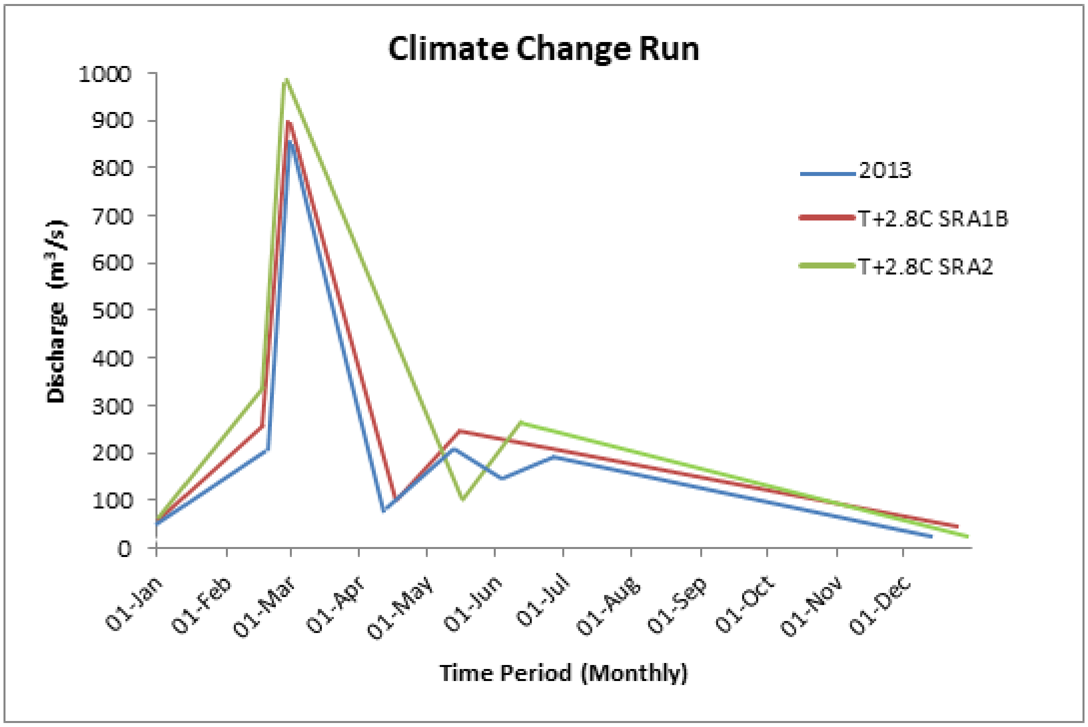

Figure 9

Climate change run of MIKE 11 model for discharge with change in temperature for the validated year 2013