Analyse der Wiederkehrperiode der maximalen täglichen Niederschlags katastrophen im Zagros-Gebirge, Iran: März (2019)

Return Period Analysis of Maximum Daily Rainfall Disasters in the Zagros Mountains, Iran: March (2019)

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Introduction

- In March 2019, maximum daily rainfall exceeded the long-term average, leading to significant flooding downstream in the Karkheh Basin.
- Key contributing factors included heavy rainfall, the impacts of climate change, and alterations in land structures along riverbanks.
- Heavy rainfall, made worse by climate change, increases the risk of floods, landslides, and damage to infrastructure, highlighting the need for better water management and disaster planning.

Goals

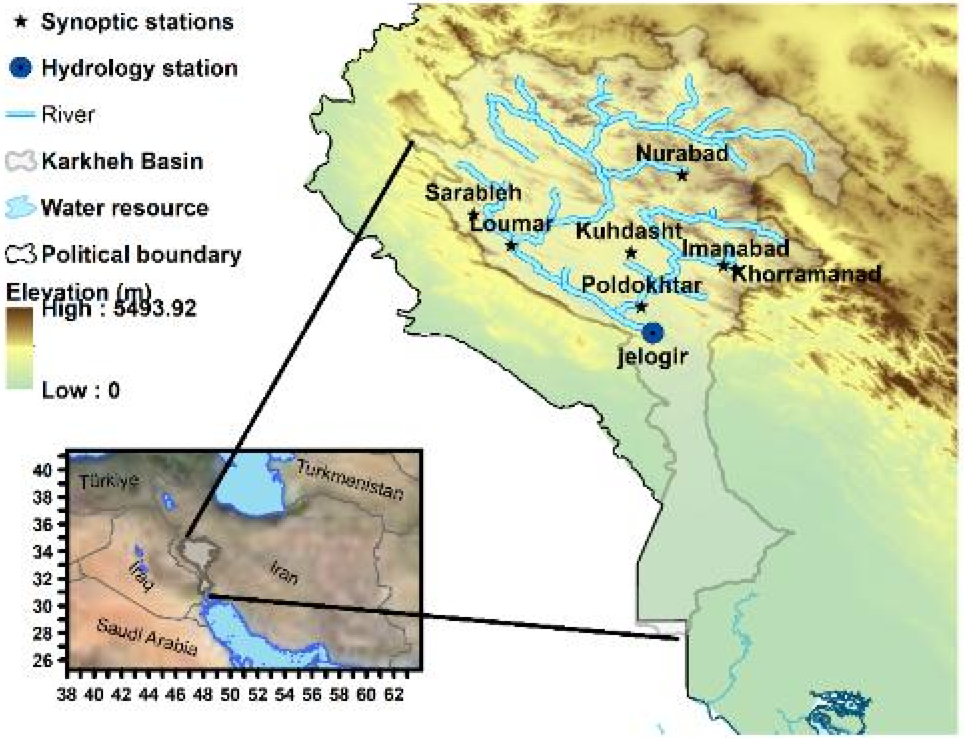
This paper aims to analyze the return period of heavy rainfall events in the Zagros Mountains of Iran, focusing on the March 2019 floods in the Karkheh River Basin. By evaluating the annual and monthly variations, statistical characteristics, and return periods of extreme rainfall, this study seeks to understand the frequency and intensity of hydrological extremes. It further explores the interplay of climate change and land surface alterations on flooding, offering insights to support climate resilience and flood mitigation strategies in vulnerable regions.

Summary of the objectives, focus, analyses, key findings, and implications of the study on the return period of heavy rainfall events in the *Zagros* Mountains, with emphasis on the March 2019 floods in the *Karkheh* River Basin

Aspect	Details
Objective	Analyze the return period of heavy rainfall events in the *Zagros* Mountains of Iran.
Focus	March 2019 floods in the *Karkheh* River Basin.
Key Analysis	- Annual and monthly variations of maximum daily rainfall.
	- Statistical characteristics of extreme rainfall events.
	- Return period estimation using statistical distributions (Gumbel, Inverse Gamma).
Key Findings	- Maximum daily rainfall shows an increasing trend, indicating more frequent heavy rainfall events.
	- Gumbel distribution best fits long-term data; Inverse Gamma fits shorter data periods.
	- Return periods for extreme events range from 50 to 300 years.
Significant Observation	- March 2019 rainfall exceeded long-term averages, leading to severe flooding downstream in the *Karkheh* basin.
	- Alterations in land surface structure contributed to increased human and financial losses.
Implications	- Provides insights into hydrological extremes.
	- Supports strategies for flood mitigation and climate resilience in vulnerable regions.

Study Area: **Zagros Mountains**

- Karkheh Basin: Located in western Iran, the basin is characterized by rugged terrain and a diverse climate.
- The March 2019 floods exposed vulnerabilities to extreme rainfall, with Pol-Dokhtar receiving 139 mm and Nurabad 101 mm of precipitation.



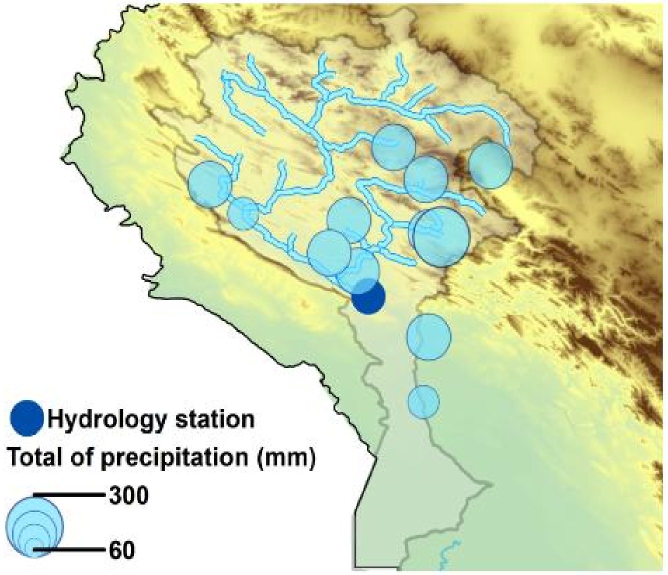
100 km

- The topographical features of the *Zagros* Mountains significantly influence precipitation patterns, particularly during extreme weather events and heavy rainfall..

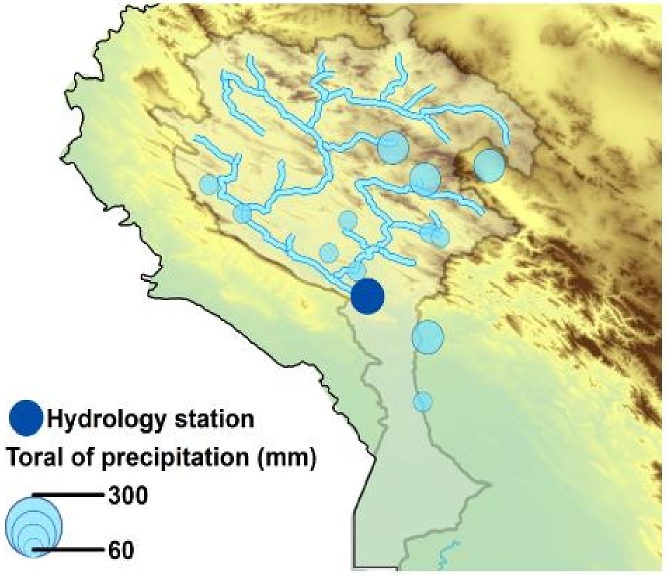
Station Name	Latitude	Longitude	Elevation (*m*)	Data Coverage (*Years*)
Khoramabad	33.43	48.28	1147.8	72
Kusdasht	33.52	47.65	1197.8	25
Poldokhtar	33.15	47.72	713.5	24
Nurabad	34.05	48.00	1859	22
Sarableh	33.78	46.57	1045	16
Loumar	33.57	46.83	850	15
Imanabad	33.40	48.37	1500	14

Total of Precipitation (March and April 2019)

(a) March 2019



(b) April 2019



100 km

Daily Maxima

Station Name	March2019 (*mm*)	April2019 (*mm*)
Khoramabad	66	85.4
Kusdasht	63	21
Poldokhtar	139.4	17
Nurabad	79.2	101
Sarableh	41.7	38
Loumar	66	9
Imanabad	117	31

- Graph a) demonstrates the amount of heavy rain in March 2019
- Graph b) shows the amount of regular rain in April 2019.
- The table shows the total precipitation in March and April 2019. The maximum amount is demonstrated by red.

Methodologies and Analyses for Rainfall and Return Period Assessment

Aspect	Details
Station Data	• Initial analysis of 7 stations with descriptive statistics (mean, median, mode, etc.). • Selected 4 stations with >20 years of data for further study.
Trend Analysis	• Trends in total annual and maximum 24-hour precipitation analyzed. • Mann-Kendall method used for trend detection.
PMP Estimation Methods	• **Hershfield Method**: Used with K_m factors of 15 and 6. • **Modified Desa Method**: Excludes max precipitation to calculate K_m.
PMP Calculation	• Equation: $X_{PMP} = X_n + S_n * K$. • Desa method adjusts K_m and uses max value across stations.
Return Period Analysis	• Evaluated empirical and mathematical return periods using historical data. • Software: HyfranPlus for probability distribution fitting.
Probability Distributions	• **Distributions Used**: GEV, Log-Normal, Log-Normal3, Pearson Type III, Gumbel, Inverse Gamma. • Parameters estimated via *M*aximum *L*ikelihood *E*stimation (MLE).
Goodness-of-Fit Tests	• Applied *A*kaike *I*nformation *C*riterion (AIC) and *B*ayesian *I*nformation *C*riterion (BIC). • Evaluated model performance and reliability.
Purpose	• To understand extreme rainfall patterns, estimate return periods, and assess risks for the *Zagros* Mountains region.

PMP (Probability Maximum Precipitation) Analysis and Return Period Estimation

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• S_n: Standard Diviation of the series
• K: Frequency factor (varies between 3-20 based on data and conditions).
Modified Desa Method:
• Excludes maximum rainfall value to calculate K_m.
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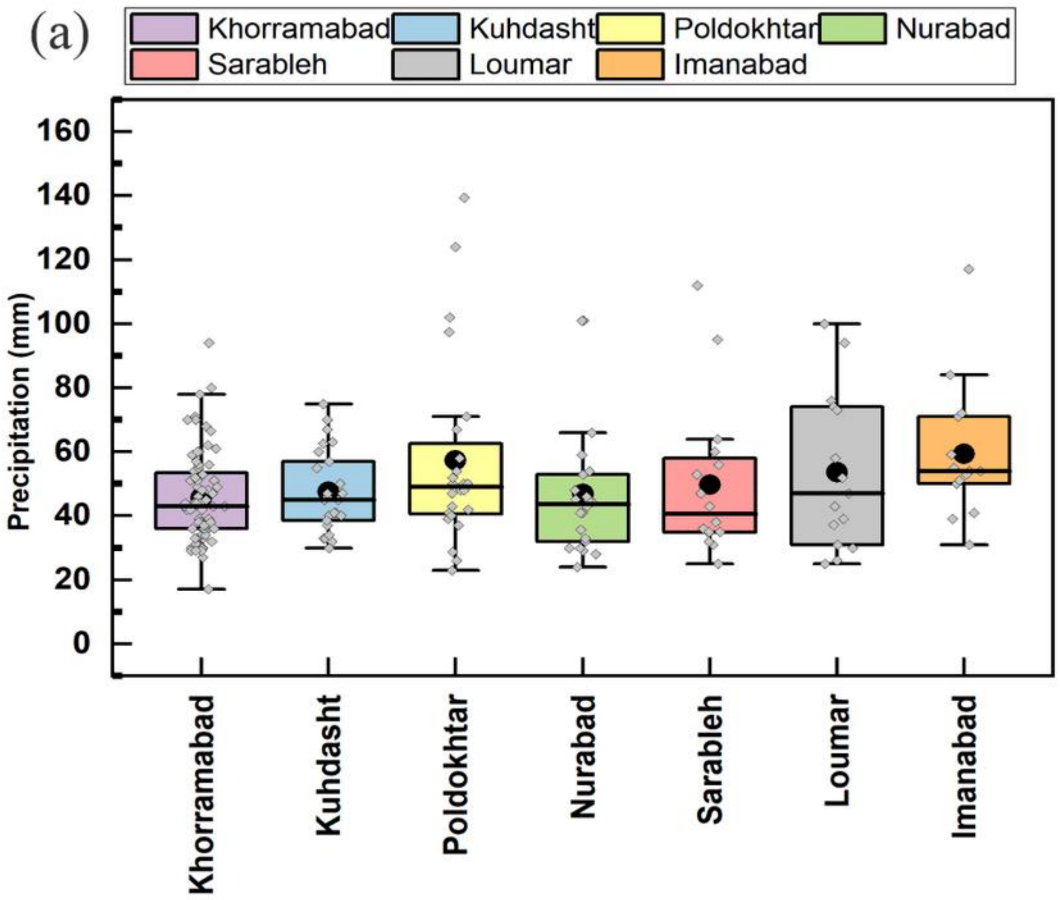
Long-term maximum daily precipitation in Karkheh

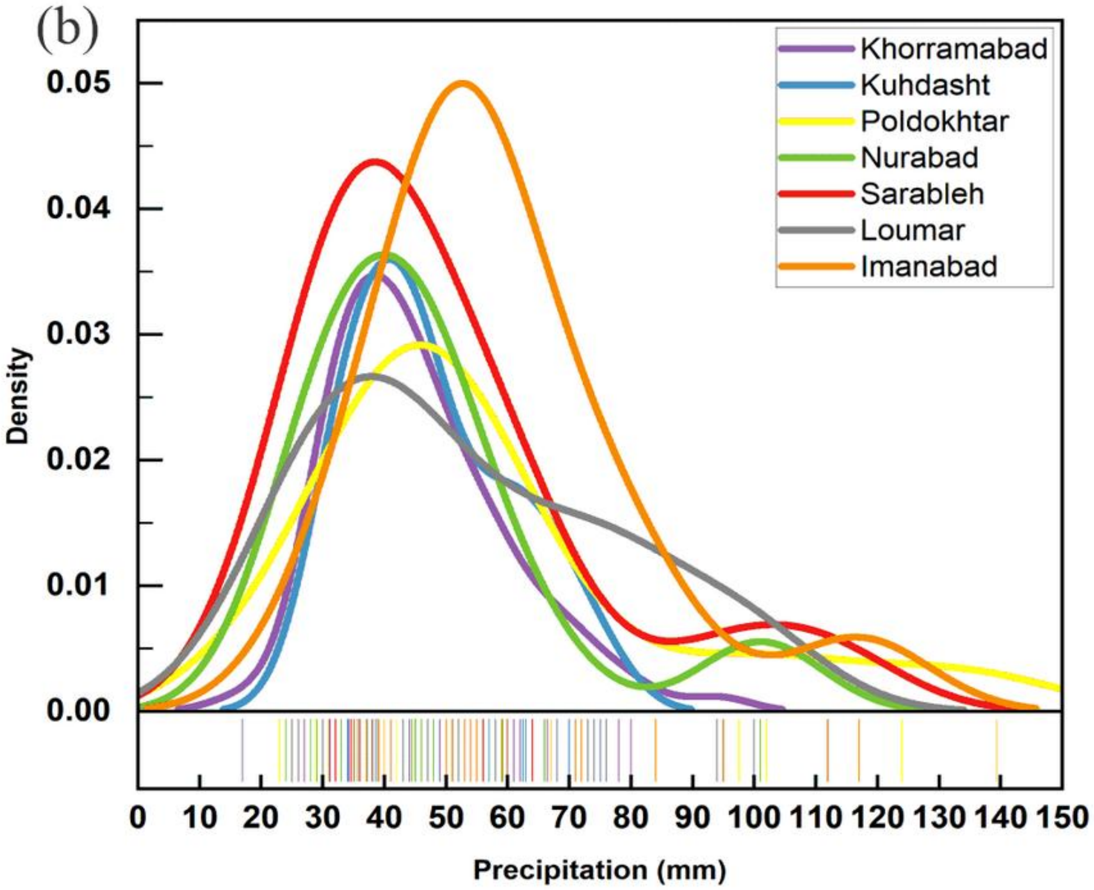
Annual total rainfall showed no significant trend.

Maximum daily rainfall displayed an increasing trend, indicating a rise in heavy rainfall events.

Positive skewness was observed at all stations, reflecting a tendency toward extreme values



(a) Box plot of Maximum daily precipitation, (In the Study Period)



(b) Distribution of Maximum daily precipitation in Karkheh stations (In the Study Period)

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Aspect	Key Finding
Long-term Maximum Daily Precipitation	• - Highest recorded rainfall: 139.4 mm (Poldokhtar), 117 mm (Imanabad). • - Bimodal distribution: Observed at Sarableh, Nurabad, and Imanabad. • - Positive skewness: Extreme values dominate.
Statistical Summary	• - Mean precipitation: Highest at Imanabad (59.4 mm). • - Skewness: Highest at Nurabad (1.73). • - Kurtosis: Highest at Imanabad (3.15). • - Flat distributions: Kuhdasht and Loumar.
Annual Trends	• - No significant trend in total annual precipitation. • - Significant increase in maximum daily precipitation at Poldokhtar ($p = 0.009$) and gradual increase at Khorramabad ($p = 0.038$).
March 2019 Rainfall Anomalies	• - March 2019: Exceptionally high rainfall at Poldokhtar and Nurabad. • - Historical peaks far exceeded, particularly at upstream stations, contributing to flooding risks.
Monthly Variability	• - March-April 2019: Extreme rainfall at Nurabad and Poldokhtar. • - Khorramabad: Rainfall lower than historical daily maximums. • - Significant monthly variability across all stations.

Statistical Summary including mean, minimum, maximum, mode, median, standard deviation, skewness and kurtosis of Maximum Daily Precipitation (mm) Data

	N	Mean	Minimum	Maximum	Mode	Median	Standard Deviation	Coefficient of Variation(%)	Skewness	Kurtosis
Khorramabad	72	45.6	17	94	36	43	14.2	31.14	0.97	1.12
Kuhdasht	25	47.6	30	75	33	45	12.9	27.10	0.60	-0.65
Poldokhtar	24	57.4	23	139.4	50	49	29.7	51.74	1.58	2.02
Nurabad	22	46.8	24	101	30	43.7	20.5	43.80	1.73	2.99
Sarableh	16	49.8	25	112	35	40.5	24.0	48.19	1.64	2.35
Loumar	15	53.7	25	100	--	47	24.5	45.62	0.63	-0.77
Imanabad	14	59.4	31	117	54	54	21.6	36.36	1.52	3.15

Statistical Analysis

- Gumbel distribution is effective for long-term data (72 years) at Khorramabad.
- Inverse Gamma distribution is best for shorter datasets.
- Return periods for extreme events range from 50 to 300 years

Discussion of Uncertainties

- Lack of long-term data (>30 years) for many stations.
- Limited synoptic data (<20 years) restricts return period analysis.
- Reliance on historical data introduces uncertainties due to climate change.

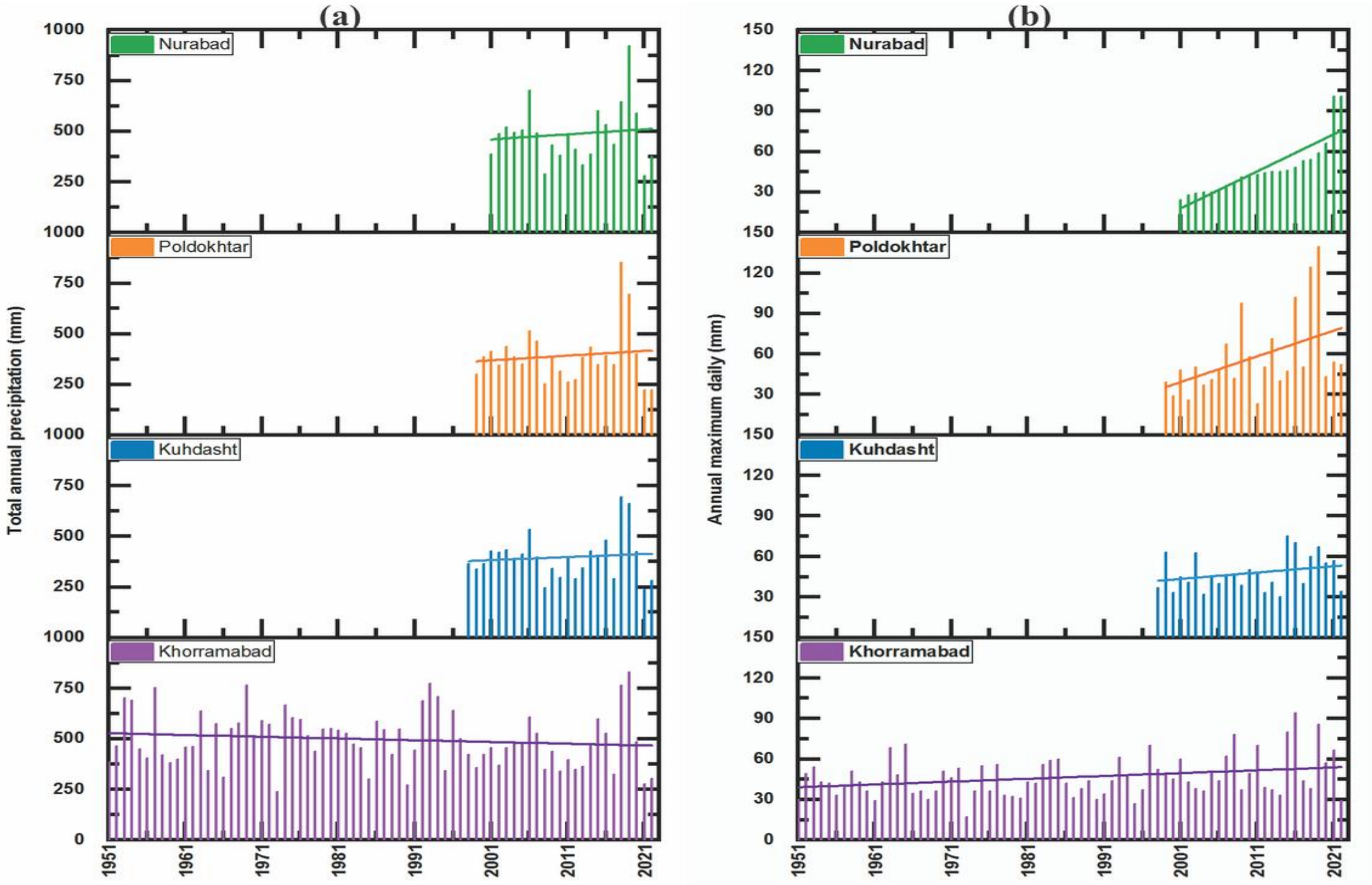
PMP (mm) calculation with different methods

PMP Method	Khoramabad (72)	Kuhdasht (25)	Pol-Dokhtar (24)	Nurabad (22)
Hershfile (K_m = 15)	268.8	240.4	502.8	355.0
PMP (24)/P24	2.86	3.21	3.61	3.52
Modified (K_m = 6)	135.40	124.71	235.58	170.08
PMP 24/P24	1.44	1.66	1.69	1.68
Desa et al (2001)	98.3	92.6	161.0	118.8
K_m	3.50	2.43	3.34	3.48
PMP (24)/P24	1.05	1.23	1.16	1.18

- Highest PMP (24-h): *Pol-Dokhtar (139 mm)* and *Nurabad (101 mm)*.
- PMP24/P24 ratio was lowest in the third estimation method
  - (Desa et al., 2001).
- Highlights critical zones for flood mitigation.
  - PMP estimation highest for Pol-Dokhtar using Hershfield method (502.8 mm).

Annual Rainfall Trends

- Annual total rainfall showed no significant trend.
- Maximum daily rainfall increased, indicating a rise in heavy rainfall events.
- Positive skewness observed in all stations, reflecting a tendency toward extreme values.



Time-series plots comparing precipitation levels during March 2019 with historical data.

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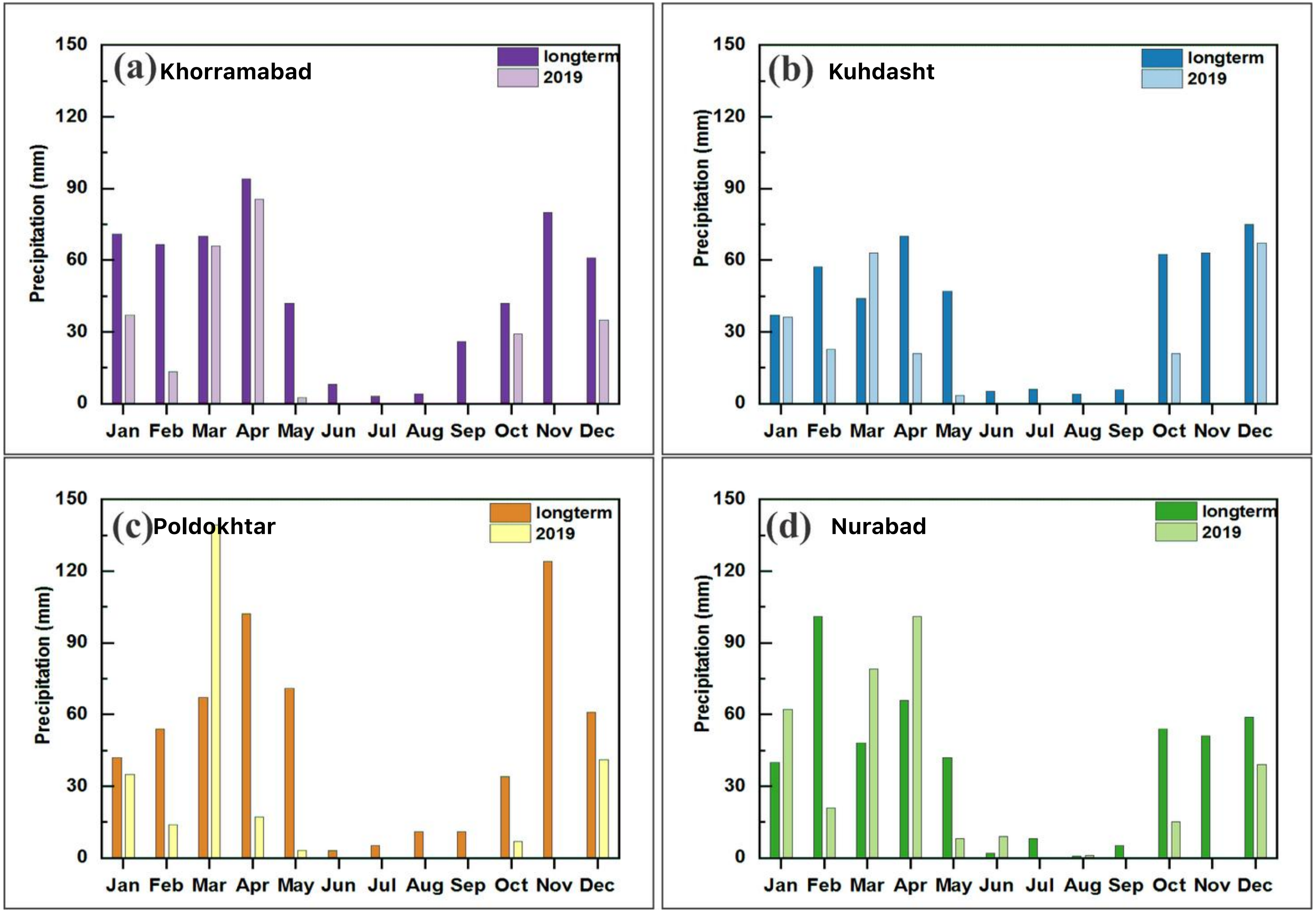
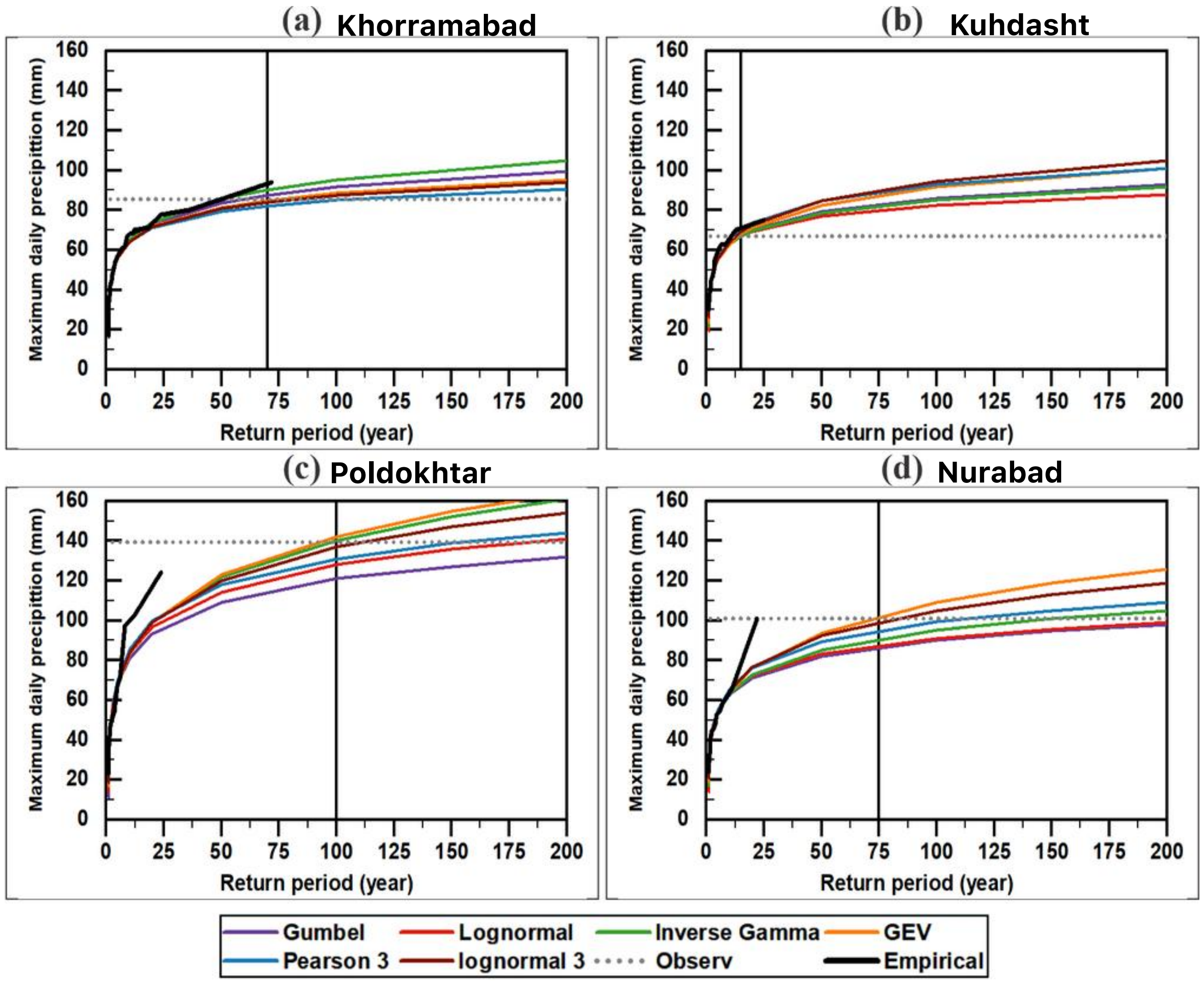
Monthly maximum daily precipitation



Return period



Annual Maximum Precipitation vs. Return Period

Aspect	Key Findings
Return Period Analysis	- Khorramabad: Empirical return period for 85 mm is 54 years; mathematical models range from 50–70 years (except Pearson III). - Kuhdasht: Empirical return period for 67 mm is 10 years; mathematical models range 15–20 years.
Performance of Statistical Distributions	- Best fit (overall): Inverse Gamma. - Khorramabad: Gumbel performed best. - Weaker fits: Pearson Type III and GEV (especially for Poldokhtar and Nurabad).
March 2019 Events	- Poldokhtar: 139 mm rainfall linked to a return period of 70–300 years. - Nurabad: 101 mm rainfall return period ranges from 70–200 years. - Differences in empirical vs. mathematical distributions were significant.
Climate Variability Insights	- Trends in extreme precipitation during March and April 2019 reflect potential shifts in rainfall patterns. - Variability in model fits indicates the need for careful evaluation and validation.
Implications for Flood Risk	- A clear relationship between precipitation magnitude and return periods highlights flood risks. - Data assists in flood management and policy planning.

Distribution Type	Khoramabad (72)		Kuhdasht (25)		Pol-Dokhtar (24)		Nurabad (22)	
	BIC	AIC	BIC	AIC	BIC	AIC	BIC	AIC
Inverse Gamma	3	3	1	2	1	1	1	1
Gumble	1	1	2	3	3	3	2	2
Lognormal	2	2	3	4	2	2	3	4
Pearson3	6	6	4	1	6	6	4	3
GEV	4	4	6	6	4	4	5	6
Lognormal3	5	5	5	5	5	5	6	5

Performance scores of statistical distributions (BIC and AIC) for analyzing maximum precipitation at selected stations. This table lists the distribution types with their corresponding scores for the Bayesian Information Criterion (BIC) and Akaike Information Criterion (AIC). Lower scores indicate a better fit.

Conclusion:

Section	Summary
Event Overview	March 2019 saw maximum daily rainfall exceeding the long-term average, causing flooding downstream in the *Karkheh* basin. Contributing factors included heavy rainfall and altered land structures along riverbanks.
Rainfall Trends	Annual total rainfall showed no significant trend, but maximum daily rainfall displayed an increasing trend, signaling more frequent heavy rainfall events. Rainfall data exhibited positive skewness toward extreme values.
PMP Analysis	*Pol-Dokhtar* and *Nurabad* had the highest PMP (24-h) estimates. The PMP24/P24 ratio was highest in *Pol-Dokhtar* and *Nurabad*, with the lowest ratio observed in the third PMP estimation method by *Desa* et al. (2001).
Statistical Distributions	Gumbel distribution was most effective for the 72-year record at *Khorramabad*, while the Inverse Gamma distribution was best for shorter records, estimating return periods of 50-300 years for extreme events at various stations.
Key Stations	Maximum daily rainfall: 139 mm (*Pol-Dokhtar*) and 101 mm (*Nurabad*) in March 2019. Return periods for these values ranged from 70 to 300 years. The highest long-term daily rainfall did not occur in March or April.
Insights and Implications	The study enhances understanding of hydrological extremes in the *Zagros* Mountains, informing flood mitigation strategies and supporting climate resilience in vulnerable regions.
Uncertainties and Limitations	Lack of long-term data (over 30 years) for many stations, especially those recording the highest rainfall. Limited synoptic data (under 20 years) restricts return period analysis. Historical data introduces climate change-related uncertainties.