Estimating the impact of climate change and human activities on streamflow variability in the Han River Basin, South Korea

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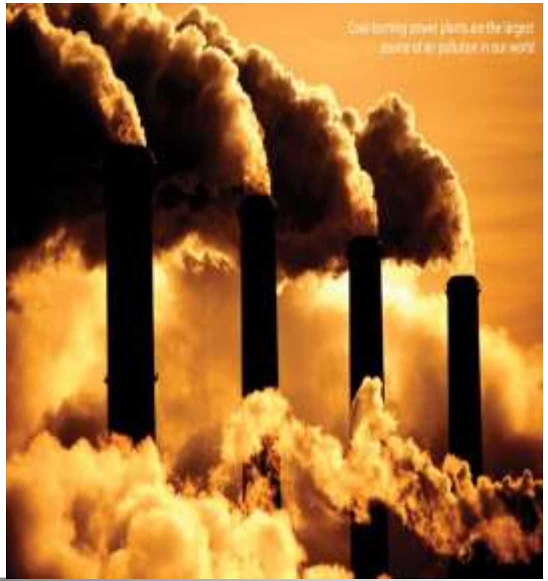
1. Introduction and Literature Review

- Climate change can be defined as a long-term shift in surface temperature and variation in typical weather patterns found in place (NASA).
- During last century, due to extensive burning of fossil fuels, A substantial amount of greenhouse gases (GHGs) has been released from the burning of fossil fuel disturbed the neutral atmosphere.
- The main driver of climate change is the greenhouse effect which causes global warming.
- Global warming has become a core concern of research in the area of hydrology and water resources (Huntington, 2006).
- This warning in the global temperature eventually results changes in rainfall, air temperature, potential evaporation, sunshine hours, humidity, or other climate variables that can lead to the possible alteration in the natural hydrological cycle (Heidari et al., 2020; Wang and Hejazi, 2011).
- The hydrological cycle is the driving factor of the physical and ecological processes on the Earth’s surface and a huge impact on the survival of the living organisms, particularity human beings (Zhang et al. 2015).



1. Introduction and Literature Review

- ❖ The streamflow is a most important element of the hydrological cycles, variation in the streamflow might be a cause of hydrological disaster.
- ❖ Therefore, it is primary important to accurately compute and forecast the temporal inconsistencies of streamflow (Ma et al. 2010).
- ❖ Experimental evidence from various parts of the globe has proven that the variation in the streamflow observed in response of **combined effects of climate and human activities**.
- ❖ Climate factors includes; changes precipitation, temperature, PET, humidity etc.
- ❖ Human activities includes; Change in Land use Land cover, construction of hydraulic structures, urbanization, deforestation and pattern of agriculture irrigation

2. Research Question..?

- A rapid variation in streamflow raised core social and ecological issues in the various parts of the world.
- The accessibility and inconsistency of water supplies stressed by sustainable growth of human society have tigered global concerns in quantifying the **effects on climate and human activities on streamflow in the basin.**
- Therebefore, significant attention is need to overcome impact studies on the watershed in the large basins having vulnerable climate conditions, to enhance the knowledge considering the climate and human activities in the vulnerable water resources.
- This study **Estimates the effect of climate change and human activities on streamflow variability in the Han River Basin, South Korea**, using streamflow time series, in combination with break/change points determination, trend analysis, hydrological modeling and sensitivity analysis.

3. Study Area & Data

- The Han River basin (HRB) is one of largest River basins of South Korea, the river is located in the middle of Korean Peninsula 37°0’ - 38°10’ latitude and 126°30’ - 127°40’ longitude, as shown in Figure 1.

- Han River provides main source of water for drinking, industry, irrigation, and hydropower generation.

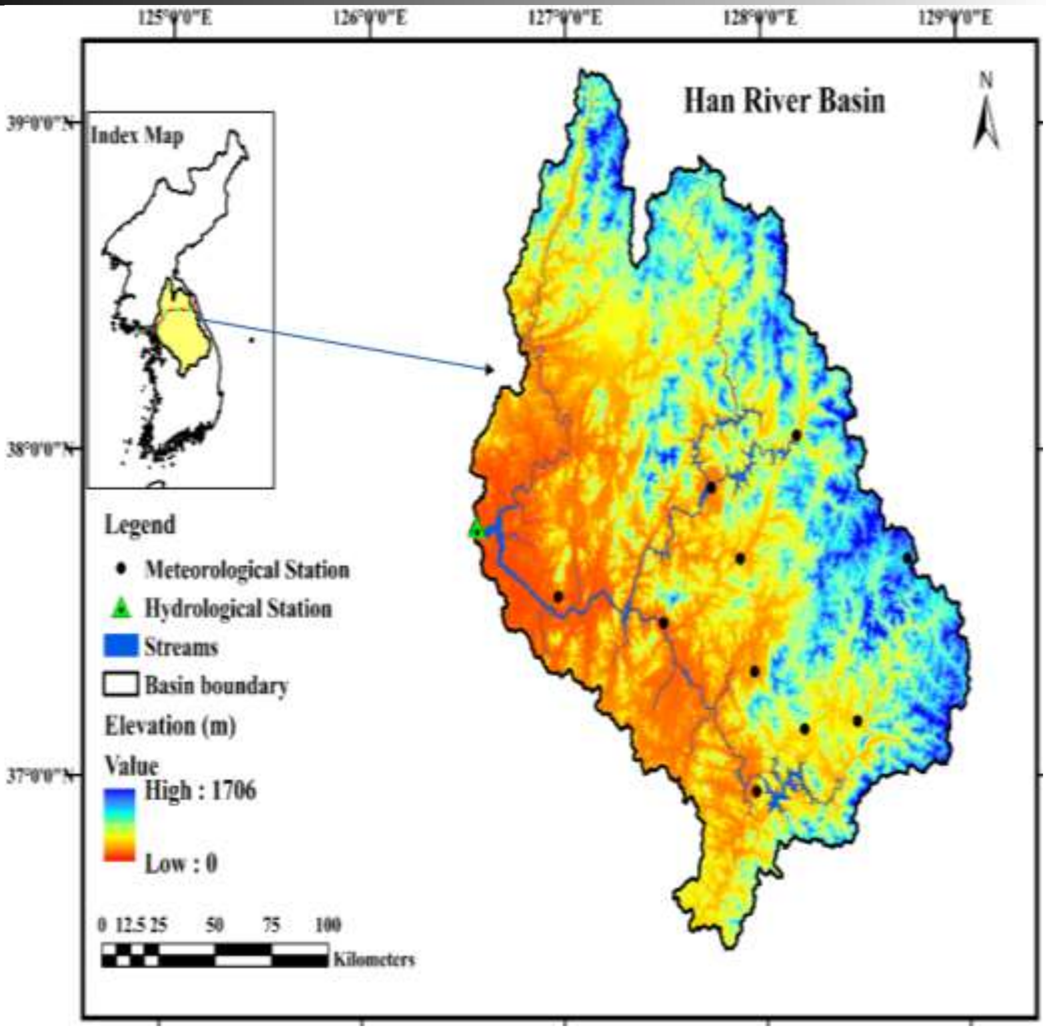


Fig. 1 Study area map and location of hydro-meteorological stations

Study Area & Data Conti…

- The meteorological data; **daily precipitation, temperature** (max and min) for a period of (1978-2014) were obtained from the official website of the **Korea Metrological Administration** (http://www.data.kma.go.kr).

- Monthly discharge, LULC and population data for various periods were collected from the official website of Water Management Information System (http://www.wamis.go.kr/Main.aspx).

- Hargreaves Eq. were used to generate PET data set.

Research Flow

- Study area **Han River basin,** was selected for research
- Main objective is to estimate the impact of climate change and human activities on streamflow variability in HRB.
- Data of monthly precipitation, maximum, minimum, mean temperature and runoff were collected for the period of 1978-2014.
- Pettit test was used to identify change point in hydrological time series, and **Mann-Kendall** was used for trend analysis.
- Temperature based **Hargreaves Method** was used to estimate **Potential Evapotranspiration**.
- **Hydrological Model (HM) and Multi-regression Model (MRM)** was used to reconstruct natural streamflow series in the impacted period.
- Separation framework was adopted to quantify and decompose the effects of each Climate change and Human Activities on streamflow conditions.

Research Framework and Results

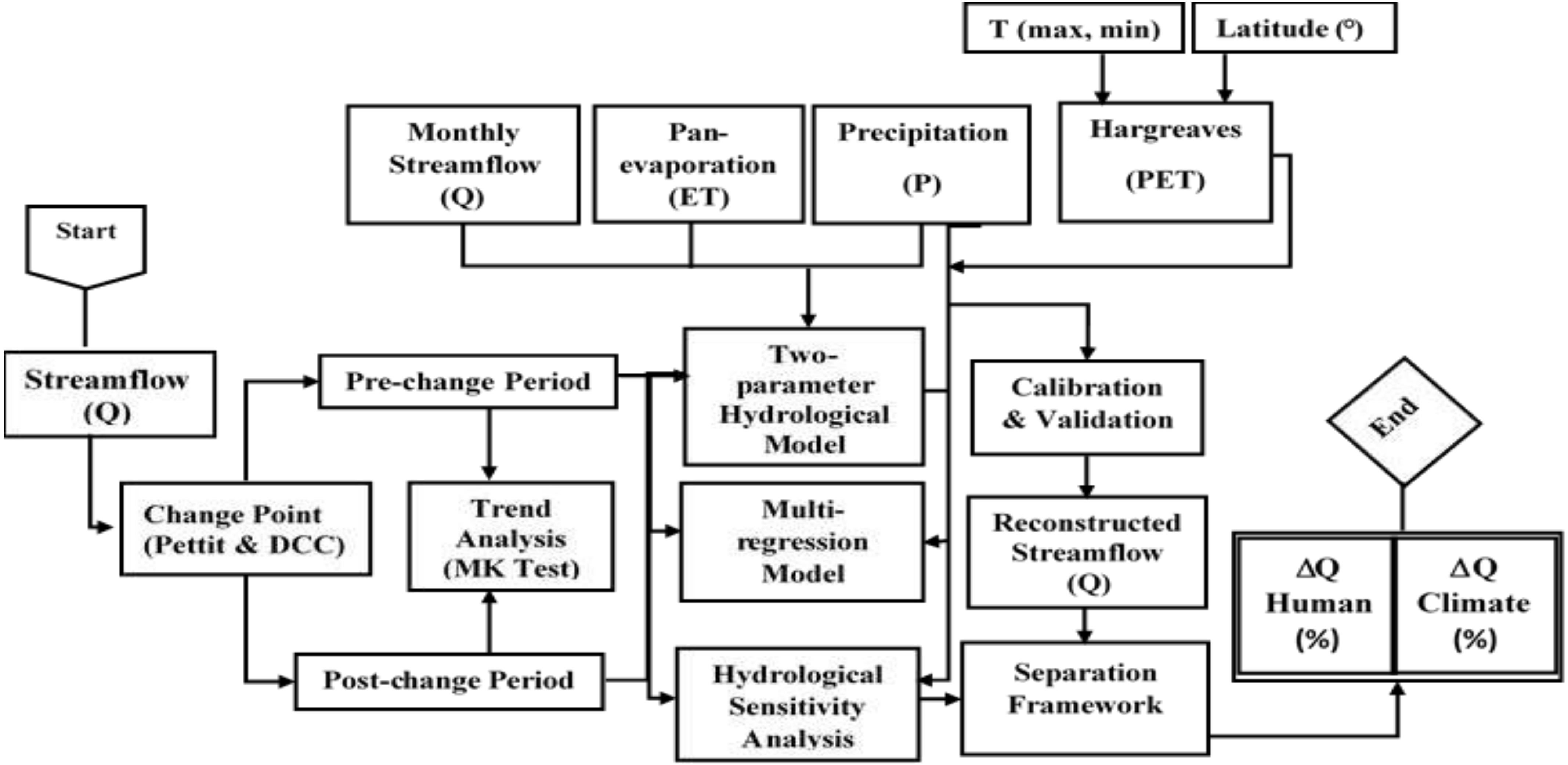


Fig. 2 Comprehensive methodology adapted in the study.

Step 01: Determination of Change Point

b) Double Mass Cumulative Curve (DCC)

- A DCC is widely used to determine hydrological change triggered by human activities.

- Generally, a DCC is a straight line; a change in the slope of the arc indicates that the primary relationship between rainfall and streamflow changes.

- Here, a DCC between rainfall and streamflow was applied for auxiliary validation of break/change points.

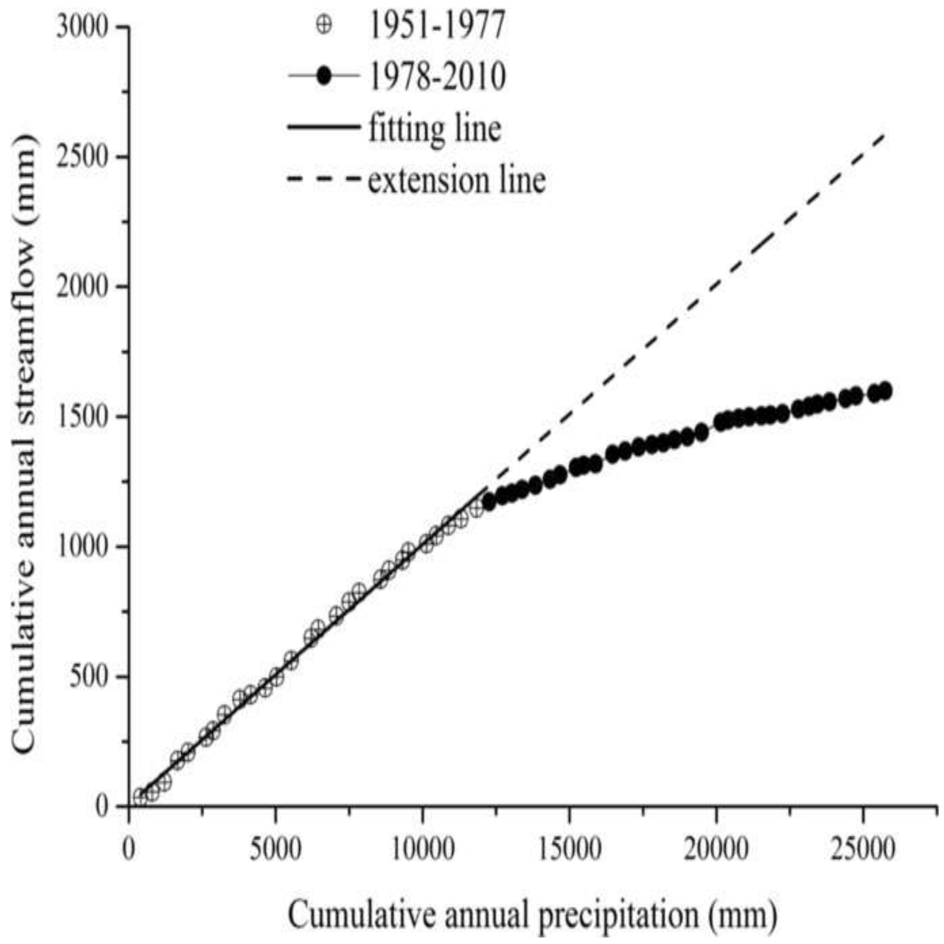


Fig 3. Double cumulative curve (Lv, X. *et al. 2011*)

Step 02: Investigation of Trend

In this study, trends in hydro-meteorological time series were examined using a non-parametric Mann-Kendall (MK) test. The test was selected for its strong performance with non-normally distributed datasets. The test's Z statistic was estimated as follows:

$$\mathbf{Z} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, if \;\; S > 0 \\ 0, \qquad\qquad if \;\; S \\ \frac{S+1}{\sqrt{Var(S)}}, if \;\; S < 0 \end{cases} \quad \Rightarrow \quad S = \sum_{k=1}^{n-1} \sum_{l=i+1}^{n} sgn(x_l - x_k) \qquad (3)$$

where *n* indicates the number of observations in the time series, $x_{k,}$ and x_l are the kth and *lth* observations

(*l* > *k*). The sign function *sgn* $(x_l - x_k)$ was determined as follows:

$$(\theta) = \begin{cases} 1, & if \;\; \theta > 0 \\ 0, & if \;\; \theta = 0 \\ -1, & if \;\; \theta < 0 \end{cases} \qquad Var\ (S) = \frac{n(n-1)(2n+5) - \sum_{q=1}^{r} t_q\,(t_q - 1)(2t_q + 5)}{18} \qquad (5)$$

where t_q is the measure of tie among the data and $\sum t_q$ indicates the sum of all ties.

Step 03: Hydrological Simulation

I- Hydrological Model

Natural runoff reconstruction is necessary in human impact assessment studies (Jiang et al. 2018).

A monthly hydrological model were used to reconstruct streamflow.

The model requires monthly precipitation and evapotranspiration as input, and yields monthly streamflow, actual evapotranspiration, and soil moisture content (Fig 4), & are given by;

$$E(t) = K \times EP(t) \times tanh\left(\frac{P(t)}{EP(t)}\right) \quad (6)$$

K indicates the first model parameter. The monthly streamflow is closely associated with soil water content, as follows:

$$Q(t) = \omega(t) \times tanh\left(\frac{\omega(t)}{FC}\right) \quad (7)$$

where *Q(t)*, *ω (t)*, and *FC* indicate the monthly streamflow, the soil water content, and field capacity, respectively.

Eq. (7) was used to estimate the t[th] month streamflow of

$$Q(t) = [\omega(t-1) + P(t) - E(t)] \times tanh\left(\frac{\omega(t-1)+P(t)-E(t)}{FC}\right) \quad (9)$$

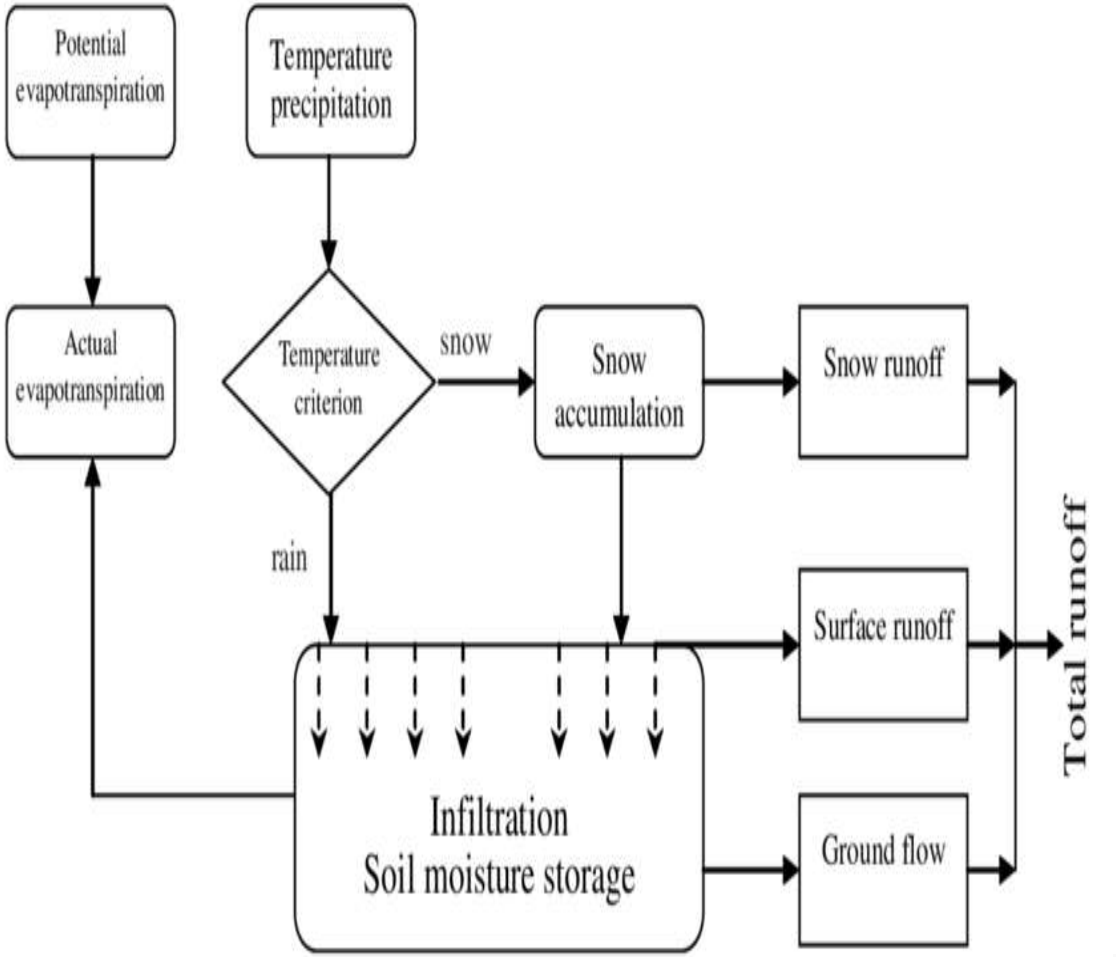


Fig. 4 Sketch of Hydrological model

Step 03: Hydrological Simulation

II- Multi-regression Model

In this model, the monthly streamflow was associated with monthly precipitation and potential evaporation. It was estimated for the baseline period as follows:

$$Q_n = a \times P_n + b \times PET_n + c \quad (11)$$

Where $_n$ indicate pre-change (natural) period, respectively. Q_n is observed streamflow. *a*, *b*, and *c* are the regression parameters.

$$Q_h = a \times P_h + b \times PET_h + c \quad (12)$$

Thus, $\Delta Q_{human} = (Q_h - Q'_h)$ is the change in the streamflow associated with the effects of human activities.

III. Hydrological Sensitivity Analysis

The hydrological sensitivity can be specified as yearly change measured in streamflow triggered by variation in the precipitation and potential evapotranspiration, and are give by:

$$\Delta Q_{Climate} = \alpha \Delta P - \beta \Delta ET \quad (13)$$

where α and β represent sensitivity coefficients of streamflow to climate variables precipitation and potential evapotranspiration, respectively.

These sensitivity coefficients can be calculated by mothed described in Li et al., (2007) and Ma et al., (2008).

Results: Determination of Change Point

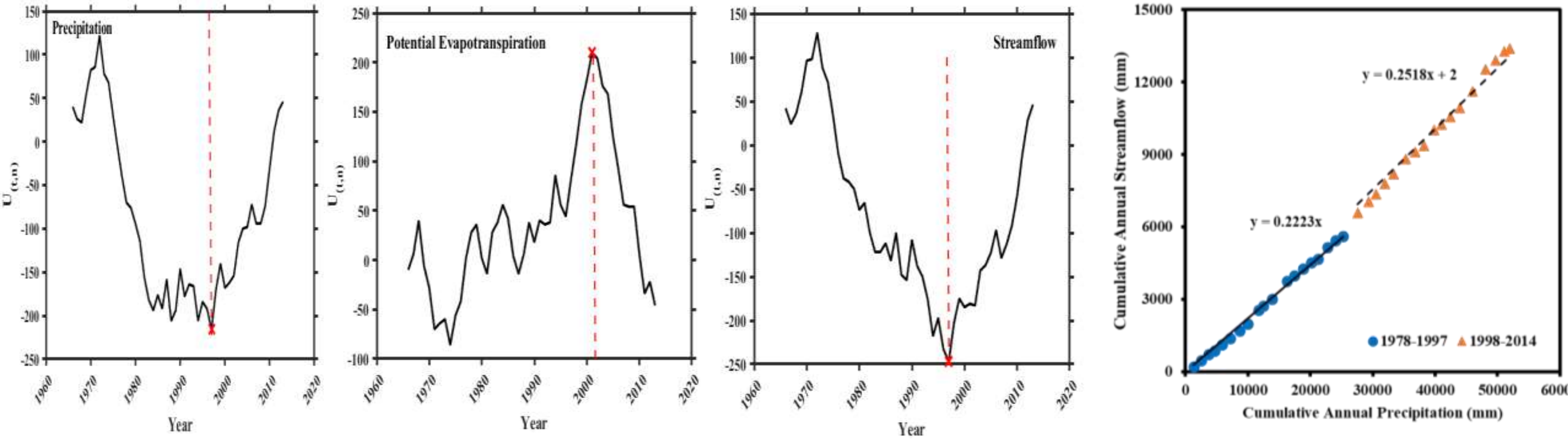


Fig.5 Illustration of the change point in the times series using Pettitt test and double mass cumulative curve

The change point in precipitation and streamflow were observed in 1997, therefore we divided timeseries into two parts as; pre-change period (1978-1997) and post-change period (1998-2016)

Results Conti….

Trends in Hydrometeorological Parameters

- Trend in hydro-metrological parameter was measured using Mann-Kendall approach and presented in Figure 6.
- Negative values of Z_{mk} were observed during pre-change period (1978-1997) indicating decreasing trend.
- However, in post-change period positive values were observed which show a shift of hydrometeorological trend from decreasing to increasing trend.

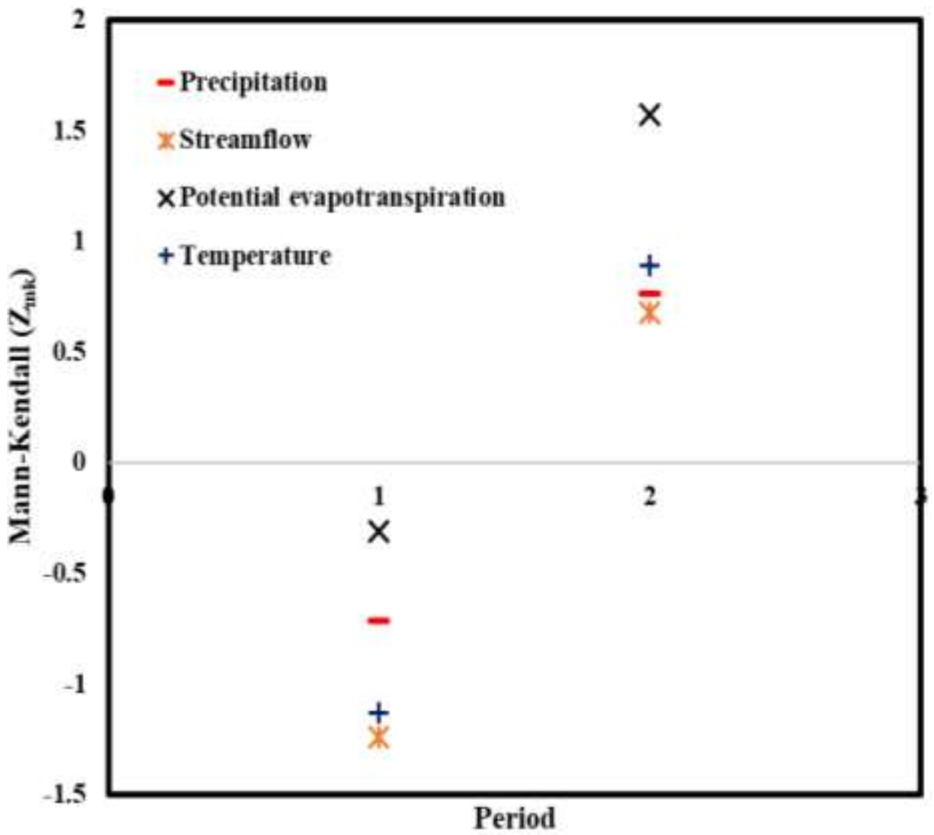


Figure 6 Variation in trend in hydro-meteorological sub-series for (1) baseline period and (2) post-baseline period

Results Results of Hydrological Simulation

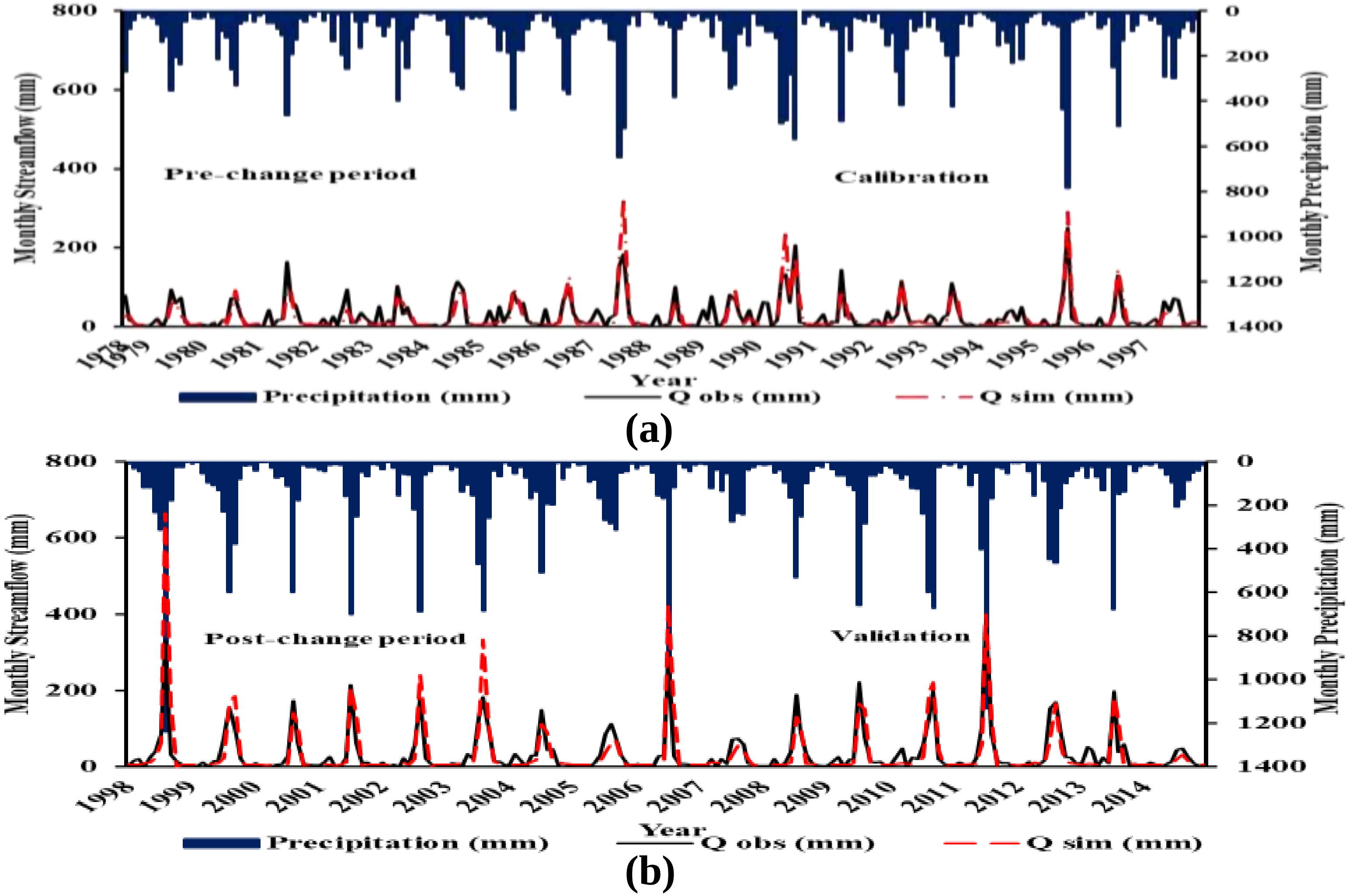


Fig. 7 Reconstruction of monthly streamflow using a two-parameter hydrological model for (a) the pre-change period (calibration) and (b) the post-change period (validation)

Table 1. Performance evaluation of hydrological models

Model	Natural Period (Calibration)				Human-induced Period (Validation)			
	R	NSE	BIAS(%)	RMSE	R	NSE	BIAS(%)	RMSE
Multi-regression	0.934	0.872	-0.202	14.082	0.970	0.940	1.340	14.564
Two-parameter Hydrological Model	0.85	0.85	1.34	22	0.899	0.914	-2.02	37

Results of Hydrological Simulation

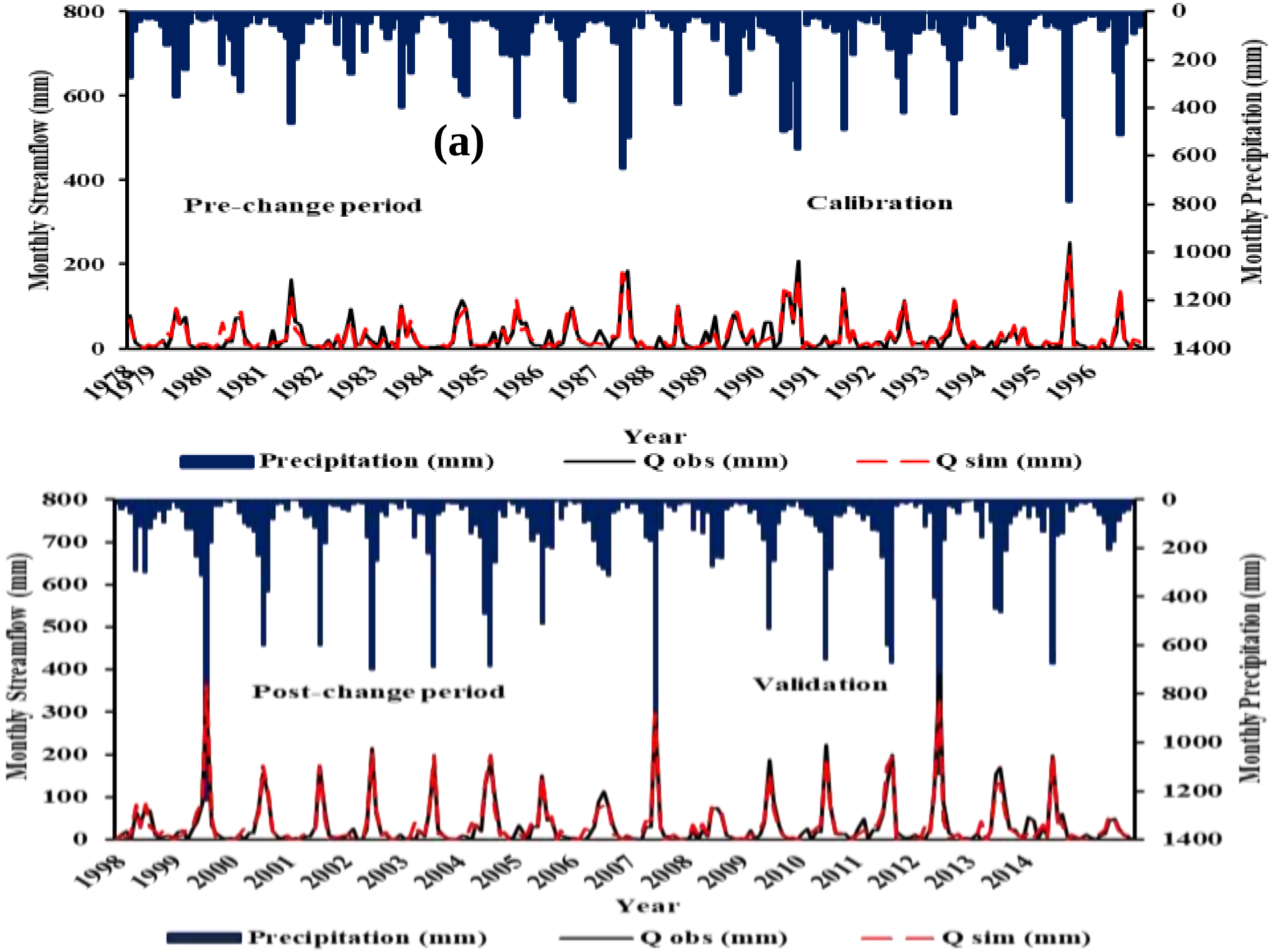


Fig. 8 Reconstruction of monthly streamflow using a multi-regression model for (a) the pre-change period (calibration) and (b) the post-change period (validation)

Table 2. Performance evaluation of hydrological models

Model	Natural Period (Calibration)				Human-induced Period (Validation)			
	R	NSE	BIAS(%)	RMSE	R	NSE	BIAS(%)	RMSE
Multi-regression	0.934	0.872	-0.202	14.082	0.970	0.940	1.340	14.564
Two-parameter Hydrological Model	0.85	0.85	1.34	22	0.899	0.914	-2.02	37

Comprehensive Results of Hydrological Simulation

- The effect of both climate change and human activities were quantified using decomposing framework.
- All the method show similar results as presented in Figure 9.
- The fractional contribution of climate accounts for 36.30% to 55.90% (average 45%) in the total change in streamflow.
- However, the contribution of human activities remains primary which accounts for 44.5% to 63.4% (average 46%) over the recording period.
- Hydrological sensibility analysis approach show relatively higher impact of human activities accounts **63.7%.**

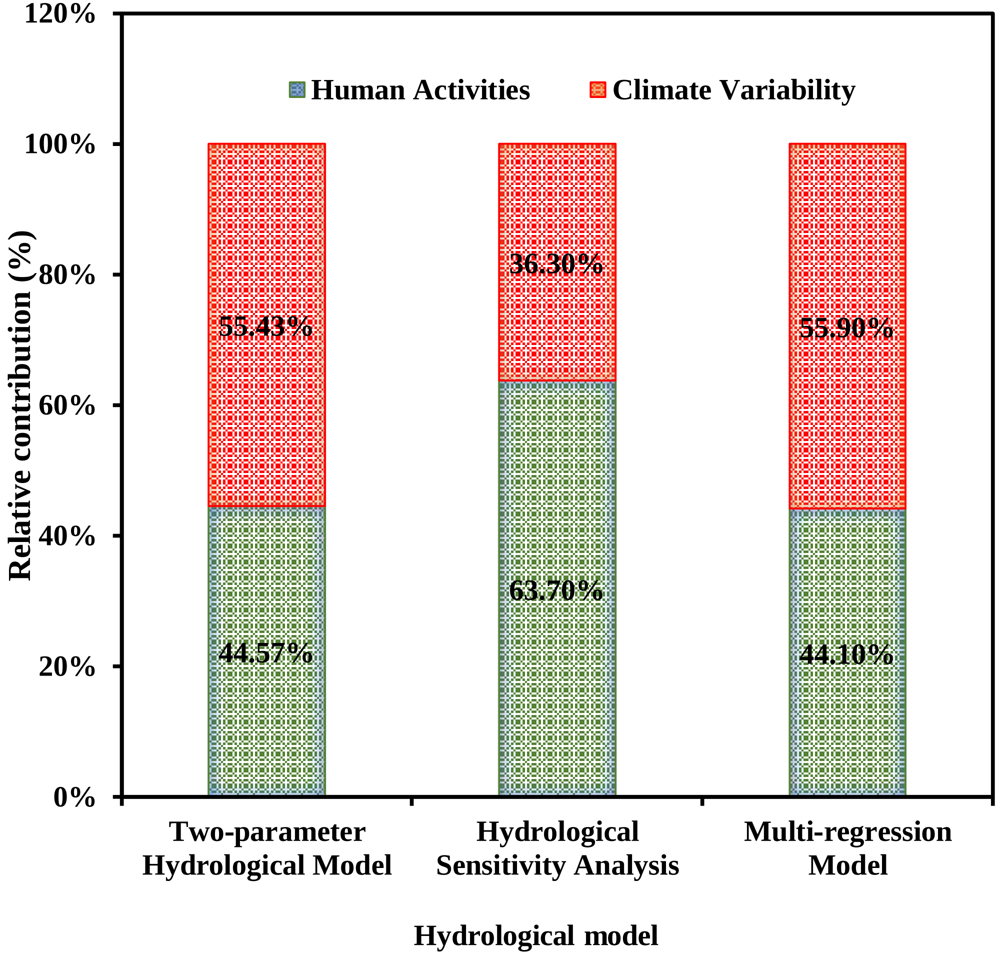


Fig. 9. Comparison of the relative contribution of climate variability and human activities on streamflow using three techniques: multi-regression model, two-parameter hydrological model and hydrological sensitivity analysis method

Conclusions & Future Work

- The primary goal of this study was to estimate the effects of climate change and human activities on the Streamflow in the basin.
- This framework would be enabled to estimate the variation in the key components of the hydrological cycle, quantification of effects of climate and human activities and decompose their effects.
- The conclusion drawn based on the research findings are as follows.
- The factor of uncertainty in always present in the hydrological model, to avoid uncertainty factor used multi-model techniques would gives good results.
- The hydrological change point was inspected during 1990s, which was taken as a point of start of human activities in the basin.

Conclusions & Future Work

- The contribution of climate change still remains major factor responsible for alteration in the streamflow.
- Then results obtained of different approaches reveals, both climate variability and human activities were the responsible factors influence streamflow conditions in the basin which accounts for 36.30% to 55.90% and for 44.5% to 63.4% of total variation in the streamflow, respectively.
- Gradual increase of human activities since change point year, might be a cause of hydrological disaster.
- The findings of thi research will provide advanced knowledge to engineers, hydrologists, and experts in regional water resources planning and management, designing the future disaster mitigation plane and decision-making considering increasing anthropogenic activities in the basin.

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Thank You

For Your Attention!

Any Questions

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