Proceedings of International Conference on Hydraulics, Water Resources and Coastal Engineering (Hydro2016), CWPRS Pune, India
8th – 10th December 2016

EFFECT OF CLIMATE CHANGE ON RIVER BASIN HYDROLOGY

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ABSTRACT

Changes in climate over the Indian region, particularly the southwest monsoon, would have a significant impact on agricultural production, water resources management and overall economy of the country. Shipra river is one of the sacred river in Madhya Pradesh state and its water is being used to meet domestic, agricultural and industrial water demand of Indore, Ujjain and Dewas districts. The present study envisages the assessment of climate change in Shipra river basin using trend analysis of rainfall, temperature and runoff data. The study has been emphasized on assessment of impact of possible climate change on river basin hydrology in terms of dependable flow, peak flow, low flow and annual yield of the river. The trend analysis of long term rainfall data of eight raingauge stations in the Shipra basin indicated falling trend at around half of the stations for monsoon as well as non-monsoon rainfall however trend was not found significant at many places. Dewas station was observed as a critical station showing significant falling trend having Z value -2.41 at 95% confidence level for the annual rainfall. The trend analysis of long term monthly temperature data observed significant rising trend during most of the months indicating overall temperature rise in the Shipra basin. It could be concluded that climate change such as significant falling trend of rainfall in Shipra basin would definitely affect the hydrology of the basin. It would cause remarkable reduction of dependable flow, peak flow and runoff yield of the river.
Keyword: *Climate change, trend analysis, rainfall, temperature, hydrology*

1. INTRODUCTION

Climate change is a change in the statistical distribution of weather patterns when that change lasts for an extended period of time i.e., decades to millions of years. Climate change is caused by factors such as biotic processes, variations in solar radiation received by Earth, plate tectonics, and volcanic eruptions. The global and local climate has been changing as evidenced by increase of temperature and rainfall intensity (Ritter, 2006). Certain human activities have also been identified as significant causes of recent climate change, often referred to as "global warming" which may have highly extensive, complicated and uncertain impact on environment. Global climate changes may influence long term rainfall pattern impacting the availability of water, along with the danger of increasing occurrences of droughts and floods. In India the southwest monsoon, which brings about 80% of the total precipitation over the country, is critical for the availability of freshwater for drinking and irrigation. The climate change expected to adversely affect its natural resources, forestry, agriculture, and change in precipitation, temperature, monsoon timing and extreme events (Fulekar and Kale, 2010). In many areas, climate change is likely to increase water demand while shrinking water supplies.

In the process of decision making for water resources and management, the information of climate change impacts on catchment hydrology may be of great help to the planners to manage future water demands likely to be affected. In view of this, the present study envisages the assessment of climate change in Shipra river basin using trend analysis of rainfall, temperature data simulated runoff data. The Shipra river basin of Madhya Pradesh comes under the region of sizeable water scares area with increasing water demand due to agricultural, domestic and industrial growth. Thus the climate change effect in this region may have adverse impact on natural resources and ultimately on its economy of the region. In this context, attempts have been made to assess the impact of possible climate change on catchment hydrology and water availability in the Shipra basin. Climate change indication can be assessed through statistical methods of trend analysis of climatic variables such as rainfall, temperature, ground water level, etc.

Shipra river basin has been extended between 76^0 06' 20''and 75^0 55'60'' North Latitude and 22^0 97'00''and 23^0 76' 20'' East Longitude and covers an area of 5679 sq. km. The Shipra, also known as the Kshipra, originates from Kakribardi hills in Vindhayan Range north of Dhar and flows north across the Malwa Plateau to join the Chambal river. It traverses total course of about 190 km through four districts namely Dewas, Indore, Ujjain, and Ratlam before joining Chambal river near Kalu-Kher village. It is considered as one of the sacred rivers in Hinduism. The holy city of Ujjain is situated on its bank where Kumbh mela; also called Simhastha is held after every 12 years, besides yearly celebrations. The index map of Shipra indicating its location is shown in Figure 1.

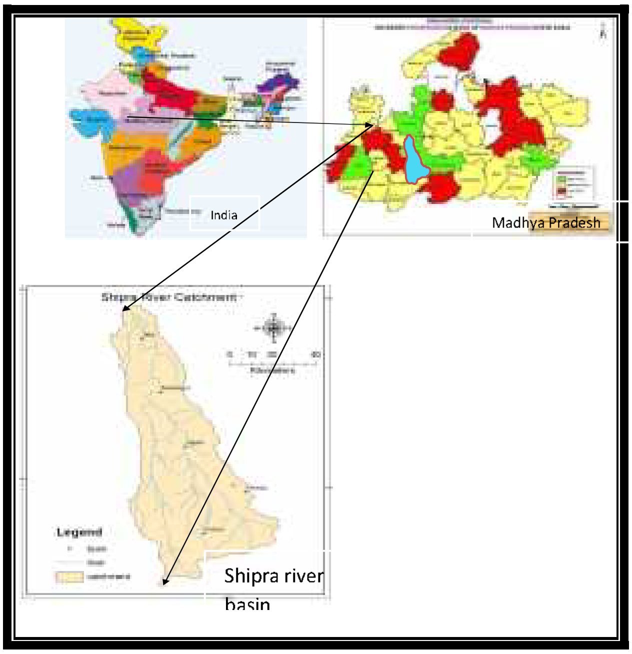

Figure 1. Index map of Shipra river basin

The main tributaries of Shipra are the Khan and Gambhir river. The rainfall in the area is due to the southwest monsoon which starts from the middle of June and ends in last week of September. The average annual rainfall of study area is about 931.87 mm. The climate condition of the study area, particularly in December and January, are severely cold, whereas summer month of May and June are intensely hot.

2. MATERIALS AND METHODOLOGY

Trend Analysis

Trend is defined as the general movement of a series over an extended period of time or it is the long term change in the dependent variable over a long period of time. In order to understand the climate variability of rainfall and temperature in Shipra basin, rainfall data of 55 years from 1958 to 2012 of eight rain gauge stations falling in Shipra basin was used for the analysis. Existence of trend in data time series has been identified using non-parametric Mann-Kendall test. It has a capability to identify positive (rising) or negative (falling) trend and demonstrate its significance. The rainfall trends over the study area were analyzed for each raingauge station for annual, monsoon, non-monsoon rainfall, individual monsoon months, maximum rainfall and rainy days. The trend analysis of temperature data of Indore observatory from year 1956 to 2012 was carried out for monthly mean maximum, mean minimum, highest maximum and lowest minimum temperature.

Both parametric and non-parametric statistical tests can be used in trend detection in order to quantify the significance of trends in a time series (Durdu, 2010). The use of statistical tests involves testing of the null hypothesis which assumes that the data are random and are not correlated. Although parametric tests are more powerful in nature, they have to satisfy the assumption of normal distribution, and independent observation (Önöz and Bayazit, 2003). If the assumptions made are not met, then the tests will yield unreliable results and interpretations, because the estimates of the significance level will not be correct (Kundzewicz and Robson, 2004). Non-parametric tests have less strict assumptions and have a higher tolerance with respect to missing values and non-normal distribution (Cunderlik and Burn, 2004). Since earth-based scientific phenomena including hydrological processes tend to have non-stationary characteristics and non-normal distributions, non-parametric tests are usually preferred over parametric tests in conducting a trend analysis (Hirsch and Slack, 1984; Lattenmaier, 1988). Furthermore, hydrological data normally exhibit autocorrelation; therefore, data values are not independent and they may also show seasonality, which violates the assumption of constant distribution (Kundzewicz and Robson, 2004). Therefore, in this study non parametric Mann-Kendall test is used for annual rainfall and temperature data to check whether the tread is significant or not at 95% level of significance.

2.1 Calculation of the Mann-Kendall statistic

Mann (1945) presented a non-parametric test for randomness against time, which constitutes a particular application of Kendall's test for correlation commonly known as the 'Mann–Kendall. The test compares the relative magnitudes of sample data rather than the data values themselves (Gilbert, 1987). One benefit of this test is that the data need not conform to any particular distribution. The data values are evaluated as an ordered time series. Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic, *S*, is assumed to be 0 (*e.g.*, no trend). If a data value from a later time period is higher than a data value from an earlier time period, *S* is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, *S* is decremented by 1. The net result of all such increments and decrements yields the final value of *S*. Let *X1, X2*… …*Xn* represents n data points where *Xj* represents the data point at time *j*. Then the Mann-Kendall statistic (*S*) is given by equation 1.

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sgn(x_j - x_i) \qquad (1)$$

Where

$$sgn(\theta) = \begin{Bmatrix} +1 & if\ \theta > 0 \\ 0 & if\ \theta = 0 \\ -1 & if\ \theta < 0 \end{Bmatrix}$$

(2)

when $n > 10$ the ***S*** statistic is approximately normally distributed with zero mean and variance as follows:

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18}$$

(3)

The standard normal deviation *(Z Value)* is computed as

$$Z = \begin{Bmatrix} \frac{s-1}{\sigma} & if\ s > 0 \\ 0 & if\ s = 0 \\ \frac{s+1}{\sigma} & if\ s < 0 \end{Bmatrix}$$

(4)

A very high positive value of *S* is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend. When $Z > +1.96$ *or* $Z<-1.96$ then null hypothesis (*Ho*) is rejected at 95% level of significance level. Significance of positive and negative trend is found by the Z values at 95% level of significance. If *Z* value is greater than +1.96, it shows significant rising trend and if *Z* value is less than -1.96, it shows significant falling trend.

Many researchers have worked on rainfall trend analysis using Mann–Kendall test to assess climate variability. Modarres and Silva (2007) analyzed the time series of annual rainfall, number of rainy-days per year and monthly rainfall to assess climate variability in the arid and semi-arid regions of Iran. Tabari and Hosseinzadeh Talaee (2011) examined temporal trends of precipitation in Iran using the Mann–Kendall test, the Sen's slope estimator and the linear regression. Singh and Sontakke (2005) analyzed rainfall data over the Indo-Gangetic Plains and found significant increasing trend in the summer monsoon rainfall, non-significant decreasing trend. Mirza et al. (1998) studied the climate changes over Ganges, Brahmaputra and Meghna basins using long term rainfall data. Singh et al. (2008) studied the changes in rainfall over the last century in nine river basins of northwest and Central India. Kumar et al. (2010) carried out analysis for trend detection of rainfall in Himachal Pradesh indicated increasing trend in annual rainfall.
Numbers of researchers have conducted research work on identification of trend in temperature using Mann-Kendall test. Arora et al. (2005) observed high percentage of significant rising trends for temperature in most cases, except for mean pre-monsoon, mean monsoon, pre monsoon mean minimum and monsoon mean minimum. Pant and Hingane (1988) observed decreasing trend in mean annual surface air temperature over the northwest Indian region consisting of the meteorological sub-divisions of Punjab, Haryana, west Rajasthan, east Rajasthan and west Madhya Pradesh. Rupa Kumar et al. (1994) carried out trend analyses of temperature data at 121 stations in India and observed increasing trend for maximum temperature and trendless minimum temperature. Kothyari and Singh (1996) found increasing annual maximum temperature over the Ganga basin and increasing average annual temperature for India starting around the second half of 1960s.

2.2 Assessment of impact of climate change on basin hydrology

Hydrologic response of the river basin is dependent on meteorological, environmental, physiological, geological, anthropological and many other parameters. Climate change certainly has its impact on fresh water availability such as stream flow, reservoir, lakes or ground water. Chaponniere and Smakhtin (2006) reviewed various methods for assessment of impacts of climate change scenarios on water resources for a Oum er Rbia river basin in Morocco. In the present study attempt are made to study the impact of climate change on hydrological behavior of the Shipra river basin. This analogous approach involves the analysis of observed runoff and modified runoff data simulated considering climate change condition as observed at nearby places in the basin. For this purpose rainfall-runoff modeling was carried out using MIKE 11 NAM Model in Shipra River basin using observed flow data from 1984 to 2014 of Ujjain Gauge Discharge site where the catchment area of river is 2102 km^2. The NAM rainfall runoff model thus developed was used for simulation of modified runoff using the rainfall data which has been subjected significant trend. The map with view of Shipra river basin and catchment area up to Ujjain is shown in Figure 2.

MIKE11 NAM is developed by Danish Hydraulic Institute (DHI), Denmark. It is deterministic, lumped and conceptual rainfall-runoff model that operates by continuously accounting for the moisture content in three different and mutually interrelated storages that represent overland flow, interflow and base flow (DHI 2003). NAM is prepared with 9 parameters, representing surface zone, root zone and ground water storage. The input data required for modelling was daily weighted average rainfall, observed discharge, potential evapotranspiration and boundary conditions. The daily rainfall data of five influencing raingauge stations Ujjain, Indore, Dewas, Mohw and Sanver was used to develop NAM model. The average monthly potential evapotranspiration values of Indore station were used in the model. The NAM model was then calibrated, validated and tested for assessing its suitability in selected sub-basin.

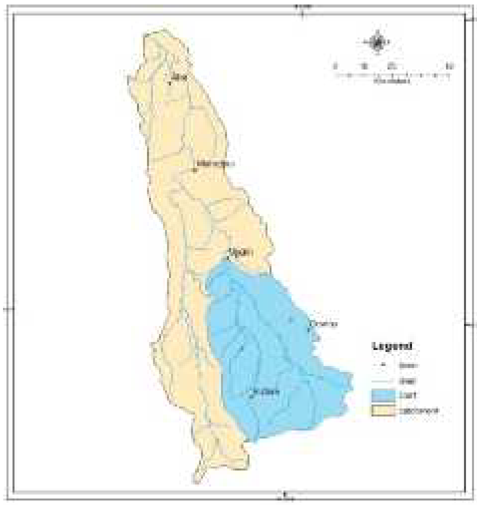

Figure 2. Catchment area up to Ujjain G/d site

The observed runoff data exhibits the hydrological response of the river under the given rainfall condition. Thus observed runoff was considered as the 'reference scenario' runoff and the NAM model simulated runoff using input rainfall data which has been subjected significant trend was considered as a 'climate change scenario' runoff. The reference and climate change scenario time series were were analyzed and compared on the basis of water availability in the river, peak flows and annual yield to study the impact of climate change on the catchment hydrology. The water availability was assessed by comparing dependable flow at Ujjain at various probability levels. To estimate the dependable flow at various probability levels, the Flow Duration Curve technique was used.

3. RESULTS AND DISCUSSION

3.1 Trend analysis

To understand the climate change scenario and to detect the presence of any trend in rainfall and temperature time series in Shipra basin non-parametric Mann-Kendall test was conducted. The Mann-Kendall test was carried out for rainfall and temperature to check whether the tread is significant or not at 95% level of significance i.e., Z > +1.96 or Z<-1.96. The Mann-Kendall test results showing Z values at 95% level of confidence for rainfall and temperature are shown in Table 1 and 2.

Table 1: Mann-Kendall tests statistics Z values for rainfall from year 1958-2012

Station	Annual	Monsoon	Non-Monsoon	June	July	Aug	Sept	Oct	Rainy days	Max. Rainfall
Dewas	**-2.41**	-1.77	**-2.87**	-1.04	-1.09	-1.62	-1.02	-0.97	**-2.32**	-1.34
Ujjain	1.07	0.93	-0.17	-0.77	0.00	0.93	1.01	2.42	-1.24	**2.67**
Indore	-0.55	-0.08	-1.35	0.80	0.08	0.17	-0.79	-0.79	0.02	0.99
Mahidpur	0.02	0.04	-0.95	0.90	0.02	0.37	0.26	-0.18	0.68	-1.37
Tarana	-0.33	-0.44	0.11	-0.54	1.38	0.18	0.00	0.16	-0.53	-0.67
Badnagar	0.60	-0.06	-0.09	1.47	0.68	0.10	0.06	-0.05	1.11	0.00
Khachrod	-1.19	-1.43	**-2.04**	0.41	-0.68	-0.15	-0.43	0.01	0.96	0.99
Sanver	0.54	0.67	-1.60	-0.71	1.04	-0.81	-0.13	0.36	-0.44	**1.96**

From the Table 1, showing Z values of long term annual rainfall time series from year 1958 to 2012 it is observed that, in Shipra basin out of eight stations around 50% stations have shown falling trend in annual rainfall and 60% stations have shown falling trend in monsoon rainfall i.e. Dewas, Mahidpur, Tarana, Badnagar, Khachrod, Sanver. On comparing trend for number of rainy days, around 50%

stations experienced falling trend. Though the data indicated falling trend at many places, the trend was not found significant at 95% of confidence level. Exceptionally Dewas station is observed as a critical station showing significant falling trend for the annual rainfall, non monsoon rainfall and for the rainy days at 95% level of confidence with Z values -2.41, -2.87 and -2.32 respectively. Some stations in Shipra basin like Ujjain, Mahidpur, Badnagar and Sanver experienced rising trend too for annual rainfall time series but they were found not significant. However significant rising trend was observed at Ujjain for rainy days and maximum rainfall.

Table 2: Mann-Kendall test statistic Z values for temperature

S.No	Month	M_{max}	H_{max}	M_{min}	L_{min}
1	January	0.89	**2.74**	1.41	1.33
2	February	0.36	1.95	**2.93**	**3.18**
3	March	**2.36**	1.55	**2.45**	**2.81**
4	April	**2.39**	1.84	0.69	0.15
5	May	1.95	1.78	0.81	1.38
6	June	0.74	**2.34**	1.31	1.97
7	July	0.93	0.34	**2.10**	-0.86
8	August	1.20	0.58	0.90	-0.22
9	September	1.92	1.60	1.49	1.76
10	October	**2.37**	**2.46**	0.88	0.95
11	November	**3.57**	**3.10**	1.76	1.94
12	December	**3.35**	**2.78**	1.82	**2.90**

From the Table 2 showing Mann-Kendall test statistic Z values for temperature, it is observed that overall temperature has been found increasing and most of the months have experienced significant rising trend at 95% confidence level. From the analysis it can be seen that March, April, October, November and December have shown significant rising trend for mean maximum temperature (M_{max}) with Z value 2.36, 2.39, 2.37, 3.57 and 3.35 respectively. For highest maximum temperature (H_{max}), January, June, October, November and December months have shown significant rising trend. For Mean minimum temperature (M_{min}), February, March and July months have shown significant rising trend. For lowest minimum temperature (L_{min}), February, March, June and December months have shown significant rising trend. However July and August experienced non-significant falling trend with Z value -0.86 and -0.22 respectively. Thus from the above trend analysis of long term temperature data, it is seen that almost each month of the year is subjected to significant rising trend either it was M_{max}, H_{max}, M_{min} or L_{min}. The constant rise in temperature is the matter of concern for climate change in the region, livelihood, especially water resources, agricultural production and other aspects of human life.

3.2 Assessment of impact of climate change on basin hydrology

Assessment of impact of climate change on hydrological behavior of the basin involves the analysis of observed runoff data and modified runoff data for climate change condition using NAM rainfall runoff model. For this purpose the NAM model was setup then calibrated, validated and tested for assessing its suitability in selected sub-basin. The coefficient of determination (R^2) value during model calibration and validation is observed as 0.72 and 0.502 and the difference in observed and simulated runoff is found reasonable. The NAM model is found performing with accuracy in Shipra basin and it can be used further for runoff simulation.

From the trend analysis of rainfall data, it is observed that the Dewas station has shown significant falling trend having Z value -2.41 at 95% confidence level. For the purpose of impact assessment of climate change on catchment hydrology it was assumed that the rainfall of the whole Shipra basin up to Ujjain site is subjected to the significant falling trend as in case of Dewas station i.e. with Z= -2.41. Therefore, rainfall data is altered manually by manipulating the original rainfall data in such a way that on applying Mann-Kendall test, it would have significant falling trend with Z value -2.41. This modified rainfall data is then used as an input in NAM rainfall runoff model for simulation of climate change scenario runoff and compared with reference scenario runoff on the basis of dependable flow at various probabilities, annual yield, peak flows and its correlation with rainfall. Comparison between reference and NAM modified climate change (CC) scenario runoff hydrographs for monsoon season of year 1994 are shown in Figure 3. The comparison of dependable flow at 75, 80, 85, 90 and 95% probability levels during monsoon runoff for reference and climate change scenario are given in Table 3.

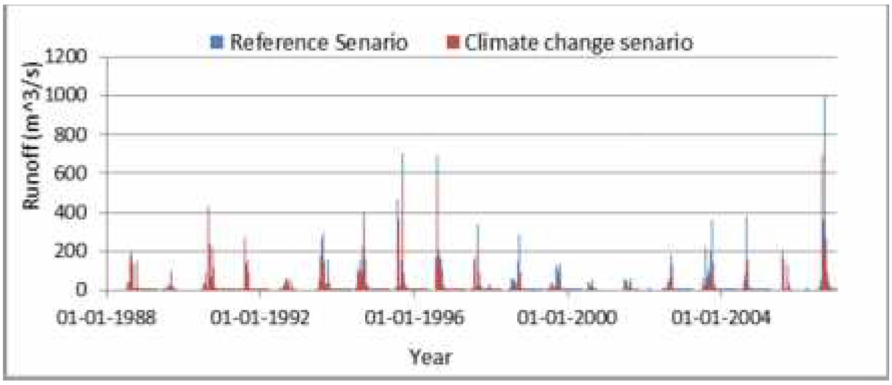

Figure 3. Comparison between reference and NAM modified CC scenario runoff hydrographs

During monsoon season, dependable flow at 70 and 75% probability of exceedance for reference scenario is observed 0.9 and 0.27 m^3/s and it is found decreased to 0.17 and 0.05 m^3/s for climate change scenario respectively. The similar results are seen for monthly rainfall also. For the month of August, dependable flow at 75 and 90% probability of exceedence is observed 9.7 and 2.21 m^3/s for reference scenario and it is found decreased to 3.25 and 0.39 m^3/s respectively for climate change scenario. The reduction in dependable flow during monsoon and individual month August under climate change condition can be seen prominently from Figure 4.

Table 3. Dependable Flow in Monsoon Season for Reference and Climate Change Scenario

Month	Probability of Exceedance (%)	Dependable Flow (m^3/s)	
		Reference Scenario	Climate Change Scenario
Monsoon Season	70	0.90	0.17
	75	0.27	0.05
	80	0.02	0
	85	0	0
	90	0	0
	95	0	0

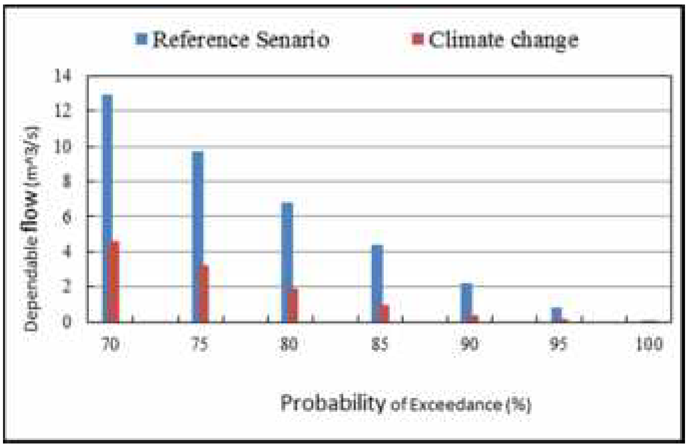

Figure 4. Dependable flow of reference and climate change scenario during August

Impact of impact of climate change on peak runoff and total runoff volume or annual yield is analyzed during the period from 1988 to 2006 as shown in Figure 5. In year 1988, peak flow under reference scenario is observed 202.38 m^3/s and it is found decreased to 186.56 m^3/s under climate change scenario, thus reduction in peak runoff due to climate change is seen as 7.8%. Similarly, highest reduction is seen during 2003 where peak flow is seen decreased by 60.9% from 361.44 to 141.22 m^3/s. Overall peak flow has been found decreased by almost 8 to 61 % during all years due to impact of climate change.

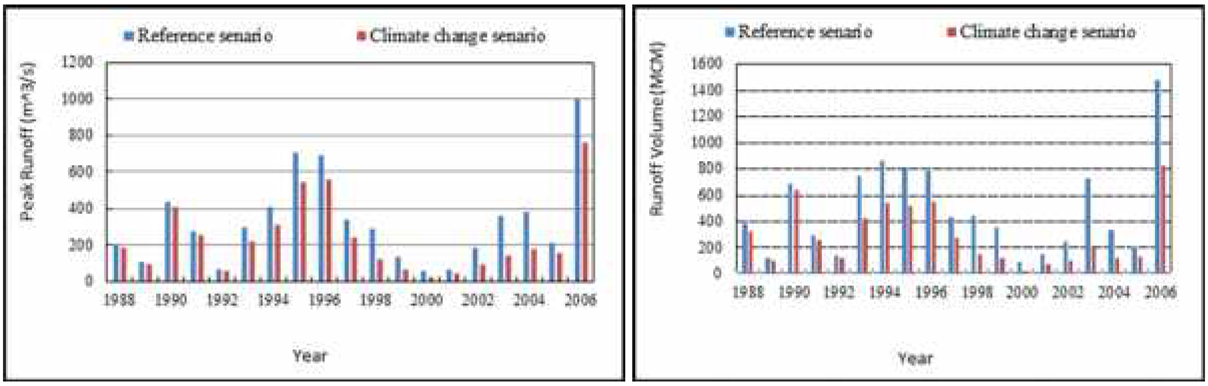

Figure 5. Comparison between Peak runoff and runoff volume of reference and climate change scenario

On comparison of total runoff volume under reference scenario and climate change scenario it was observed that the total runoff volume of the river at Ujjain was seen decreased to great extent under climate change scenario. In year 1988, total runoff volume was decreased from 386.6 MCM to 331.17 MCM i.e. 14% decreased in the runoff volume from reference scenario to climate change scenario. This trend was seen during all the year as shown in the Figure 5. From the analysis of results it can be concluded that the climate change in Shipra basin may have its severe impacts on river basin hydrology. It would cause significant reduction of seasonal flow, monthly flow, peak flows and annual yield of the river.

4. CONCLUSIONS

Mann-Kendall test result indicated falling rainfall trend and rising temperature trend which has been found significant at some places provides sufficient indication that like other parts of India, the Shipra basin of Madhya Pradesh is also experiencing the impact of climate change, though the magnitude of change may not be the same. It is seen that if rainfall in Shipra basin is subjected to adverse impact of

climate change, it would definitely affect the runoff yield of the river. Climate change will have severe impact on river basin hydrology and falling rainfall trend will not only reduce the runoff yield but also reduce the peak flows, low flows and it would have adverse impacts on the total water resource scenario of the basin. The basin may face huge water scarcity and reduction in dependable flow in river which may ultimately increases the demand deficit and may alter the economical activity of the region.
The non-parametric Mann-Kendall test was found to be the suitable method for identification of existence of trend in the time series. It gives idea of significance of the trend. The NAM rainfall runoff model was found suitable model for Shipra basin and can be used for runoff simulation for various climate change scenarios. The present Study offers remarkable insight and new prospective for policy makers, decision makers, water resource managers, agriculturist and planners in helping them to take proactive measures for water resources development and planning in context of climate change for regional level planning. Timely measures can help in reducing irreparable damages that can be caused due to climate change.

ACKNOWLEDGEMENT

Authors are grateful to National Institute of Hydrology, Roorkee and Bhopal for providing facilities to conduct the present research work. Authors are grateful to State Data Centre, WRD, Govt. of Madhya Pradesh, Bhopal and IMD, Pune for providing data and pertaining information. Authors are also grateful Chief Engineer (Yamuna Basin), CWC, New Delhi and Executive Engineer, Chambal Division, CWC, Jaipur for providing discharge data.

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