Spatiotemporal Variation Characteristics of Different-Grade Precipitation Days and Intensity in the Loess Plateau from 1960 to 2017 (Postprint)

Authors: An Bin, Xiao Weiwei

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Abstract

Studies on the variation characteristics of precipitation days and intensity hold significant scientific importance for climate change adaptation and water resource development and utilization in the Loess Plateau. Using daily precipitation data from 55 surface meteorological stations in the Loess Plateau region from 1960 to 2017, this study analyzes the spatiotemporal variation patterns of total precipitation and different precipitation grades (light rain, moderate rain, heavy rain, and rainstorm) in terms of days, intensity, and precipitation amount, and quantifies the contributions of precipitation days and intensity of each grade to precipitation increments. The results indicate that: (1) Over the past 58 years, precipitation days and amount of different grades, as well as the intensity of heavy rain and rainstorm, all show decreasing trends in the Loess Plateau region, whereas the intensity of total precipitation, light rain, and moderate rain exhibits increasing trends, with light rain days being the predominant form of precipitation in the Loess Plateau. (2) The spatial distribution patterns of precipitation days and amount and their variation trends for total precipitation, light rain, and moderate rain in the Loess Plateau region are basically consistent, specifically, both total precipitation and light rain grades show high values in the southwest and low values in the northwest, with the magnitude of decrease being greater in the south than in the north; the moderate rain grade decreases from southeast to northwest, with trends showing a decrease in the south and an increase in the north; grades above heavy rain decrease from southeast to northwest, with trends characterized by increase in the central region and decrease in the north and south. The intensity of each precipitation grade is basically consistent with the distribution characteristics of the corresponding precipitation amount, but the spatial distribution of intensity trends is relatively complex. (3) The decreasing trend of precipitation amount in most areas of the Loess Plateau is caused by the reduction in precipitation days. The trend changes in precipitation days contribute mainly to precipitation increments for total precipitation, light rain, and moderate rain grades, with a spatial pattern characterized by high values in the south and low values in the north; only grades above heavy rain show trend changes in precipitation intensity that contribute mainly to precipitation increments, displaying a spatial pattern of high values in the northeast-to-southwest corridor and low values on both flanks.

Full Text

Spatio-temporal Characteristics of Precipitation Days and Intensity with Different Grades in the Loess Plateau During 1961–2017

AN Bin[1,2], **XIAO Weiwei**[2], **ZHANG Shulan**[1,3], **ZHANG Jiandong**[1,3]
[1]College of Tourism and Environment Resources, Ankang University, Ankang 725000, Shaanxi, China
[2]Engineering Technology Research Center for Water Resource Protection and Utilization of Hanjiang River, Ankang 725000, Shaanxi, China
[3]Academician and Expert Workstation of Shaanxi, Ankang 725000, Shaanxi, China

Abstract

The study of variation characteristics in precipitation days and intensity holds significant scientific importance for climate change adaptation and water resource development in the Loess Plateau. Based on daily precipitation data from 55 surface meteorological stations across the Loess Plateau from 1960 to 2017, this paper analyzes the spatio-temporal patterns of precipitation days, intensity, and rainfall amount for total precipitation and different grades (light rain, moderate rain, heavy rain, and rainstorm). The contribution of precipitation days and intensity at each grade to precipitation increment was quantified. Results indicate that: (1) Over the past 58 years, precipitation days and rainfall amounts for all grades, as well as the intensity of heavy rain and rainstorm, showed decreasing trends, while the intensity of total precipitation, light rain, and moderate rain increased. Light rain days represent the primary precipitation form in the Loess Plateau. (2) The spatial distribution patterns of precipitation days and rainfall amounts for total precipitation, light rain, and moderate rain were basically consistent: total precipitation and light rain grades showed higher values in the southwest and lower in the northwest, with decreasing amplitude greater in the south than in the north; moderate rain grades decreased from southeast to northwest, with trends showing a pattern of decrease in the south and increase in the north; heavy rain and above grades decreased from southeast to northwest, with trends characterized by increase in the middle and decrease in the north and south. The precipitation intensity of each grade was consistent with its corresponding precipitation distribution, but the spatial distribution of intensity trends was more complex. (3) The decreasing precipitation trend in most areas of the Loess Plateau was caused by the reduction in precipitation days. The trend changes in precipitation days contributed primarily to precipitation increments for total precipitation, light rain, and moderate rain, showing a spatial pattern of high contribution in the south and low in the north. Only heavy rain and above grades showed precipitation intensity trend changes as the primary contribution to precipitation increments, with a spatial distribution featuring high values in the northeast-southwest direction and low values on both sides.

Keywords: precipitation days; precipitation intensity; precipitation increment; precipitation grades; the Loess Plateau

Introduction

Research on precipitation changes under global warming has remained a focal issue. In recent years, numerous scholars have investigated spatio-temporal evolution characteristics of precipitation and extreme precipitation events [1-4]. Some scholars have explored the relationship between precipitation days, intensity, and precipitation amount [5-7]. Influenced by differences in natural geographical environments, precipitation amount, precipitation days, and intensity exhibit distinct regional characteristics. For instance, rainy days in China show a spatial pattern of more in the south and east, fewer in the north and west [8-9], with the annual decrease in rainy days significantly higher than the decrease in precipitation amount, while precipitation intensity shows an increasing trend [10]. Many studies have shown that trends in precipitation days and intensity vary across different regions and grades. Bai et al. [11] found that total precipitation and precipitation days of all grades in Guizhou Province decreased to varying degrees. Wu et al. [12] revealed that moderate and heavy rain days in Zhejiang Province showed increasing trends, while other precipitation days decreased. Li et al. [13] found that in the Haihe River Basin, heavy and rainstorm intensities showed insignificant decreases, while light and moderate rain intensities increased slightly. Yuan et al. [14] found that weak and moderate precipitation intensities in Beijing summer decreased significantly.

The Loess Plateau (33°41 ~41°16 N, 100°52 ~114°33 E) is located in the transitional zone from the eastern monsoon region to the northwest arid region of China [15] and represents a typical rain-fed agricultural area where agricultural and pastoral production is highly dependent on regional climate conditions [16]. Many studies have shown that annual, summer, and autumn precipitation in this region is decreasing, while spring and winter precipitation is increasing [17-18]. Wang et al. [19] analyzed and pointed out that the decreasing magnitude of annual precipitation in the Loess Plateau gradually becomes smaller from southeast to northwest, with erosive precipitation ($ $10 mm) significantly decreasing. Zhao et al. [20] analyzed the spatio-temporal characteristics of extreme precipitation events in the Loess Plateau, indicating that precipitation intensity showed an increasing trend, while light rain (<10 mm) days decreased. Existing research mainly focuses on annual and seasonal variation characteristics in the Loess Plateau, with few reports on variation characteristics of precipitation days and intensity for different grades. Under global warming, in-depth study of precipitation amount, days, and intensity changes for different grades in the Loess Plateau can directly or indirectly determine whether precipitation distribution is uniform in the region, which is important for clarifying spatio-temporal evolution patterns of different grades of precipitation. Therefore, this paper uses precipitation data from 1960–2017 in the Loess Plateau to analyze trends and spatial patterns of precipitation amount, days, and intensity for different grades, and quantifies the contribution of precipitation days and intensity to precipitation increments, aiming to deepen understanding of precipitation variation characteristics in the Loess Plateau and provide a basis for rational water resource utilization, flood and drought disaster prevention, and agricultural production improvement.

1. Data and Methods

1.1 Data Sources Daily precipitation data were obtained from the China Meteorological Data Network (http://data.cma.cn/). Quality checks were performed on the precipitation data using RHtest [15]. Based on the principle of selecting stations with the longest observation period and data availability, and ensuring missing data at each station was less than 1%, 55 meteorological stations were finally selected with daily precipitation data from 1960 to 2017, with effective data spanning 58 years. Specific locations are shown in [Figure 1: see original paper]. Precipitation grade classification follows the "Grade of Precipitation" standard issued by the China Meteorological Administration, dividing daily precipitation into four grades: light rain (0.1–9.9 mm), moderate rain (10.0–24.9 mm), heavy rain (25.0–49.9 mm), and rainstorm ($ $50.0 mm). Using this standard, precipitation days and amounts for each grade at each station were counted, with the sum of precipitation days (or amounts) for the four grades recorded as total precipitation days (or total precipitation amount). The ratio of total (each grade) precipitation amount to total (each grade) precipitation days was recorded as total (each grade) precipitation intensity.

1.2.1 Analysis Methods Long-term trends in precipitation days, intensity, and precipitation amount for different grades were calculated using linear fitting [16] and tested for significance, categorized as non-significant ($P > 0.05$), significant ($P < 0.05$), and extremely significant ($P < 0.01$). Spatial representation of each precipitation index was performed using the inverse distance weighting interpolation method in ArcGIS 10.2 [17].

1.2.2 Analysis of Precipitation Days and Intensity Contributions to Precipitation Increment The long-term trends of precipitation intensity and days in a region jointly affect the trend of regional precipitation amount

[18]. It is believed that precipitation amount change can be decomposed into: the trend component of precipitation amount caused by the trend change in precipitation days, and the trend component of precipitation amount caused by the trend change in precipitation intensity [19-20]. This method has been widely applied [18,20]. The calculation formula is as follows:

$$\begin{aligned} \text{Trend}_p &= \text{Trend}_{pd} + \text{Trend}_{pi} \\ \text{Trend}_{pdz} &= \bar{p} \times \text{Trend}_{pd} \\ \text{Trend}_{piz} &= \bar{d} \times \text{Trend}_{pi} \end{aligned}$$

Where: p represents precipitation amount on effective precipitation days ($\text{mm} \cdot \text{d}^{-1}$); $\bar{p}$ represents average precipitation amount on effective precipitation days ($\text{mm} \cdot \text{d}^{-1}$); Trend_p represents precipitation amount trend ($\text{mm} \cdot \text{a}^{-1}$); Trend_{pd} represents precipitation days trend ($\text{d} \cdot \text{a}^{-1}$); Trend_{pdz} represents precipitation increment caused by precipitation days trend change ($\text{mm} \cdot \text{a}^{-1}$); Trend_{pi} represents precipitation intensity trend ($\text{mm} \cdot \text{d}^{-1} \cdot \text{a}^{-1}$); Trend_{piz} represents precipitation increment caused by precipitation intensity trend change ($\text{mm} \cdot \text{a}^{-1}$); $\bar{d}$ represents average precipitation days (d). When Trend_{pdz} (Trend_{piz}) is positive, it indicates that the precipitation amount trend increases due to precipitation days (precipitation intensity) trend change; when negative, it indicates the opposite.

To further compare the contribution differences of precipitation days and intensity at each grade to precipitation increments, the absolute value difference ratio to effective precipitation day precipitation amount was calculated [18,21]:

$$R = \frac{|\text{Trend}_{pdz} - \text{Trend}_{piz}|}{\bar{p}} \times 100\%$$

Where: R is the difference percentage; when $R > 0$, it indicates that the precipitation increment caused by precipitation days trend change is greater than that caused by precipitation intensity; when $R < 0$, it indicates the opposite.

2. Results

2.1.1 Temporal Characteristics of Precipitation Days, Intensity, and Precipitation Amount Based on the long-term variation trends of precipitation amount, days, and intensity for different grades in the Loess Plateau from 1960 to 2017 (FIGURE:2), the annual total precipitation days in the Loess Plateau showed an extremely significant decreasing trend at a rate of -0.239 $\text{d} \cdot \text{a}^{-1}$ ($P < 0.01$), with a maximum value of 120.40 d and a multi-year average of 81.00 d. Total precipitation days exhibited a "more-less-more" interdecadal variation characteristic, reaching 88.56 d in the 1960s, the highest in the study period; then continuously decreasing to 61.09 d in the 1990s, the lowest in the study period; and then turning to a slight increase to 75.02 d in the 2000s. Precipitation days for all grades showed fluctuating decreasing trends, with light rain days decreasing most significantly, followed by moderate rain and rainstorm days, and heavy rain days decreasing least. Except for the extremely significant decreasing trend in light rain days ($P < 0.01$), trends for other grades were non-significant ($P > 0.05$). The interdecadal variation characteristics were basically consistent with total precipitation days, with light rain, heavy rain, and rainstorm days reaching maximum values in the 1960s, then gradually decreasing until the 1990s, and turning to slight increases after the 2000s. Moderate rain days decreased from the 1960s to the 1990s and then slightly rebounded in the 2000s.

Statistics show that in recent 58 years, light rain, moderate rain, heavy rain, and rainstorm days were 68.45 d, 9.68 d, 2.40 d, and 0.47 d respectively, accounting for 84.51%, 11.95%, 2.96%, and 0.58% of annual total precipitation days. Thus, light rain days are the most important precipitation form in the Loess Plateau, with their precipitation amount accounting for 67.09% of annual precipitation. However, the contribution of moderate rain, heavy rain, and rainstorm days to annual precipitation cannot be ignored, accounting for 19.04%, 7.54%, and 6.35% of annual precipitation respectively.

The multi-year average total precipitation intensity in the Loess Plateau was 6.85 $mm \cdot d^{-1}$, varying between 4.01-9.24 $mm \cdot d^{-1}$, showing a significant fluctuating upward trend ($P < 0.01$) with a climate tendency rate of 0.0091 $mm \cdot a^{-1}$. The multi-year average intensities of light rain and moderate rain were 2.33 $mm \cdot d^{-1}$ and 15.21 $mm \cdot d^{-1}$ respectively, fluctuating upward at rates of 0.0036 $mm \cdot a^{-1}$ and 0.0035 $mm \cdot a^{-1}$, with the light rain intensity increase being extremely significant ($P < 0.01$). The multi-year average intensities of heavy rain and rainstorm were 33.26 $mm \cdot d^{-1}$ and 67.12 $mm \cdot d^{-1}$ respectively, fluctuating downward at rates of -0.0095 $mm \cdot a^{-1}$ and -0.0224 $mm \cdot d^{-1} \cdot a^{-1}$, with neither trend passing the 0.05 significance level test.

Interdecadal variations show that total precipitation, light rain, and heavy rain amounts were highest in the 1960s, then continuously decreased to the 2000s, with slight rebounds thereafter. Moderate rain and rainstorm amounts were also highest in the 1960s, reaching the lowest in the 2000s. Annual precipitation in the Loess Plateau varied between 291.22–640.40 mm (average 418.73 mm), showing a non-significant decreasing trend at -0.574 $mm \cdot a^{-1}$ ($P > 0.05$), indicating more severe drought risk in the Loess Plateau. Precipitation amounts for all grades showed non-significant decreasing trends ($P > 0.05$), with light rain showing the largest decrease, followed by moderate rain and rainstorm, and heavy rain the smallest, consistent with the decreasing magnitude ranking of precipitation days.

In summary, the trend changes and interdecadal characteristics of precipitation days and intensity for different grades in the Loess Plateau are not entirely consistent. Before the 1990s-2000s, the Loess Plateau was in a stage of decreasing precipitation days and amount but increasing precipitation intensity, after which it turned to a stage of increasing precipitation days and amount but decreasing precipitation intensity.

2.1.2 Spatial Characteristics of Precipitation Days, Intensity, and Precipitation Amount After sorting precipitation data for different grades at each station in the Loess Plateau, some stations had only a few or even no rainstorm days. Therefore, this paper only analyzes the spatial characteristics of total precipitation, light rain, moderate rain, and heavy rain. Based on the natural breaks classification principle, the multi-year average values of precipitation days, intensity, and precipitation amount at each station in the Loess Plateau during 1960–2017 were calculated to obtain their spatial distribution patterns.

FIGURE:3 shows that total precipitation and light rain days in the Loess Plateau exhibited a pattern of high values in the southwest and low values in the northwest, with the highest at Menyuan Station in Qinghai and the lowest at Huining Station in Gansu. Calculations found that the proportion of light rain days to total precipitation days at each station ranged between 78.45%-91.31%. Moderate rain and heavy rain days decreased from southeast to northwest. Among them, moderate rain days formed a high-value area similar to total precipitation days in the west; moderate rain days were highest at Changwu Station in south-central Loess Plateau and lowest at Huinong Station in the northwest, while heavy rain days were highest at Mengjin Station in the east and lowest at Guide Station in the west.

Total precipitation, moderate rain, and heavy rain intensities all showed a pattern of high values in the southeast and low values in the northwest, while light rain intensity formed a "high-secondary high" pattern from east to west. The spatial distribution characteristics of precipitation amount for each grade were consistent with their precipitation intensity. Calculations of the ratio of light rain, moderate rain, and heavy rain amounts to total precipitation at each station revealed that 67.09% of the Loess Plateau area was dominated by light rain precipitation, concentrated in the vast area west of the Baotou–Pingliang line; 26.06% of the area was dominated by moderate rain precipitation, roughly distributed in southeastern Shanxi and northern Henan; and 6.85% of the area was dominated by heavy rain and above precipitation, concentrated in the Fenwei Valley.

The decreasing amplitude of total precipitation days in the Loess Plateau showed a pattern of more in the south and less in the north, more in the east and less in the west. Among them, Huanxian Station in Gansu showed the most obvious decrease (-0.56 $d \cdot a^{-1}$). The spatial distribution of decreasing amplitude of -0.14 to -0.28 $d \cdot a^{-1}$ was most extensive, mainly distributed in areas outside southeastern Shanxi, northern Shaanxi, and the strip from Yuzhong in Gansu to Dongsheng in Inner Mongolia, accounting for 52.73% of all meteorological stations. The spatial distribution of light rain days trend was similar to total precipitation, also showing the most obvious decrease (-0.53 $d \cdot a^{-1}$), but with more stations showing decreases of -0.14 to -0.28 $d \cdot a^{-1}$, accounting for 67.27% of all stations. Notably, total precipitation and light rain days in local western areas of the Loess Plateau showed increasing trends, most obviously at Xining Station in Qinghai.

Moderate rain days showed a latitudinal zonal pattern of decrease in the south and increase in the north, with 67.27% of stations showing decreasing trends, most significantly at Linfen Station in Shanxi (-0.063 $d \cdot a^{-1}$). Moderate rain days increased significantly in Datong in the northeast and Xining in the west of the Loess Plateau. Heavy rain days showed a spatial pattern of increase in the middle and decrease in the north and south, with an overall decreasing trend at 58.18% of stations.

Most areas of the Loess Plateau showed increasing trends in total precipitation intensity, with the increase amplitude showing a spatial pattern of high in the middle and low around the periphery. The southeastern edge of the Mu Us Sandy Land and northern Shanxi showed more obvious increases, most significantly at Yulin Station in Shaanxi (0.0296 $mm \cdot a^{-1}$). Additionally, total precipitation intensity in western Yulin and other areas showed decreasing trends. Light rain intensity changes showed faster increases in the north-central and northeastern parts and slower increases in the eastern and western parts, with 65.45% of the region showing increasing trends, most significantly at Yulin Station (0.0096 $mm \cdot a^{-1}$). Light rain intensity at 34.55% of stations in central and southern Loess Plateau showed decreasing trends, most obviously at Yan' an Station in Shaanxi (-0.0036 $mm \cdot a^{-1}$).

Moderate rain intensity showed increasing trends at 67.27% of stations in the Loess Plateau, with greater increases in the northeast and northwest, most significantly at Taole Station in Ningxia (0.023 $mm \cdot a^{-1}$). Decreasing trends were observed in Yushe–Xingxian in central-eastern and southwestern areas. Heavy rain intensity trends mainly showed a spatial pattern of increase in the west-central direction and decrease in the east and west, with decreasing trends at 58.18% of stations. The largest increasing and decreasing amplitudes were at Yinchuan (0.16 $mm \cdot a^{-1}$) and Hohhot (-0.19 $mm \cdot a^{-1}$) respectively.

2.2 Impact of Precipitation Days and Intensity Trend Changes on Precipitation Increment To clarify the contribution differences of precipitation days and intensity to precipitation increments in the Loess Plateau, formula (1) was used to calculate the precipitation increment caused by precipitation days trend change (Trend dz), precipitation increment caused by precipitation intensity trend change (Trend iz), and the difference percentage (R) between them. Results are shown in TABLE:2.

TABLE:2 shows that Trend d for total precipitation days in the Loess Plateau was -0.239 $d \cdot a^{-1}$, meaning the trend change in total precipitation days caused a decrease in total precipitation trend. Trend i for total precipitation intensity was 0.0091 $mm \cdot d^{-1} \cdot a^{-1}$, meaning the trend change in total precipitation intensity caused an increase in total precipitation trend. Trend dz was -1.233 mm $\cdot$ a^{-1}, Trend iz was 0.659 mm $\cdot$ a^{-1}, and the difference percentage R was 11.12%, indicating that precipitation days trend change contributed mainly to total precipitation increment. Trend d for light rain, moderate rain, heavy rain, and rainstorm days were -0.206 d $\cdot$ a^{-1}, -0.021 d $\cdot$ a^{-1}, -0.003 d $\cdot$ a^{-1}, and -0.0003 d $\cdot$ a^{-1} respectively, with corresponding Trend dz values of -0.521 mm $\cdot$ a^{-1}, -0.196 mm $\cdot$ a^{-1}, -0.094 mm $\cdot$ a^{-1}, and -0.013 mm $\cdot$ a^{-1}. Trend i for light rain, moderate rain, and heavy rain intensities were 0.0036 mm $\cdot$ d^{-1} $\cdot$ a^{-1}, 0.0035 mm $\cdot$ d^{-1} $\cdot$ a^{-1}, and -0.0095 mm $\cdot$ d^{-1} $\cdot$ a^{-1} respectively, with corresponding Trend iz values of 0.252 mm $\cdot$ a^{-1}, 0.029 mm $\cdot$ a^{-1}, and -0.022 mm $\cdot$ a^{-1}. Except for heavy rain and rainstorm intensities, all other Trend dz values were negative and Trend iz values positive. The difference percentage R for all grades except heavy rain was positive, indicating that precipitation days trend change contributed mainly to precipitation increments for light rain, moderate rain, and rainstorm, while precipitation intensity trend change contributed mainly for heavy rain.

FIGURE:5 shows that Trend dz and Trend iz for different grades in the Loess Plateau were similar to the spatial patterns of precipitation days and intensity trends. Trend dz for each grade was mainly negative, causing precipitation decreases in the Loess Plateau, while Trend iz for total precipitation, light rain, and moderate rain intensities was mainly positive, causing precipitation increases. The trend change in total precipitation days contributed mainly to total precipitation increments in most areas, consistent with conclusions that precipitation day trends contribute more to precipitation increments than intensity trends in eastern northwest China and southern Gansu-Ningxia summer rainfall [18,22]. The contribution rate spatially showed a roughly south-high and north-low pattern, with alternating "high-low-high"distribution in the central-southern part in the east-west direction. The trend change in total precipitation intensity contributed mainly to total precipitation increments in the central-western part of Qinghai, Dingbian and Yulin in Shaanxi, and Wuzhai and Datong in Shanxi.

Light rain and moderate rain days trend changes contributed mainly to precipitation increments, with spatial patterns showing south-high and north-low, but with slight east-west differences: Trend dz for light rain days showed alternating "secondary high-low" distribution in the east-west direction, while Trend dz for moderate rain days only showed "high-low-high" distribution in the central-southern part in the east-west direction. Areas where light rain intensity trend change was the main contribution were located in central Qinghai and the Qinghai-Gansu border, with sporadic distribution in Wuzhai and Dongsheng in the northeast. Areas where moderate rain intensity played a dominant role were sporadically distributed in Yanchi, Yulin, and Hequ in the north-central region.

Compared with total precipitation, light rain, and moderate rain grades, heavy rain and above intensity trend changes contributed mainly to precipitation increments in broader areas, mainly concentrated in eastern Guanzhong, southwestern Shanxi, and northwestern Henan. Areas with high contribution rates of heavy rain and above days were located in the northeast, southwestern central part, and eastern Shanxi of the Loess Plateau, showing alternating high-low distribution from northeast to southwest.

3. Discussion

Under global warming, annual precipitation and light rain days in the Loess Plateau show decreasing trends [11,14], while total precipitation intensity increases [19,20]. These research results are basically consistent with this study' s conclusions, but there are some differences in calculation results, possibly due to different study periods, meteorological stations, and data processing methods. This study further found that precipitation amount and days for total precipitation, light rain, and moderate rain in the Loess Plateau all showed decreasing trends, while corresponding precipitation intensities showed increasing trends; heavy rain and rainstorm days and intensities both showed decreasing trends. Combined with the proportion of each grade' s precipitation days in total precipitation days and corresponding precipitation amounts in total precipitation amount, light rain days were found to be the primary precipitation form in this region.

Studies on the impact of different precipitation grades in China show that weak precipitation is mainly affected by precipitation days trend change [18,21], which matches the conclusion for most areas in this study. However, heavy precipitation is mainly affected by precipitation intensity trend change [18,22], a view only supported by the Shanxi-Henan-Shaanxi border area in the southeastern Loess Plateau. Therefore, the decreasing precipitation trend in most areas of the Loess Plateau is caused by the reduction in precipitation days. Future research should utilize higher-resolution meteorological data and comprehensively consider multiple factors such as atmospheric circulation and water vapor transport to further explore the spatio-temporal differences of different precipitation grades in the Loess Plateau.

Additionally, based on Hurst index analysis [23], the Loess Plateau will experience continuous precipitation decrease in the future, which will intensify drought risk in the region [24]. Under the background of decreasing precipitation amount and days for most grades but increasing intensity for most grades, the Loess Plateau should strengthen farmland water conservancy infrastructure, establish scientific irrigation and drainage systems, and focus on addressing agricultural disaster threats from heavy precipitation to minimize crop damage.

4. Conclusions

Based on daily precipitation data from 55 meteorological stations from 1960 to 2017, this study analyzed spatio-temporal distribution patterns of precipitation days and intensity for different grades in the Loess Plateau and quantified the impact degree of precipitation days and intensity at each grade on precipitation, reaching the following conclusions:

(1) Temporally, trend changes in precipitation days and intensity for different grades in the Loess Plateau were not entirely consistent. Total precipitation, light rain, moderate rain, heavy rain, and rainstorm days and amounts all showed varying degrees of decreasing trends, with total precipitation and light rain day decreases being extremely significant ($P < 0.01$). Light rain days are the primary precipitation form in the Loess Plateau, accounting for 84.51% of precipitation days and 67.09% of annual precipitation amount. Total precipitation intensity increased at a rate of 0.0091 $mm \cdot a^{-1}$, light rain and moderate rain intensities fluctuated upward, while heavy rain and rainstorm intensities fluctuated downward. The decreases in total precipitation and light rain days were significant ($P < 0.05$) and extremely significant ($P < 0.01$) respectively. Before the 1990s–2000s, the Loess Plateau was in a stage of decreasing precipitation days and amount but increasing precipitation intensity, after which it turned to a stage of increasing precipitation days and amount but decreasing precipitation intensity.

(2) Spatially, the distribution patterns of precipitation days, intensity, and amount for each grade and their change rates showed different characteristics. The spatial patterns of precipitation days and amounts for total precipitation, light rain, and moderate rain were basically consistent: total precipitation and light rain grades showed low values in the northwest and high in the southwest, with decreasing amplitude greater in the south than in the north; moderate rain grades decreased from southeast to northwest, with trends showing a pattern of decrease in the south and increase in the north; heavy rain and above grades decreased from southeast to northwest, with trends characterized by increase in the middle and decrease in the north and south. Precipitation intensity for each grade was consistent with its corresponding precipitation distribution, but the spatial distribution of intensity trends was more complex.

(3) The decreasing precipitation trend in most areas of the Loess Plateau was caused by the reduction in precipitation days. The trend changes in total precipitation, light rain, moderate rain, and rainstorm days contributed mainly to precipitation increments, while the trend change in heavy rain precipitation intensity contributed mainly to precipitation increments. The main contribution of total precipitation, light rain, and moderate rain day trend changes to precipitation increments showed a spatial distribution pattern of high in the south and low in the north, but with slight differences in the east-west direction. Heavy rain and above intensity contributed mainly to precipitation increments with a spatial distribution pattern of high in the northeast-southwest direction and low on both sides.

References

[1] Chen Jie, Liu Yujie, Pan Tao, et al. Spatiotemporal variation of precipita-

tion in China and its impact on surface dry-wet conditions during 1961-2010[J]. Journal of Natural Resources, 2019, 34(11): 2440-2453.

[2] Yang Jia, Hao Guizhen, Zhang Jing, et al. The spatial and temporal variation characteristics of precipitation in Northwest Hebei Province during 1960-2016[J]. Journal of Water Resources and Water Engineering, 2019, 30(5): 117-123, 133.

[3] Kong Feng, Shi Peijun, Fang Jian, et al. Advances and prospects of spatiotemporal pattern variation of extreme precipitation and its affecting factors under the background of global climate change[J]. Journal of Catastrophology, 2017, 32(2): 165-174.

[4] Xie Z Q, Du Y, Zeng Y, et al. Classification of yearly extreme precipitation events and associated flood risk in the Yangtze-Huaihe River Valley[J]. Science China Earth Sciences, 2018, 61(9): 1341-1356.

[5] Li Huifang, Yin Shuyan. Temporal and spatial variation of precipitation intensity and days with different grades in Haihe River Basin[J]. Chinese Journal of Agrometeorology, 2014, 35(6): 603-610.

[6] Wu Haomin, Liao Bijun, Cai Shouqiang. Temporal and spatial distribution characteristics of different level rainfall days in Zhejiang Province[J]. Journal of Arid Meteorology, 2012, 30(3): 360-366.

[7] Yuan Yufeng, Zhai Panmao, Li Jian, et al. Changes in classified precipitation in the urban, suburban and mountain areas of Beijing[J]. Climate Change Research, 2017, 13(6): 589-597.

[8] Gu Chaojun, Mu Xingmin, Gao Peng, et al. Characteristics of temporal variation in precipitation and temperature in the Loess Plateau from 1961 to 2014[J]. Journal of Arid Land Resources and Environment, 2017, 31(3): 136-143.

[9] Li Zhi, Zheng Fenli, Liu Wenzhao. Analyzing the spatial-temporal changes of extreme precipitation events in the Loess Plateau from 1961 to 2007[J]. Journal of Natural Resources, 2010, 25(2): 291-299.

[10] Wang Qixiang, Fan Xiaohui, Wang Mengben. Precipitation trends during 1961-2010 in the Loess Plateau region of China[J]. Acta Ecologica Sinica, 2011, 31(19): 5512-5523.

[11] Zhao Anzhou, Zhu Xiufang, Pan Yaozhong. Spatiotemporal variations of extreme precipitation events in the Loess Plateau from 1965 to 2013[J]. Journal of Beijing Normal University (Natural Science Edition), 2017, 53(1): 43-50.

[12] Bai Shuying, Mo Ting, Shi Jianqiao, et al. Spatial and temporal variations of rainfall days with different intensities in Guizhou in recent 50 years[J]. South-North Water Transfers and Water Science & Technology, 2015, 13(2): 220-224.

[13] Wang Weiping, Yang Xiuqun, Zhang Zuqiang, et al. The climatic characteristics and trends of rainy days over China[J]. Journal of the Meteorological Sciences, 2017, 37(3): 317-328.

[14] Wang Ying, Shi Neng, Gu Junqiang, et al. Climatic variations of wet days in China[J]. Chinese Journal of Atmospheric Sciences, 2006, 31(1): 162-170.

[15] Wang X L, Chen H, Wu Y, et al. New techniques for detection and adjustment of shifts in daily precipitation data series[J]. Journal of Applied Meteorology and Climatology, 2010, 49(12): 2416-2436.

[16] Xu Jianhua. Quantitative Geography[M]. 2nd ed. Beijing: Higher Education Press, 2014.

[17] Tang Guoan, Yang Xin. Experimental Course on Spatial Analysis of Geographic Information Systems[M]. 2nd ed. Beijing: Science Press, 2012.

[18] Xu Xinchuang, Zhang Xuezhen, Dai Erfu, et al. Research of trend variability of precipitation intensity and their contribution to precipitation in China from 1961 to 2010[J]. Geographical Research, 2014, 33(7): 1335-1347.

[19] Karl T R, Knight R W. Secular trends of precipitation amount, frequency, and intensity in the United States[J]. Bulletin of the American Meteorological Society, 1998, 79(2): 231-241.

[20] Chen Xiaoyan, Shang Kezheng, Wang Shigong, et al. Analysis on the spatiotemporal characteristics of precipitation under different intensities in China in recent 50 years[J]. Arid Zone Research, 2010, 27(5): 766-772.

[21] Lin Yunping, Zhao Chunsheng. Trends of precipitation of different intensity in China[J]. Acta Scientiarum Naturalium Universitatis Pekinensis, 2009, 45(6): 995-1002.

[22] Yang Zhaoming, Zhang Tiaofeng. Analysis of precipitation change and its contribution in the rainy season in the northeast Qinghai-Tibet Plateau from 1961 to 2017[J]. Arid Zone Research, 2021, 38(1): 22-28.

[23] Sun Yijie, Liu Xianfeng, Ren Zhiyuan, et al. Spatiotemporal changes of droughts and heatwaves on the Loess Plateau during 1960-2016[J]. Progress in Geography, 2020, 39(4): 591-601.

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