

Investigating Streamflow Variability of HUC-2 Regions in the Contiguous United States from Water Year 2003 to 2022

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Abstract

Runoff in natural rivers, commonly termed as streamflow, is a major process in the water cycle and a crucial variable in water resources engineering. While the increase in extreme rainfall events over the Conterminous United States (CONUS) has been well-documented, understanding the variability of streamflow remains challenging due to the nonlinear relationship between rainfall and runoff. In this study, daily streamflow data from 18 USGS gauge stations with the largest drainage area in its respective Hydrologic Unit Code 2-digit (HUC-2) region throughout the CONUS with contiguous records spanning from 2003 to 2022 water years is used to gain insights into streamflow variability over the past two decades. The original Mann-Kendall (MK) Test is employed to assess the potential temporal trends in the basic statistics (maximum, mean, minimum, and standard deviation) of annual streamflow data over the past 20 water years. Additionally, the seasonal MK Test is performed to explore the trends in the same basic statistics of the daily streamflow on a monthly basis. Furthermore, the statistical distributions of the normalized daily streamflow within each decade (2003-2012 and 2013-2022) are compared for each HUC-2 region. The results of the original MK Test indicate that no discernible trend in the annual streamflow and its standard deviation for most of the HUC-2 regions. However, the results of the seasonal MK Test suggest either an increasing or decreasing trend in around 30% of the HUC-2 regions. Moreover, low flows demonstrate a more significant change in frequency compared to high flows between the past two decades. Overall, this study highlights the complexity of the streamflow variability and the potential implications for changes in flood or drought risk under a changing climate.

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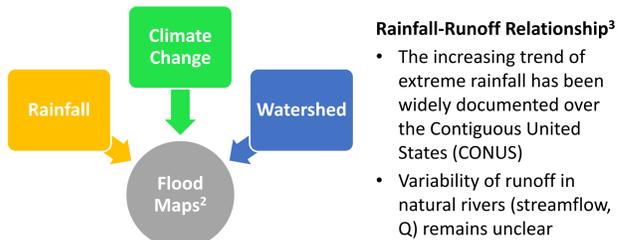
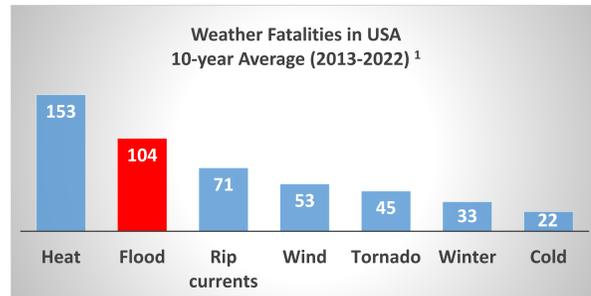
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Introduction



Rainfall-Runoff Relationship³

- The increasing trend of extreme rainfall has been widely documented over the Contiguous United States (CONUS)
- Variability of runoff in natural rivers (streamflow, Q) remains unclear

Mann-Kendall (MK) Test⁴

Original MK Test

- Used to analyze time series data for consistently increasing or decreasing trends (monotonic trends)
- Non-parametric test, and the assumption of normality is not required
- Insensitive to outliers

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(Q_j - Q_k)$$

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}}, & \text{if } S < 0 \end{cases}$$

- If $Z_{MK} > Z_{0.025}$, the null hypothesis (H_0) (no-trend) is rejected, namely, the streamflow series exhibits significant trends
- Otherwise, the alternative hypothesis (H_1) (there exist a trend) is rejected

Seasonal MK Test

- Insensitive to the existence of seasonality (e.g., monthly data)

Let $Q = (Q_1, Q_2, Q_3, \dots, Q_{12})$ and

$$Q_i = (Q_{i1}, Q_{i2}, Q_{i3}, \dots, Q_{i12})$$

$$S_i = \sum_{k=1}^{n_i-1} \sum_{j=k+1}^{n_i} \text{sgn}(Q_{ij} - Q_{ik})$$

Research Objectives

For 18 Hydrologic Unit Code 2-Digit (HUC-2) Regions in CONUS:

- detect the potential temporal trends of the basic statistics (max, mean, min, and standard deviation) of daily streamflow data each water year (2003-2022) using the original MK test
- assess the potential temporal trends of the same statistics (max, mean, min, and sd) of daily streamflow data each month over the water years (2003-2022) using the seasonal MK test
- compare the statistical distributions of the normalized daily streamflow within each decade (2003-2012 and 2013-2022) for each HUC-2 region

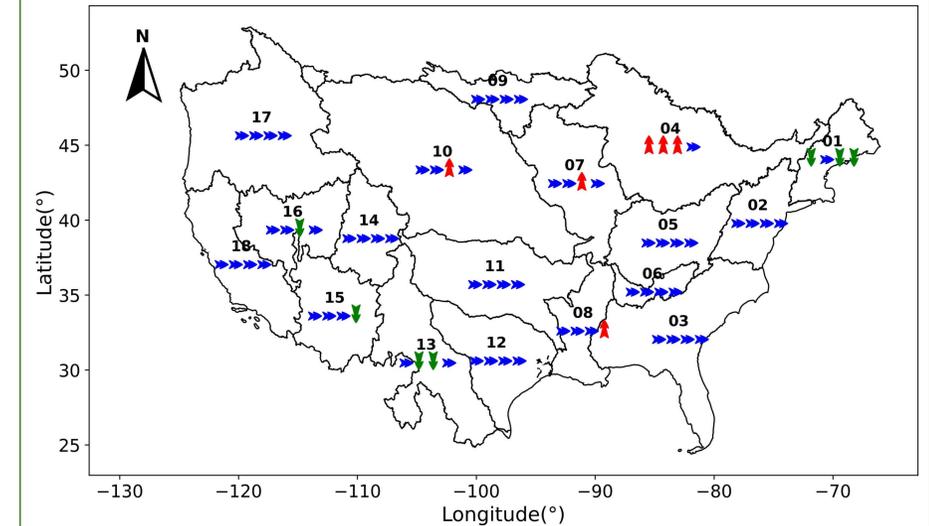
Study Area and Data

HUC-2	Region Name	USGS Gauge	Drainage Area (mile ²)	HUC-2	Region Name	USGS Gauge	Drainage Area (mile ²)
01	New England	01184000	9,660	10	Missouri	06935965	524,000
02	Mid-Atlantic	01578310	27,100	11	Arkansas-White-Red	07249455	145,940
03	South Atlantic-Gulf	02359170	19,200	12	Texas-Gulf	08116650	45,339
04	Great Lakes	04119000	4,900	13	Rio Grande	08447000	40,685
05	Ohio	03381700	141,000	14	Upper Colorado	09380000	111,800
06	Tennessee	03603000	2,557	15	Lower Colorado	09520500	57,850
07	Upper Mississippi	07022000	713,200	16	Great Basin	10333000	15,504
08	Lower Mississippi	07374000	1,125,810	17	Pacific Northwest	14246900	256,900
09	Souris-Red-Rainy	05092000	34,800	18	California	11303500	13,539

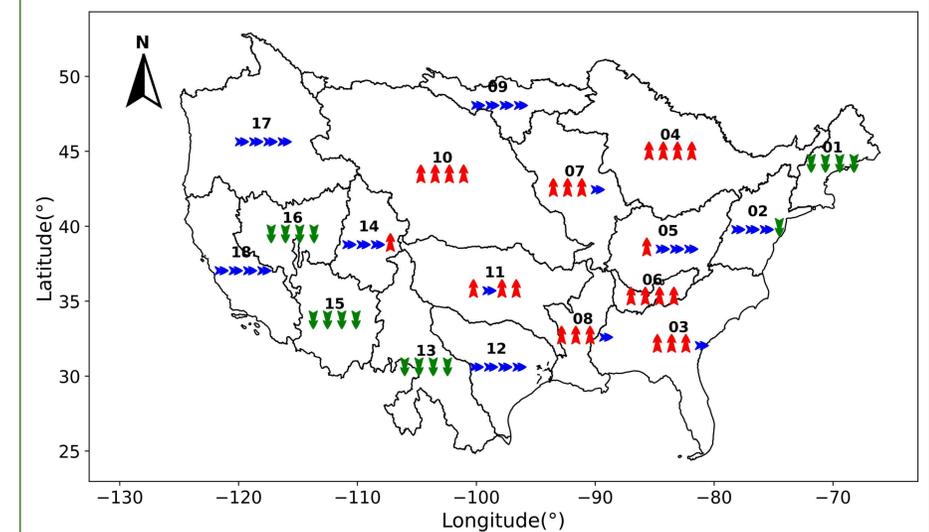


Results and Discussion

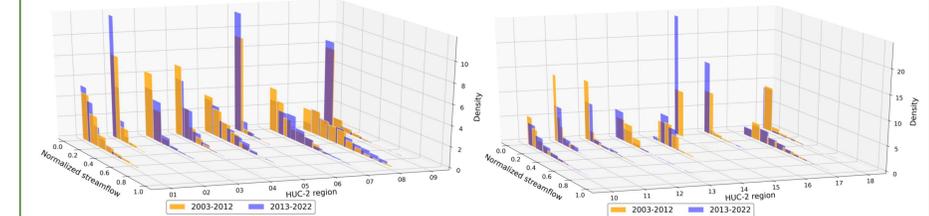
Results of Original MK Tests (arrows from left to right: max, mean, min, sd)



Results of Seasonal MK Tests (arrows from left to right: max, mean, min, sd)



Comparison of statistical distributions of the normalized daily streamflow



Conclusions

- Original MK Tests show that there is no trend in streamflow for most of the HUC-2 regions.
- Seasonal MK Tests suggest either an increasing or decreasing trend for around 30% of the HUC-2 regions.
- Low flows demonstrate a more significant change in frequency between past two decades.
- Overall, this study demonstrates the complexity of the streamflow variability and implies the possible changes in flood or drought risk under a changing climate.

References

- Data source: <https://www.weather.gov/hazstat/>
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