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Impact of Climate Change Using Trend Analysis of Rainfall, RRL AWBM Toolkit, Synthetic and Arbitrary Scenarios

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The integrated approach for assessment of the impact of climate change is important, as climate impacts are likely to transcend sectoral or regional boundaries, with impacts of change in hydrological and geological behaviour of one sector affecting the behaviour of another or simultaneously any other sector, or region, to respond. Modelling is often used by hydrologists in the analysis of empirical data to gain insights into the underlying dynamics of simulated runoff and its trend changing pattern. Thus, these models extrapolate from a climate-related (usually temperature-related) relationship derived by observations and experiment. The climate changes have adverse and drastic impacts on climate-sensitive sectors such as water resources, agriculture and ultimately livelihood and economy of the people. Thus consequently increase or decrease in temperature, rainfall and other climatic parameters due to climate change affect the river discharge, flood, reservoir storages, groundwater levels, soil moisture, evapotranspiration, crop production, sea levels

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etc. Keeping this insight patches of major changes from the whole study area were selected to assess the intensity of rainfall, discharge and the incremental impact of rainfall. The temporal analysis in selected patches revealed that increment and decrement in the study area simultaneously affect the runoff by the same proportion. The trend generated through the Mann-Kendall test not only helped in assessing the impact of climate change but also identified its causative actors. The results of the study can effectively be utilized for setting priorities of hydrological behaviour in different geographical regions at various scales.

Keywords: RRL AWBM toolkit; Mann-Kendall test; incremental method; hydrological; spatial; temporal.

1. INTRODUCTION

Modelling and analysing techniques of various kinds are used to study potential impact and responses of agriculture to changing the climate and atmospheric composition. The agricultural sector is well defined and chosen to illustrate the ranges of modelling techniques because agriculture field is a key socioeconomic and potential sector for development in many regions, agricultural land use is a primary driver of land-use change, and agriculture is a sector vulnerable to global and spatial environmental change [1,2]. The choice of technique depends on the data availability, sphere of analysis considered and the research questions proposed. The long-term climatic impact related to changes in rainfall patterns, rainfall variability, and temperature change will most likely increase the frequency of occurrence of droughts and floods in Asia and India in particular. The country's dependency on rain-fed and sustainable agriculture increases its vulnerability to the adverse effects of these climatic changes. Haifang et al. [3] used the spatial and temporal data of temperature, wind, precipitation, water discharge, and sediment load to estimate the change in runoff and sediment load of the Xiliugou basin in the upper Yellow River and the contribution of climate change and human activities to these changes were quantitatively and fundamentally estimated.

The assessment of climate change impact(s) mostly concentrates on the changing meteorological forcing, and the land-use-change and focuses more on the internal and external dynamics of the hydrological system. River water discharge is affected by several drivers such as land use changes, water withdrawals, anthropogenic interruption and climate variations. Variability in climate, and especially in rainfall and runoff, plays a significant role in flow variation Meng et al. [4]. In view of global warming, which will affect key climate variables such as rainfall and temperature, the changes in hydrological regimes could become even more important in the future Wuebbles and Ciuro [5]. Hydrological response of any river basin is dependent on various meteorological, environmental, physiological, geological, anthropological and many other parameters [6,7,8]. Climate change certainly has its impact on freshwater availability such as stream flow, discharge variation, reservoir, interflow, lakes or groundwater [9]. Adverse impacts of climate change on freshwater systems aggravate the impacts of other stresses, such as population growth, changing economic activity, land-use change and civilization [10,11,12]. Climate change may also have its impact on the groundwater regime of the river basin. Chiew et al. (2009) describes the modelling of climate change impact on runoff across southeast Australia using a conceptual rainfall-runoff model SIMHYD and presents the results and assesses the robustness of the modelling approach [13].

2. MATERIALS AND METHODS

2.1 Data Sources

Rinfall datasets were obtained from the India Metereological Department (IMD) data partially filled by Wharton Research Data (WRD). In this study, the data are from 4 stations where climate observations (temperature, solar radiation, wind speed, sunshine hours and relative humidity) were recorded every day from 1991 to 2010. These stations are well maintained and extensive quality checks were performed.

Upstream of its confluence with the Chambal, the Shipra has a catchment area of 5600 km^2. It is considered as sacred as the Ganga river by the Hindus. Shipra river is located at an average altitude of 553 metres above MSL. The region is known for its fertile soil, gentle slopes and moderate rainfall. The region has flat topography with very gentle slopes varying from 1 in 1000 to 1 in 3000. The river flows in a general north-westerly direction and has a very sinuous course.

The total course of river Shipra is about 190km which flows through Indore, Dewas and Gwalior districts of the state, it finally joins the Chambal near Kalu-Kher village (23° 53' N. and 75° 31"). The main tributaries of Shipra include the Khan river near Ujjain and the Ghambir river near Mahidpur. The main course of the Shipra lies over the grassy plains of Malwa between low banks and from Mahidpur and it is characterised by high rocky banks. The majority of the Shipra basin area (Fig. 1) falls in Indore and Ujjain districts however small part come under Ratlam & Dewas districts. The areas of districts fall in Shipra basin are given in Table 1. The rain gauging station considered in the study were Ujjain, Indore, Dewas and Sanwer.

2.2 Trend Analysis of Rainfall

Examining the spatiotemporal dynamics of meteorological variables in the context of changing the climate, particularly in countries like India where rainfed agriculture is predominant, is vital to assess climate-induced changes and suggest feasible adaptation and innovation strategies. To that end, trend analysis has been employed to inspect the change of rainfall in the Shipra river basin using gridded monthly precipitation data obtained from IMD data partially filled by WRD from 1991 to 2010. Data have been analyzed to detect the time series rainfall trend.

Mann (1945) presented a non-parametric test for randomness against time, which constitutes a particular application of Kendalls test for correlation commonly known as the Mann Kendall. The Mann-Kendall test is a non-parametric test for identifying trends in time series data Mugume et al. [14]. The test compares the relative magnitudes of the sample data rather than the data values themselves Gilbert and RO [15]. One benefit of this test is that the data need not conform to any particular distribution. Moreover, data reported as non-detects can be included by assigning them a common value that is smaller than the smallest measured value in the data set. The procedure

Table 1. District wise area distribution of Kshipra basin

S. No.	Name of district	Area under Shipra Basin (km2)
1	Ujjain	2421
2	Indore	1855
3	Ratlam	714
4	Dewas	689
Total Basin Area		5679

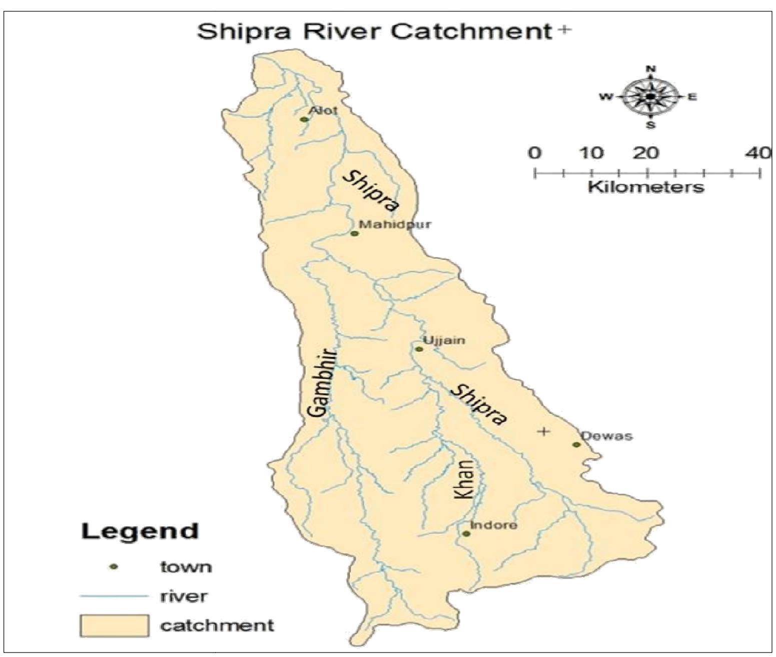

Fig. 1. Shipra river catchment and drainage network

that will be described in the subsequent paragraphs assumes that there exists only one data value per time period. When multiple data points exist for a single time period, the median value is used Mugume et al. [14].

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) to (4)

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

Where,

$$\text{sgn}(\theta) = \begin{cases} +1 \text{ if } \theta > 0 \\ 0 \quad \text{if } \theta = 0 \\ -1 \text{ if } \theta < 0 \end{cases} \quad (2)$$

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

$$\sigma^2 = \frac{\text{n}(\text{n}-1)(2\text{n}+5)}{18} \quad (3)$$

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

$$Z = \begin{cases} \frac{s-1}{\sigma} & \text{if s > 0} \\ 0 & \text{if } s = 0 \\ \frac{s+1}{\sigma} & \text{if s < 0} \end{cases} \quad (4)$$

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. The 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 a significant falling trend.

2.3 Assessment of Impact of Climate Change on Catchment Hydrology Using Incremental and Decremental Methods

In the present study, attempt has been made to study the impact of climate change on hydrological behaviour of the basin [16]. It involves the analysis of observed runoff data and modified runoff data for climate change condition using a suitable tool like rainfall-runoff model [17,18]. To carry out the analysis the runoff data of Shipra basin for the period from 1990 to 2010 was used. The weighted rainfall data of the Ujjain catchment comprising four rain gauge stations Ujjain, Indore, Dewas and Sanwer was tested for the existence of any trend using the Mann-Kendall trend test described in Section (2.2) above. 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. Then the runoff data was simulated for a climate change scenario using AWBM rainfall-runoff model. To achieve this, the rainfall-runoff model was developed in the Shipra river basin using *Rainfall-runoff* library (RRL). The incremental scenarios – also called synthetic or arbitrary scenarios – are the easiest scenarios one can develop and apply, and so the first one ever implemented. In those scenarios, one climatic parameter e.g. mean temperature, precipitation amount, etc is changed incrementally, perturbed from its historical records. This can provide quick information on a wide range of possible changes, by allowing the test of a lot of different parameters, to generate different future climate and it is applicable in any area of study [19,20].

In the current study the RRL Australian Water Basin Model (AWBM) model was calibrated (Figs. 2 and 3) and the parameters were set and the rainfall was incremented and decremented by 5% and 10% keeping all other parameters constant then the runoff was observed and the relation between simulated runoff of Shipra basin and incremented and decremented runoff was observed and the graph between them was plotted.

3. RESULTS

The model is run in genetic optimiser algorithm method and the primary objective selected is Nash- Sutcliffe Efficiency for the calibration and validation period and the results are depicted.

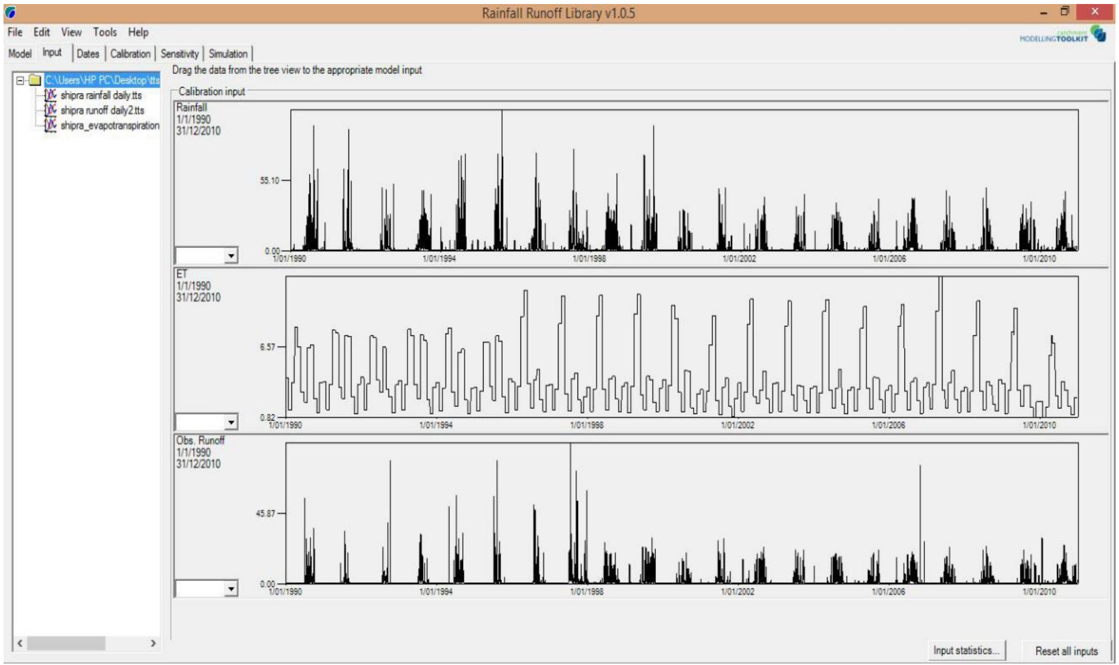

Fig. 2. Graphical representation of input data of RRL AWBM Model

Table 2. Results of AWBM RRL rainfall runoff model for calibration period

Parameters	AWBM RRL model
Coefficient of determination (R^2)	0.842
Coefficient of correlation (r)	0.910
Nash Sutcliff Efficiency (%)	82.3
Root Mean Square Error	41.40

Table 3. Results of AWBM RRL rainfall runoff model for validation period

Parameters	AWBM RRL model
Coefficient of determination (R^2)	0.658
Coefficient of correlation (r)	0.807
Nash Sutcliff Efficiency (%)	62.57
Root Mean Square Error	39.74

3.1 Trend Analysis of Rainfall

To understand the trends in climatic variables, the variation of annual rainfall from year 1990 to 2010 in all four rain gauging stations was done by analysis of anomaly time series of annual rainfall and Mann-Kendall test and were analyzed for presence of any trend which can be assessed visually in the data series as shown in Figs. 4-7.

From Fig. 4 it is observed that the annual rainfall of Dewas station is following a decreasing trend from the year 1990 to 2010 as the Z value -0.21. Therefore the trend is not a significant decreasing trend because Z is not less than 1.96.

From Fig. 5 it is observed that the annual rainfall of Indore station is following a significant decreasing trend from year 1990 to 2010 as the Z value -1.97. Therefore the trend is a significant decreasing trend because Z is less than 1.96.

From Fig. 6 it is observed that the annual rainfall of Sanwer station is following a decreasing trend from year 1990 to 2010 as the Z value -0.27 . Therefore the trend is not a significant decreasing trend because Z is not less than 1.96.

From Fig. 7 it is observed that the annual rainfall of Ujjain station is following an increasing trend from year 1990 to 2010 as the Z value 0.75. Therefore the trend is not significant increasing trend because Z is not less than 1.96.

Fig. 8 depicts the trend of all the four raingauge stations that are Indore, Ujjain, Dewas and Sanwer.

3.2 Comparison of Simulated Runoff of Shipra River Basin and Simulated Runoff of Indore District

The simulated runoff of the Shipra river basin was obtained from RRL AWBM rainfall runoff for the whole period that is from 1/1/1990 to 31/12/2010 and it was assumed that the rainfall in the Indore district is the rainfall of the whole basin and the model was run keeping all other set parameters constant and the simulated runoff was obtained. Subsequently, the simulated runoff of the Shipra river basin and the simulated runoff of the Indore district was evaluated.

From Table 4 and Fig. 9 it can clearly be depicted that the simulated runoff of the Indore district was subsequently less than the simulated runoff of the Shipra river basin.

Table 4. Z value for annual rainfall for year 1990 to 2010

Raingauge station	Z Value
Dewas	-0.21
Ujjain	0.75
Sanwer	-0.27
Indore	-1.97

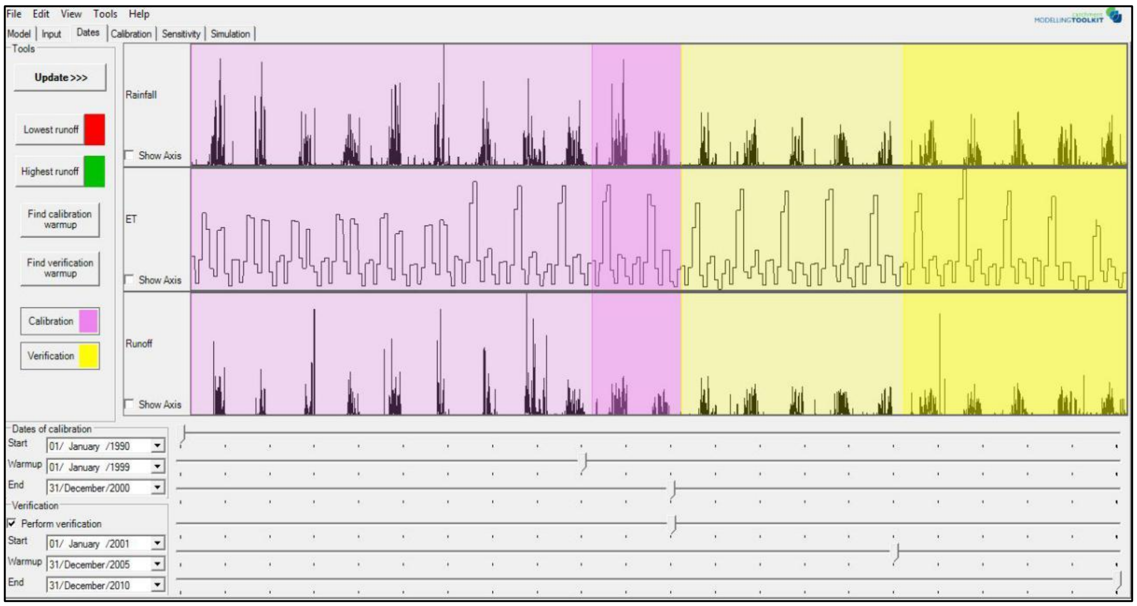

Fig. 3. Setting of calibration and validation time series in the model

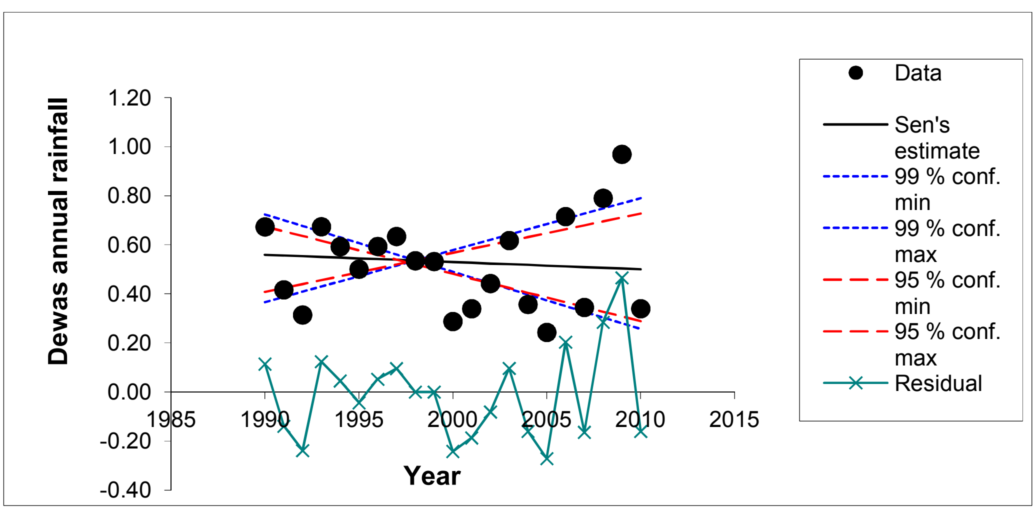

Fig. 4. Graphical trend analysis of rainfall at Dewas station

4. DISCUSSION

Our results document the long-term averages and trends of rainfall and runoff in the Shipra river basin between 1990 and 2010, and the effects of increment and decrement (Tables 6 and 7). The evaluations of the paper revealed a number of issues relating to protocols for modelling impacts of climate change on simulated runoff. Issues noted regarding access to papers may have slightly biased with the results, but the trends seem likely to hold and of course, are directly relevant to the various number of papers that were reviewed. Based on the analysis method used in our assessment, no single technique would be judged as "complete." A "complete" technique would fully justify the selection of analysis technique, locations, and models output (Tables 2 and 3) and evaluate key responses of the climate change including sources of uncertainty, apply the incremental (Table 6) and decremental (Table 7) scenarios (with a robust methodology for down-scaling, use clearly described output from model that reflect variation in discharge (Figs. 10 and 13) and consider various options for adaptation selected in part through consulta-tion with producers, and analyze the results both in terms of impacts and variability or risk.

This methodology has allowed a systematic comparison of climate change experiments across four rain gauging stations (Table 4). In the current study the RRL AWBM model was calibrated and the parameters were set and the

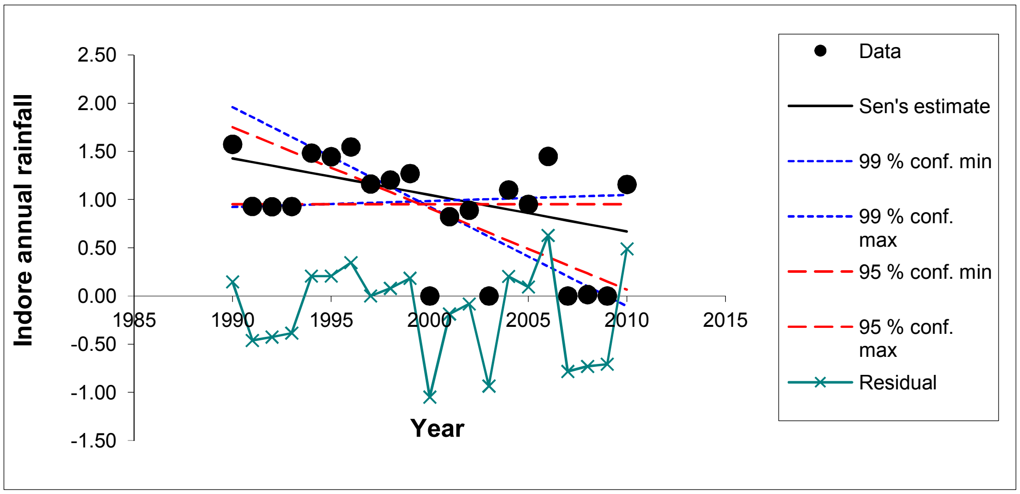

Fig. 5. Graphical trend analysis of rainfall at Indore station

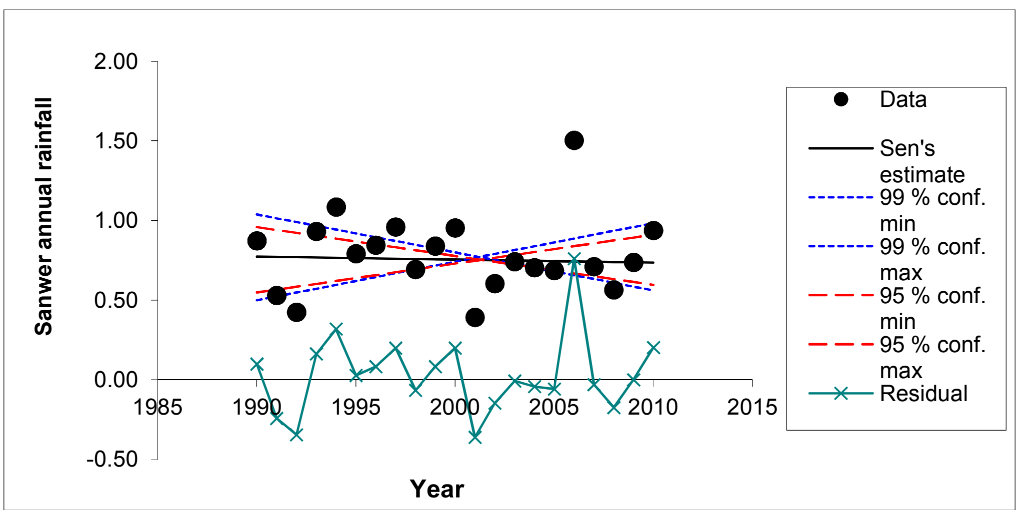

Fig. 6. Graphical trend analysis of rainfall at Sanwer station

rainfall was incremented and decremented by 5% and 10% keeping all other parameters constant then the runoff was observed and the relation between simulated runoff of Shipra basin (Table 5) and incremented and decremented runoff was observed (Figs. 11,12 to Figs. 14,15). The long-term effectiveness of experiments and their interaction across scales are issues beyond the scope of this analysis to be addressed with future research [21,22,23]. However, along with case-study based research, this methodology provides a fruitful and beneficial avenue to understand climate change and runoff experimentation in context. Revealing the underlying drivers in climate change experimentation, factors hindering action, effectiveness on the ground and impact could be further developed through additional survey work, focused on specific regions or metro politan areas. Overall, the methodology reveals the heterogeneity and ubiquity of climate change experimentation and traces the opening up of new spaces for climate change governance in the area [24,25,26].

The new method of analysis gives a formulated set of AWBM parameter values that can be used to estimate runoff from a group of catchments to any required degree of precision if small adjustments of input data that is precipitation are made. The adjustments of areal precipitation in the order of ≤ 10% are within the accepted range of errors in estimating areal precipitation for rainfall- runoff modelling

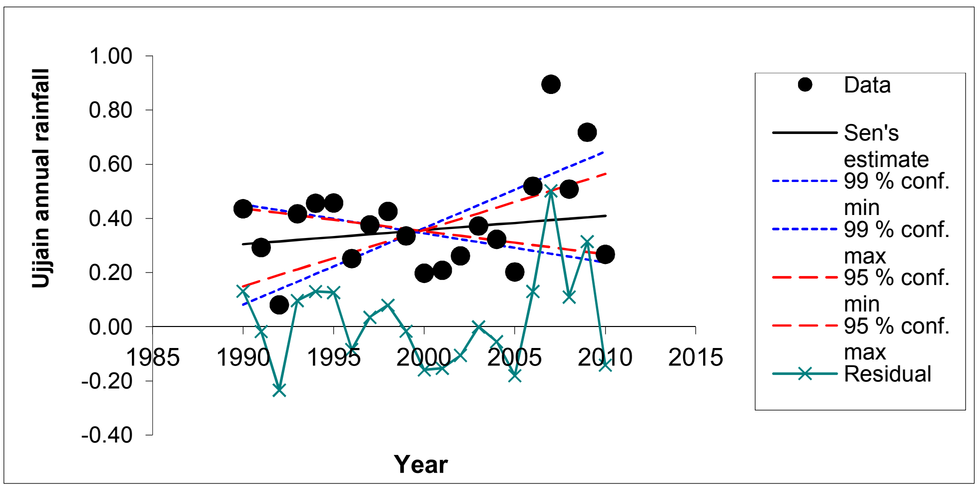

Fig. 7. Graphical trend analysis of rainfall at Ujjain station

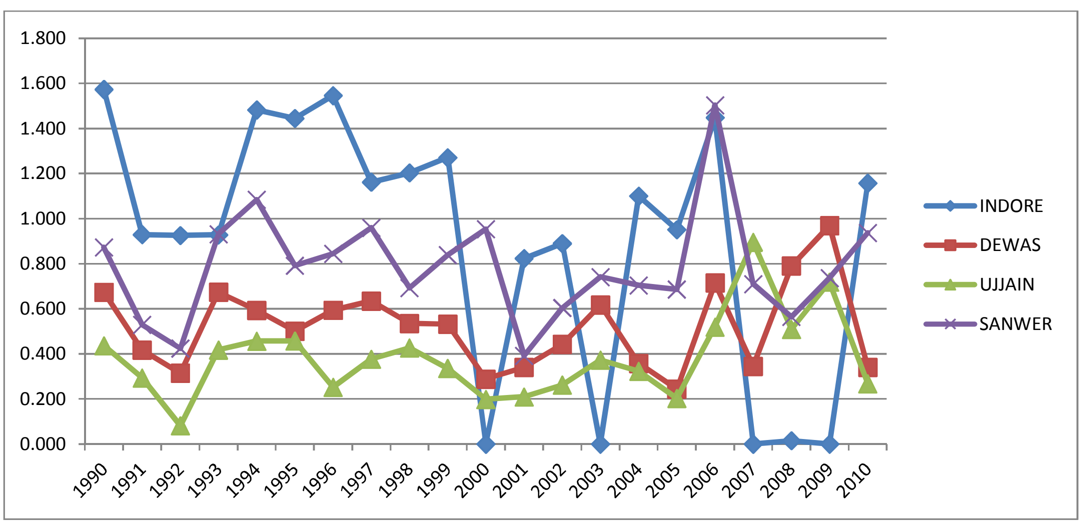

Fig. 8. Graphical representation of trend of annual rainfall of all four stations

Table 5. Comparison of simulated runoff of Indore district and simulated runoff of Shipra river basin

Year	Simulated runoff of Shipra basin (mm)	Simulated runoff of Indore (mm)
1990	478.28	186.40
1991	354.68	136.01
1992	237.25	41.73
1993	377.96	98.28
1994	669.65	186.84
1995	464.64	205.87
1996	417.87	225.55
1997	460.85	152.41
1998	419.69	156.55
1999	516.49	185.72
2000	197.54	273.50
2001	245.14	120.21
2002	291.5	102.39
2003	241.12	156.87
2004	276.14	159.55
2005	175.6	138.37
2006	393.49	199.41
2007	215.22	124.98
2008	251.43	175.97
2009	348.53	123.98
2010	326.54	159.40

on catchments ≥ 100 km^2. A single set of parameter values can be used to estimate runoff from any catchments in the same region as the gauged catchments used to determine the values. This provides a systematic method of runoff generating parameters among the gauged catchments in a region for use on ungauged catchments. The method specifically allows for errors in the estimation of areal rainfalls in the catchments by normalizing the rainfall adjustments in the calibration and validation process Uniyal et al. [27].

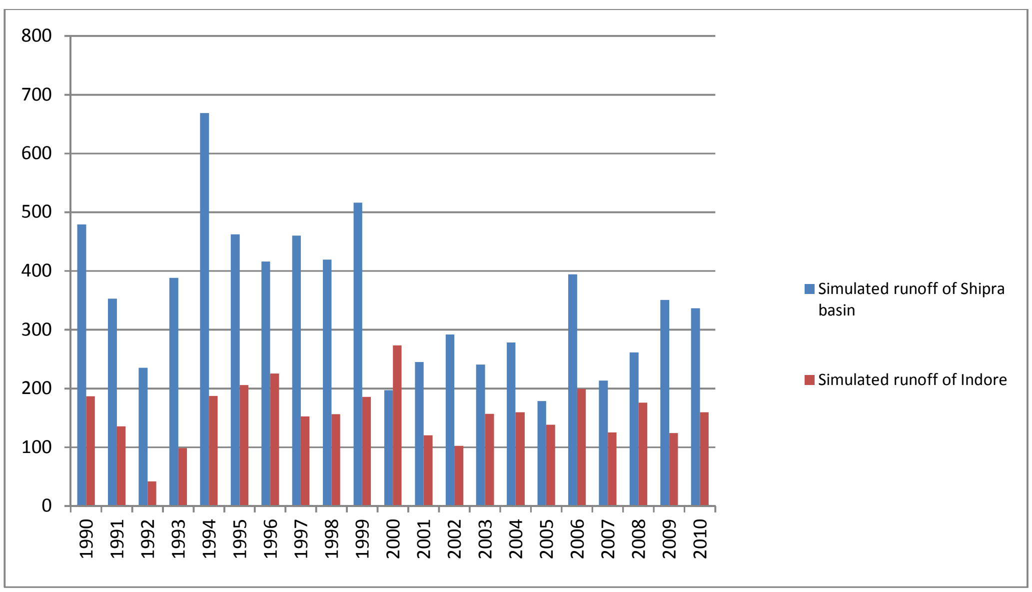

Fig. 9. Comparison of simulated runoff of Indore district and simulated runoff of Shipra river basin

Table 6. Comparison of runoff with 5% increment and decrement rainfall

Year	Reference runoff of Shipra basin (mm)	Potential runoff when rainfall increased by 5% of average rainfall (mm)	Climate change runoff when rainfall decreased by 5% of average rainfall (mm)	% Increase with respect to reference runoff	% Decrease with respect to reference runoff
1990	478.28	510.85	450.89	6.809819	-5.72677
1991	354.68	370.78	330.1	4.539303	-6.93019
1992	237.25	247.99	224.25	4.52687	-5.47945
1993	377.96	397.72	362.69	5.228066	-4.04011
1994	669.65	705.22	639.44	5.31173	-4.51131
1995	464.64	487.17	443.62	4.848915	-4.52393
1996	417.87	438.86	397.21	5.023093	-4.94412
1997	460.85	486.57	440.25	5.580992	-4.47
1998	419.69	445.08	397.07	6.049703	-5.38969
1999	516.49	552.43	495.45	6.958508	-4.07365
2000	197.54	207.27	183.95	4.925585	-6.87962
2001	245.14	257.72	234.56	5.131761	-4.3159
2002	291.5	306.56	274.83	5.166381	-5.7187
2003	241.12	252.58	229.51	4.75282	-4.81503
2004	276.14	288.31	259.46	4.407185	-6.04041
2005	175.6	185.05	165.35	5.381549	-5.83713
2006	393.49	415.23	374.94	5.524918	-4.71422
2007	215.22	227.99	204.54	5.933463	-4.96236
2008	251.43	265.7	238.19	5.675536	-5.26588
2009	348.53	362.92	326.85	4.128769	-6.22041
2010	326.54	346.49	304.47	6.109512	-6.75874

Table 7. Comparison of runoff with 10% increment and decrement rainfall

Year	Reference runoff of Shipra basin (mm)	Potential runoff when rainfall decreased by 10% of average rainfall (mm)	Climate change runoff when rainfall increased by 10% of average rainfall (mm)	% increase with respect to reference runoff	% decrease with respect to reference runoff
1990	478.28	431.34	536.97	12.27105	-9.81433
1991	354.68	309.33	397.09	11.95726	-12.7862
1992	237.25	205.17	264.54	11.50263	-13.5216
1993	377.96	347.62	425.9	12.68388	-8.0273
1994	669.65	608.8	754.11	12.61256	-9.08684
1995	464.64	412.64	526.82	13.3824	-11.1915
1996	417.87	376.8	467.45	11.86493	-9.82842
1997	460.85	414.35	498.72	8.217424	-10.0901
1998	419.69	375.75	455.61	8.558698	-10.4696
1999	516.49	459.45	582.74	12.82697	-11.0438
2000	197.54	178.08	218.01	10.36246	-9.85117
2001	245.14	216.47	278.33	13.5392	-11.6954
2002	291.5	256.25	328.23	12.60034	-12.0926
2003	241.12	214.83	267.49	10.93646	-10.9033
2004	276.14	250.38	310.98	12.61679	-9.3286
2005	175.6	153.17	198	12.75626	-12.7733
2006	393.49	353.1	432.04	9.796945	-10.2646
2007	215.22	187.99	238.45	10.79361	-12.6522
2008	251.43	216.71	278.89	10.92153	-13.809
2009	348.53	302.9	378.28	8.535851	-13.0921
2010	326.54	287.4	367.42	12.51914	-11.9863

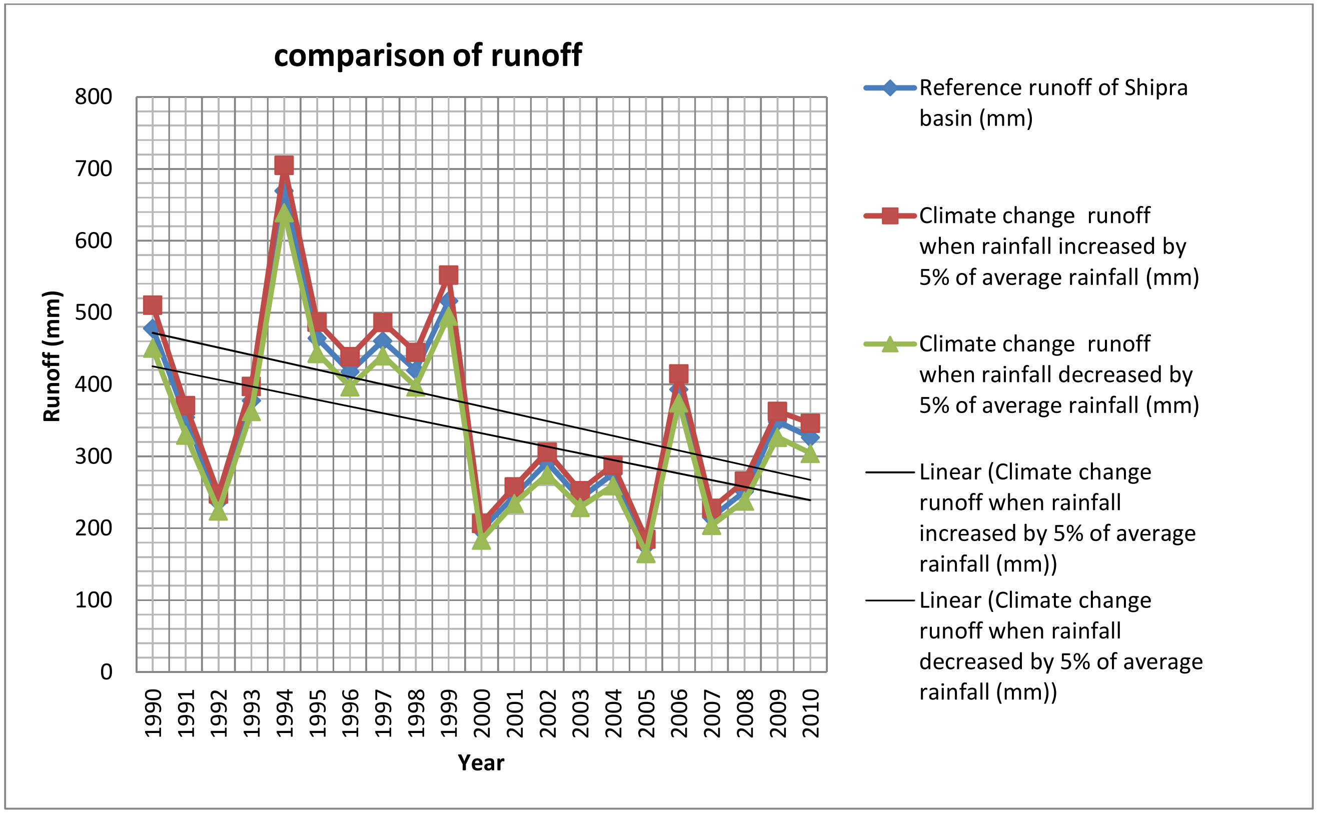

Fig. 10. Comparison of runoff when rainfall increased and decreased by 5%

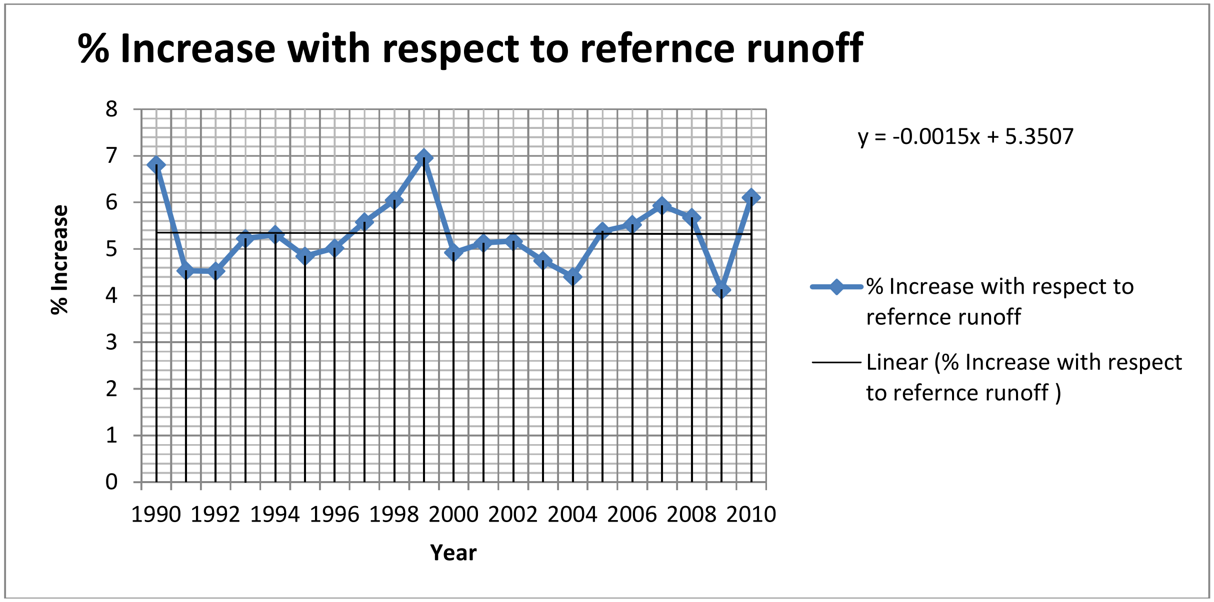

Fig. 11. % Increase with respect to refernce runoff when rainfall increased by 5%

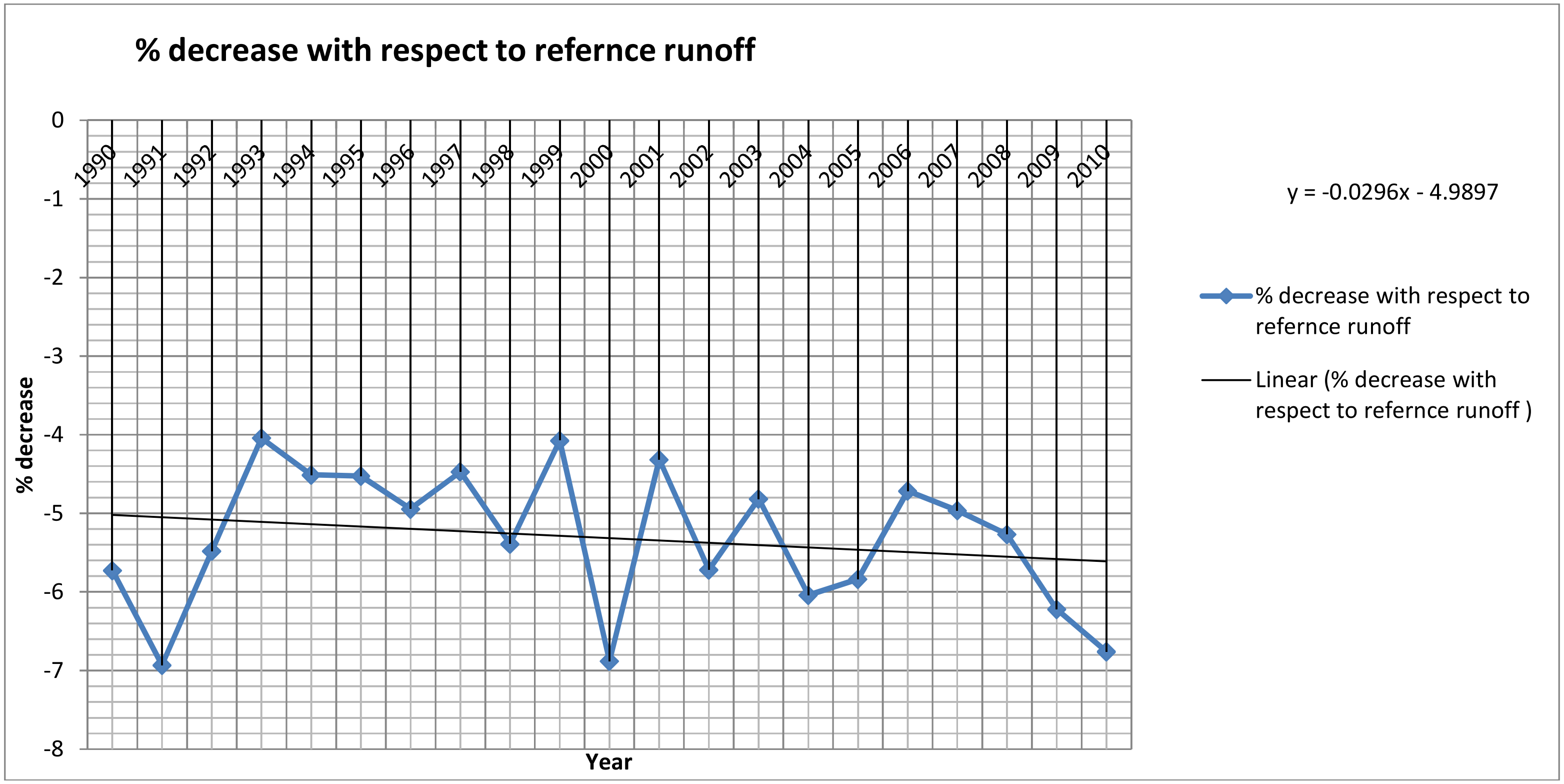

Fig. 12. % Decrease with respect to reference runoff when rainfall decreased by 5%

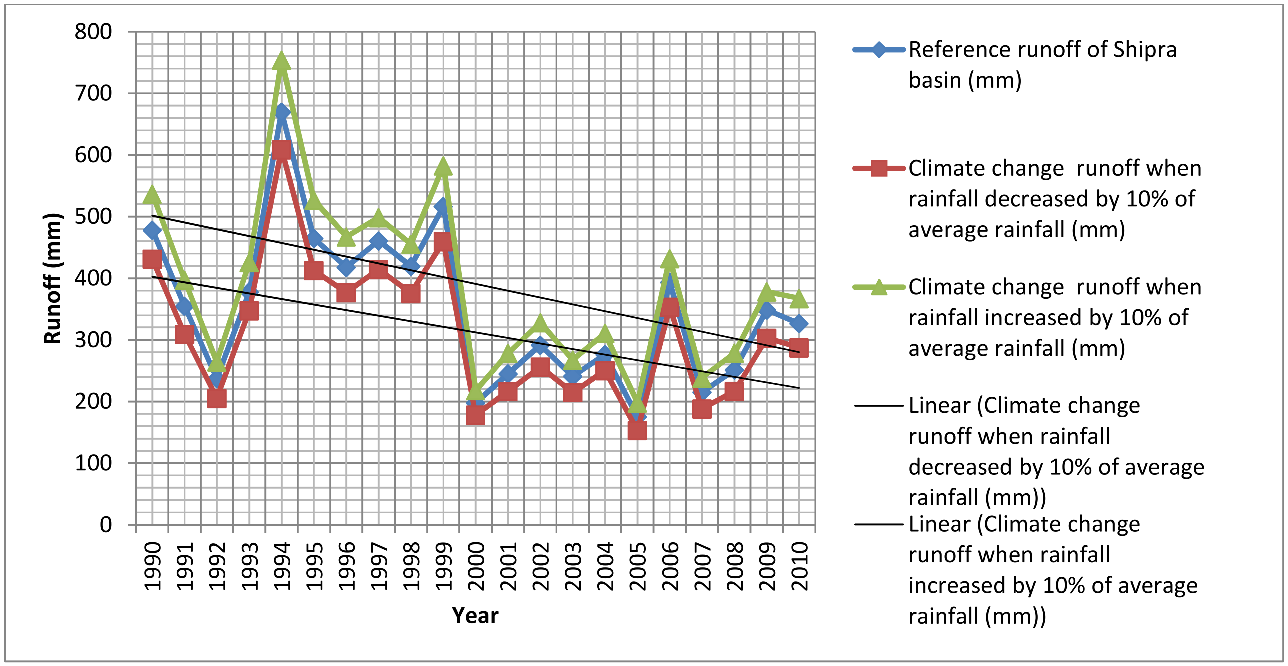

Fig. 13. Comparison of runoff when rainfall increased and decreased by 10%

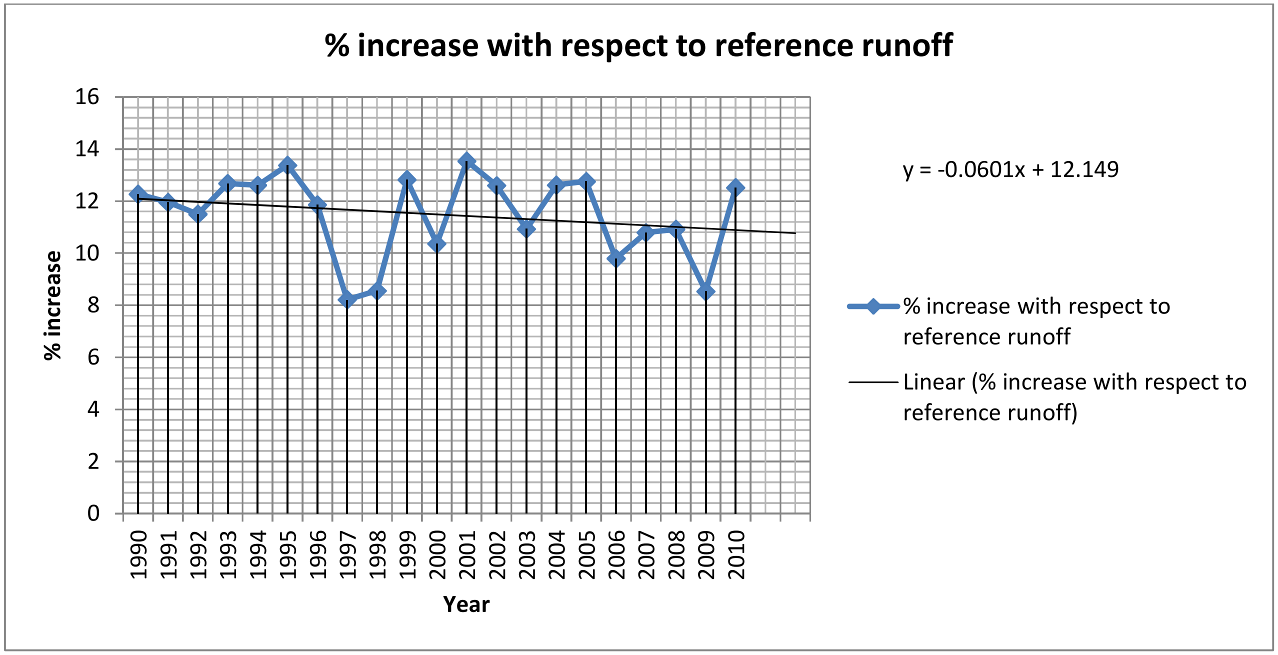

Fig. 14. Percentage increase with respect to reference runoff when rainfall increased by 10%

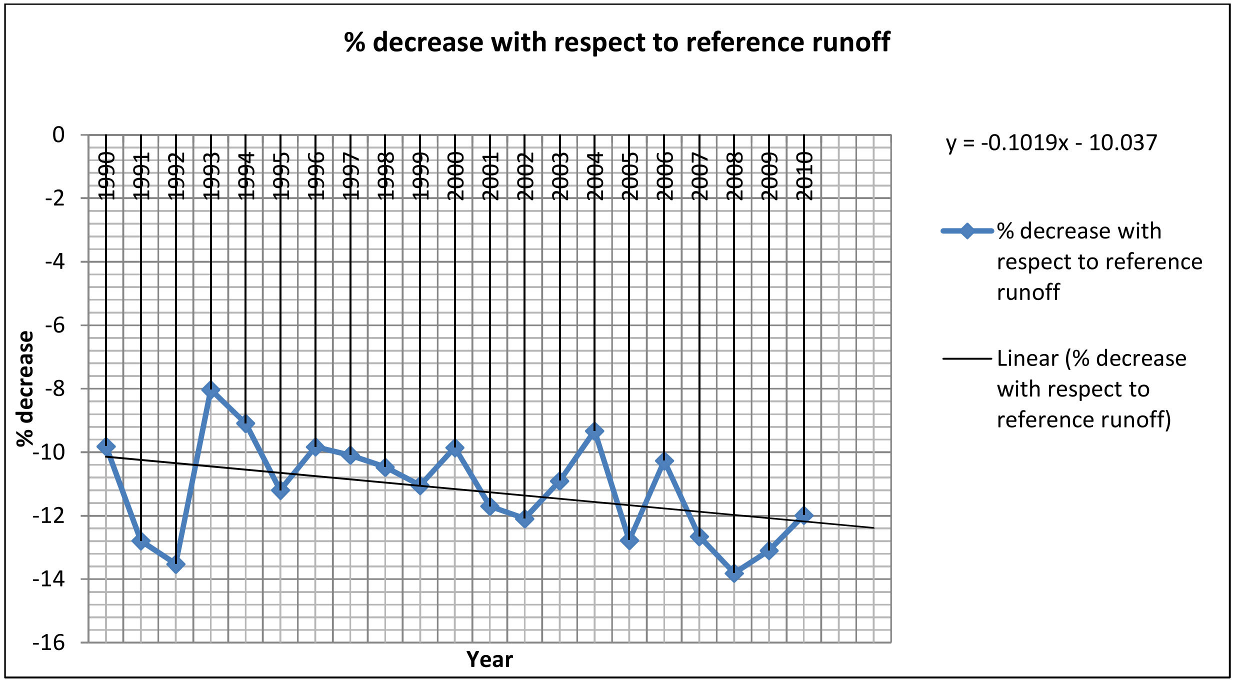

Fig. 15. Percentage increase with respect to reference runoff when rainfall decreased by 10%

5. CONCLUSION

This study presented the impact of climate change on runoff from Shipra river basins in Ujjain that cover a combined area of 2012 km^2, using RRL AWBM hydrological models for the time series 1990-2010. Overall, the mean annual runoff will increase in the future by between 2 and 18%. The associated uncertainty is also substantial and the coefficient of correlation ranges from 0.80 to 0.93. The most rapidly increasing trends of the runoff is shown for the basin when the rainfall was incremented by 5 and 10%. The substantial uncertainty in the runoff was attributed to the uncertainty in the projected rainfall, however; a direct relationship could neither be determined by river basin nor RCP or time period. Overall, a runoff will increase because the increase in rainfall was predicted to be larger than the increases in evapotranspiration demand over the study area. The performance of the hydrological model in climate change impacts assessment is looked into by comparing the baseline flows under incremental scenarios, with the observed flows. The validated model when provided with the future climate variables, i.e. daily rainfall values as inputs, generated the future streamflows at the outlet of the basin. The impacts of climate change on the hydrology of the study area are then investigated by comparing the flows, PET, and water balance during the baseline (1990-2010).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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