Precipitation Variation Characteristics in the Shule River Mainstream (Postprint)

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Abstract

Monthly and annual precipitation data from 1956 to 2016 at three hydrological stations along the main stream of the Shule River were selected as the basic dataset. Linear trend analysis, cumulative anomaly, moving average, Mann-Kendall abrupt change test, and other methods were employed to analyze the annual, intra-annual, interdecadal, seasonal, and abrupt change characteristics of precipitation in the main stream of the Shule River. The results indicate that annual precipitation exhibits varying degrees of increasing trends. The ranking of annual precipitation tendency rates is as follows: Changmabao Station 5.47 mm · (10a)^{1} > Shuanggangbao Reservoir Station 1.454 mm · (10a)^{1} > Panjiazhuang Station 0.866 mm · (10a)^{1}. The intra-annual distribution of precipitation is extremely uneven, being mainly concentrated from May to August, which accounts for over 65% of the annual precipitation. Interdecadal variations show that precipitation in the 1960s and 1990s was below the multi-year average, while precipitation in the 1970s and 2010s was above the multi-year average. Seasonal precipitation variations exhibit different characteristics across stations: summer precipitation contributes the most at Changmabao Station, while autumn precipitation contributes the most at both Panjiazhuang Station and Shuanggangbao Reservoir Station. Meanwhile, seasonal precipitation anomalies in different decades display distinct variation patterns. The abrupt change years of precipitation exhibit different mutation characteristics and timing across seasons. The annual average precipitation mutation points are 1964 and 2001 for Changmabao Station, 1988 for Panjiazhuang Station, and 1987 for Shuanggangbao Reservoir Station.

Full Text

Preamble

Research on Variation Characteristics of Precipitation in the Mainstream of Shule River

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Abstract: As the third largest inland river basin in the Hexi Corridor of Gansu Province, northwest China, the Shule River Basin constitutes an important ecological security barrier. The mainstream of the Shule River, as the primary zone of societal, economic, and human activity, also serves as a vital ecological defense at the forefront of the basin. This study analyzed precipitation variation in the mainstream of the Shule River Basin to elucidate precipitation trends. Monthly and annual precipitation data from Changmabao, Panjiazhuang, and Shuangtaobao Reservoir hydrological stations along the mainstream were used. Variations in annual change, intra-annual distribution, inter-annual change, seasonal change, and precipitation mutation from 1956 to 2016 were analyzed using linear trend, cumulative anomaly, moving average, and Mann-Kendall mutation tests. Results showed that annual precipitation in the mainstream exhibited an overall increasing trend (to varying degrees) in the order: Changmabao (5.47 mm·(10a) ^{1}) > Shuangtaobao Reservoir (1.454 mm·(10a) ^{1}) > Panjiazhuang (0.866 mm·(10a) ^{1}). The intra-annual precipitation distribution was extremely uneven, concentrated mainly in May–August, accounting for over 65% of annual precipitation. Inter-annual precipitation in the 1960s and 1980s was lower than the annual average, whereas in the 1970s and 2010s it was higher than the annual average. Seasonal precipitation variation showed different characteristics across stations, with summer, autumn, and autumn being the dominant contributors at Changmabao, Panjiazhuang, and Shuangtaobao Reservoir, respectively. Average seasonal precipitation anomalies varied by season and year. Annual average and seasonal precipitation mutations showed different characteristics and timing. Mutation points for annual average precipitation occurred in 1964 and 2001 at Changmabao, in 1988 at Panjiazhuang, and in 1987 at Shuangtaobao Reservoir. These results are practically important for promoting integrated water resources management and scientific allocation. Future studies will further investigate regional precipitation trend characteristics and prediction under changing environments.

Keywords: mainstream of Shule River; precipitation; variation characteristics; Mann-Kendall mutation test; Gansu

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1. Study Area

The Shule River mainstream is located between 92°11 -98°30 E and 38°00 - 42°48 N, with a length of approximately 670 km and a basin area of 4.13×10 km^2 [28]. The region has an average annual temperature of 6.98–9.82°C, annual precipitation of 40.2–57.5 mm, and annual evaporation of 2577.4–2653.2 mm. Precipitation is concentrated primarily in June–September, accounting for 61% of the annual total [29]. The study area is shown in [Figure 1: see original paper].

Figure 1. Schematic diagram of study area

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2. Data and Methods

2.1 Data Sources

Precipitation data were obtained from Changmabao, Panjiazhuang, and Shuangtaobao Reservoir hydrological stations along the Shule River mainstream [30–33].

2.2 Analytical Methods

Linear trend analysis, cumulative anomaly, moving average, and Mann-Kendall mutation tests were employed to analyze precipitation variation characteristics [31-35]. The Mann-Kendall test is a non-parametric statistical method widely used for trend and mutation detection in hydro-meteorological time series.

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3. Results and Analysis

3.1 Annual Precipitation Variation

Average annual precipitation at Changmabao, Panjiazhuang, and Shuangtaobao Reservoir stations was 95.77 mm, 51.39 mm, and 52.52 mm, respectively. Maximum annual precipitation at Changmabao was 184.60 mm (2007), with a minimum of 35.4 mm (1956), a range of 149.2 mm, and a coefficient of variation of 5.21. At Panjiazhuang, maximum precipitation was 146.8 mm (1979), minimum was 22.3 mm (1982), range was 124.5 mm, and coefficient of variation was 6.58. At Shuangtaobao Reservoir, maximum precipitation was 141.1 mm (1979), minimum was 17.6 mm (1960), range was 123.5 mm, and coefficient of variation was 8.02.

As shown in [Figure 2: see original paper]a, 2b, and 2c, annual precipitation at all three stations showed an increasing trend. Linear regression equations were $y = 0.547x + 78.809$ (Changmabao), $y = 0.0866x + 48.835$ (Panjiazhuang), and $y = 0.1454x + 48.3$ (Shuangtaobao Reservoir), with rates of 5.47 mm · (10a) ^{1}, 0.866 mm · (10a) ^{1}, and 1.454 mm · (10a) ^{1}, respectively. Over 61, 58, and 57 years, this corresponded to increases of 33.37 mm, 5.02 mm, and 8.29 mm, respectively, indicating significant rising trends, particularly at Changmabao.

[Figure 2: see original paper]d shows the cumulative anomaly curves for the three stations. Changmabao exhibited a "decrease-increase-decrease-increase" pattern: below-average precipitation during 1956–1972, above-average during 1973–1984, below-average during 1985–2001, and above-average during 2002–2016. Panjiazhuang showed a "decrease-increase-decrease" pattern: below-average during 1956–1970 and 1980–1989, above-average during 1971–1979 and 1990–2011, and below-average during 2012–2016. Shuangtaobao Reservoir displayed a "decrease-increase" pattern: below-average during 1960–1987 and above-average during 1988–2016.

3.2 Inter-Annual Variation

Inter-annual precipitation variation was analyzed using 10-year moving averages. Precipitation at Changmabao was low in the 1950s–1960s and 1990s, and high in the 1970s–1980s and 2000s–2010s. At Panjiazhuang, precipitation was low in the 1960s and 1990s–2000s, and high in the 1970s–1980s and 2010s. At Shuangtaobao Reservoir, precipitation was low in the 1960s and 1980s, and high in the 1970s and 2000s–2010s. The trend magnitude followed the order: Changmabao (5.47 mm·(10a) ^{1}) > Shuangtaobao Reservoir (1.454 mm·(10a) ^{1}) > Panjiazhuang (0.866 mm·(10a) ^{1}).

3.3 Seasonal Precipitation Variation

Seasonal precipitation distribution was extremely uneven, concentrated mainly in May–August and accounting for over 65% of annual precipitation. As shown in , seasonal precipitation characteristics varied across stations.

Table 2. Seasonal precipitation characteristics at Panjiazhuang station in Shule River Basin (mm)

Period	Average	Maximum	Year	Minimum	Year	Coefficient of Variation
1959–1969	44.45	71.9	1964	22.5	1960	3.20
1970–1979	63.65	146.8	1979	39.0	1975	3.76
1980–1989	53.18	77.1	1981	28.8	1986	2.68

Further analysis revealed that 50% and 90% of annual precipitation occurred in specific months at different stations, with 70% and 90% probability thresholds showing distinct patterns.

3.4 Seasonal Anomaly Variation

3.4.1 Seasonal Anomaly Characteristics shows seasonal precipitation anomalies at the three stations. Spring (March–May) anomalies were negative across all stations, with Changmabao showing the largest negative anomaly (-10.39 mm). Summer (June–August) anomalies were positive, with Changmabao showing the largest positive anomaly (10.37 mm). Autumn (September–November) and winter (December–February) anomalies varied by station.

Table 4. Seasonal anomaly variation of precipitation in Shule River mainstream (mm)

Season	Changmabao	Panjiazhuang	Shuangtaobao
Spring	-10.39	-8.48	-2.74
Summer	10.37	10.10	2.02
Autumn	-0.01	5.26	-0.18
Winter	-0.19	-1.39	4.37

Key findings: (1) Spring anomalies were negative, with the largest deficit at Changmabao (-10.39 mm). (2) Summer anomalies were positive, with the largest surplus at Changmabao (10.37 mm). (3) Autumn anomalies showed mixed patterns. (4) Winter anomalies were generally small.

3.4.2 Decadal Seasonal Anomaly Variation Decadal analysis revealed that spring precipitation at Changmabao decreased at -0.187 mm·(10a)^{1}, while summer precipitation increased at 0.925 mm·(10a)^{1}. Autumn precipitation increased at 0.749 mm·(10a)^{1} at Changmabao and 0.065 mm·(10a)^{1} at Panjiazhuang, but decreased at -0.285 mm·(10a)^{1} at Shuangtaobao Reservoir. Winter precipitation showed minimal trends.

3.5 Precipitation Mutation Analysis

3.5.1 Annual Precipitation Mutation Mann-Kendall mutation tests identified significant change points. For Changmabao, the UF curve exceeded the critical value ($\pm$1.96) in 1988, indicating a significant increasing trend after 1988 (significant at =0.05). The intersection of UF and UB curves in 1964 and 2001 identified these years as mutation points, dividing the series into 1956–1964, 1965–2001, and 2002–2016 periods.

For Panjiazhuang, the UF curve exceeded the critical value in 1965, indicating a significant increase after 1965. The intersection point in 1988 identified a mutation dividing the series into 1959–1965 and 1966–2016 periods.

For Shuangtaobao Reservoir, the UF curve exceeded the critical value in 1969, 1988, and 2011, with intersections in 1969, 1988, and 2011, dividing the series into four periods: 1959–1969, 1970–1988, 1989–2011, and 2012–2016.

3.5.2 Seasonal Precipitation Mutation Spring precipitation mutation: Changmabao showed a significant increasing trend after 1966, with mutation points in 1966, 1985, 1997, and 2011, dividing the series into five periods. Panjiazhuang showed a significant increase after 1970, with mutation points in 1970 and 2001, creating three periods. Shuangtaobao Reservoir showed increases after 1966, 1985, 1997, and 2011, with four periods.

Summer precipitation mutation: Changmabao showed a significant increasing trend after 1987, with mutation points in 1970 and 2001, creating three periods. Panjiazhuang showed increases after 1970 and 2001, with three periods. Shuangtaobao Reservoir showed increases after 1969, 1988, and 2011, with four periods.

3.5.3 Monthly Precipitation Mutation Monthly precipitation mutations showed distinct patterns. At Changmabao, January precipitation had mutation points in 1970 and 2003, creating three periods. February precipitation had mutations in 1974 and 2002, also creating three periods. Panjiazhuang and Shuangtaobao Reservoir showed similar but distinct monthly mutation patterns.

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4. Discussion

Annual precipitation in the Shule River mainstream showed increasing trends at all stations, with rates of 5.47 mm · (10a) ^{1}, 0.866 mm · (10a) ^{1}, and 1.454 mm · (10a) ^{1} at Changmabao, Panjiazhuang, and Shuangtaobao Reservoir, respectively. Over 57-61 years, this corresponded to total increases of 33.37 mm, 5.02 mm, and 8.29 mm. The increasing trend was most pronounced at Changmabao, consistent with regional climate change patterns.

The intra-annual distribution was extremely uneven, with 65-70% of precipitation concentrated in May-August. Seasonal anomalies varied significantly, with spring deficits and summer surpluses being most notable at Changmabao. Decadal variations showed low precipitation in the 1960s and 1980s, and high precipitation in the 1970s and 2010s.

Mutation analysis revealed that annual precipitation mutation points occurred in 1964 and 2001 at Changmabao, 1988 at Panjiazhuang, and 1987 at Shuangtaobao Reservoir. Seasonal mutations showed different characteristics, with summer mutations being most significant. These findings are crucial for water resources management and scientific allocation in the Shule River Basin.

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Note: Figure translations are in progress. See original paper for figures.