

Diurnal Variation Characteristics of Precipitation in the Shiyang River Basin of Northwest China in Summer

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Abstract

Based on the hourly precipitation data from 32 regional meteorological stations and 5 automatic meteorological stations in summer (from June to August) over the Shiyanghe River basin from 2009 to 2013, we analyzed the diurnal variation characteristics of precipitation over the Shiyanghe River basin, by using four precipitation indices (hourly precipitation, hourly precipitation frequency, hourly precipitation intensity, and different duration precipitation). The results show that the spatial distribution of hourly precipitation, hourly precipitation frequency in summer declines from upstream to downstream over the Shiyanghe River basin because of geographical position, altitude, latitude and weather systems, and the spatial distribution of hourly intensity is complex. The precipitation, the precipitation frequency and the precipitation intensity over the Shiyanghe River basin present a diurnal pattern of double-peak distribution, with the peak periods at 01:00-09:00 and 14:00-23:00, strong precipitation present single-peak with the peak period at 14:00-23:00. Total precipitations and precipitation frequencies of 1 - 3 h short-time rainfall are more than long time rainfall continued more than 10 h over the Shiyanghe River Basin. The short-time rainfall continuing within 1 - 6 h often occurs from afternoon to evening, the long time rainfall continuing more than 6 h often occurs from evening to early morning or late afternoon to evening.

Keywords

Shiyanghe River Basin, Hourly Precipitation, Different Duration Precipitation,

1. Introduction

As the supply source of surface and ground water, precipitation plays an important role in the terrestrial hydrological cycle and the evolution of freshwater resources. In-depth research on the diurnal variation of precipitation is of considerable significance to an adequate understanding of weather and climate systems, the formation mechanism of precipitation, the evaluation of regional climate and water vapor cycle characteristics, the higher accuracy of weather forecast and the prevention and reduction of natural disasters etc [1] [2] [3] [4]. Existing research findings in China and abroad have shown that the day-night cycle of precipitation obviously changes with space and seasons, which is generally embodied in that precipitation appears more frequently on land in the afternoon during warm seasons (14:00-18:00 LST (Local Standard Time)), but maximum precipitation occurs between midnight and dawn (22:00-06:00 LST) on the sea and small islands [5] [6] [7], and the day-night cycle of precipitation is weaker in cold seasons than in warm seasons. Many ocean regions and their adjacent continental regions are relatively different in the day-night cycles of precipitation and surface wind fields [5] [8]. However, there are exceptions to the general model in some areas, such as central areas of the United States [8] and the southeast of China [5], where maximum precipitation occurs between midnight and the early morning in summer. These maximum values at night tend to be related to the night environment, when convective systems can hardly be restrained and will spread downwind through the mountains [9] [10] [11] [12], while it is difficult for convection to occur in the central areas of the United States in the afternoon due to the restriction of large-scale downward flows [13]. During cold seasons, the day-night cycle of precipitation is much weaker than in summer, with the occurrence of maximum precipitation in most land areas in the morning, which is because the high relative humidity facilitates the formation of condensation on winter mornings [5] [13]. Through a study of the hourly rainfall data in the United States [13], Japan and Malaysia [14], it was found that the day-night cycle of precipitation was mainly embodied in precipitation frequency rather than precipitation intensities, as the day-night cycle of the latter was much weaker than that of the former. Though the records of rainfall at most stations were mainly characterized by a single precipitation peak, there was a secondary peak in many tropical (03:00 LST around) and mid-latitude regions (the peak appeared at about 06:00) [14] [15].

Existing studies showed significant diurnal variation and distinct regional characteristics of precipitation in China in summer. In 2007, Yu *et al.* [16] comprehensively described the regional characteristics of diurnal variation of precipitation in mainland China for the first time, that is, precipitation peaks are in

the afternoon in the south and northeast of China, and in the midnight on the Tibetan Plateau, with the phase of diurnal variation varies towards the east along the Yangtze River, to reach a peak at midnight in the upper reaches, in the morning at the middle reaches, and in the afternoon at the lower reaches respectively; the diurnal variation of precipitation in the Yellow River and Yangtze River basins shows a bimodal distribution, with a peak appearing in the morning and the afternoon respectively. Precipitation for different duration differs in diurnal variation. The peak of long persistent precipitation is usually in the morning, which accounts for more than 60% of precipitation in central and eastern China, while short persistent precipitation mainly appears in the afternoon [4]. The extreme precipitation events in coastal areas, the Yangtze River basin and across the eastern slope of the Tibetan Plateau lasted for a long time on average, while those in north China lasted for a short period [17]. Against the background of southern flood and northern drought, the hourly amount and frequency of precipitation have also changed significantly, with an increase in the amount of precipitation but a decrease in its intensity, due to the persistent increase of precipitation. In the meantime, southern flood and northern drought is mainly attributed to the variation of precipitation of low and medium intensities, but less affected by the frequency and amount of hourly extreme precipitation [17] [18]. Literature mentioned above shows the distribution characteristics of hourly extreme precipitation, interdecadal variation of hourly precipitation at different levels, its contributions to the interdecadal variation of precipitation. However, it is still unclear how hourly extreme precipitation varies in amount and frequency during a day, and whether it is also in bimodal distribution.

The Shiyang River basin is one of the inland river basins in China with the largest population, the highest level of water resources development and utilization, the most prominent contradiction in water consumption and the severest ecological and environmental problems. Besides, due to its location in the arid and semi-arid climatic areas, the uneven distribution of precipitation results in frequent drought and flood, cause serious impacts on the lives, production and life safety of people living in the basin. In recent years, relevant scholars have made a lot of research on the climate, ecology, water resources and runoff variation of the Shiyang River basin from different perspectives [19] [20] [21] [22]. Nevertheless, most of these studies were restricted to the observation data of several automatic meteorological stations on daily and monthly precipitation, and no in-depth study has been carried out on the diurnal variation of precipitation in the Shiyang River basin based on the data about hourly precipitation observed at automatic meteorological stations and densified regional meteorological stations. Therefore, this paper studied the diurnal variation of precipitation in the Shiyang River basin in summer by analyzing the data about hourly precipitation observed by 37 meteorological stations (32 densified regional meteorological stations and 5 automatic meteorological stations) in the Shiyang River basin in summer (June to August) from 2009 to 2013 with 4 indicators, namely

the hourly amount, frequency and intensity of precipitation at different time within a day, and precipitation for different duration. It was aimed to provide references for improving the accuracy of weather forecasts, making some assessment of the climate, preventing disasters and reducing damages through a further understanding of the changing mechanism of precipitation in the Shiyang River basin.

2. Study Area

The Shiyang River basin is one of the three major inland river basins at the Hexi Corridor of Gansu Province, located between the eastern section of the Qilian Mountains and the southern edges of the Badain Jaran Desert and the Tengger Desert ($36^{\circ}29' - 39^{\circ}27'N$, $101^{\circ}41' - 104^{\circ}16'E$), covering an area of $41,600 \text{ km}^2$ (**Figure 1**), with a terrain high in the south and low in the north and tilting from southwest to northeast. The whole basin can be divided into 4 different geomorphic units, including the region of the Qilian Mountains in the south, the corridor plain in the center, the region of low mountains and hills in the north, and the desert area. The upper reach of the basin is in the cold, semiarid and semi-humid region, at an altitude of $2000 - 5000 \text{ m}$, with annual precipitation of $300 - 600 \text{ mm}$, an annual evaporation capacity of $700 \text{ mm} - 1200 \text{ mm}$ and an annual average temperature of $2 - 6^{\circ}\text{C}$; the middle reach is on an oasis plain which is cool and arid, at an altitude of $1500 - 2000 \text{ m}$, with annual precipitation of $150 - 300 \text{ mm}$, an annual evaporation capacity of $1300 \text{ mm} - 2000 \text{ mm}$, and an

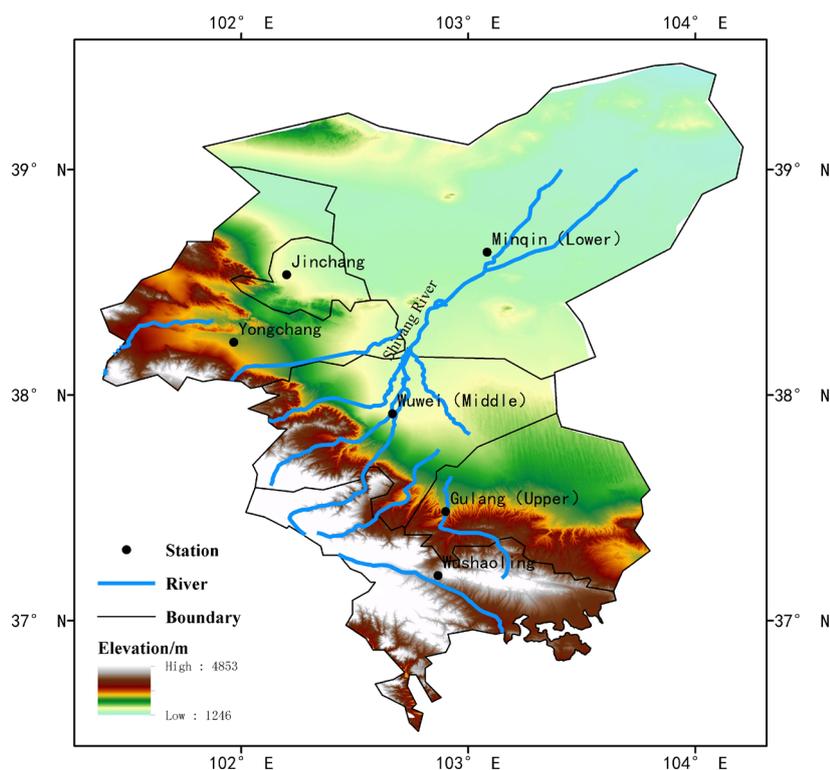


Figure 1. Study area (Shiyang River Basin, Northwest China).

annual average temperature of 6 - 8°C; the lower reach is in the warm and arid desert area, at an altitude of 1300 - 1500 m, with annual precipitation of less than 150 mm, an annual evaporation capacity of 2000 mm - 2600 mm, and an annual average temperature of above 8°C.

3. Data and Analysis Methods

This paper studied the diurnal variation of precipitation in the Shiyang River basin with conventional methods of climatic statistics and by adopting 4 indicators, namely the hourly amount, frequency and intensity of precipitation at different time within a day, and precipitation for different duration, based on the full data about the hourly precipitation of this area in summer (June to August) from 2009 to 2013 at 37 meteorological stations in total, including 32 densified regional meteorological stations and 5 automatic meteorological stations (19 stations in the mountain areas Gulang and Tianzhu counties at the upper reaches, 8 stations on the oasis plain of Liangzhou at the middle reaches, and 10 stations on the desert plain of Minqin at the lower reaches). The total precipitation in summer (the number of days with precipitation) refers to the 5-year average of the total accumulation (the number of days with precipitation) of all the hourly precipitation (≥ 0.1 mm) from 20:00 (Beijing Time, the same below) the day before to 20:00 this day from June to August; total hourly precipitation (the number of days) means the 5-year average of total precipitation (≥ 0.1 mm) (the number of days) within 1 full hour (1 h) from its start to end on the clock from June to August; the intensity of precipitation is defined as the ratio of total precipitation to the number of days with precipitation; the duration of precipitation is the number of hours from the start to the end of one precipitation event; the precipitation that reaches more than 20.0 mm within 1 hour is called heavy precipitation.

4. Results and Discussions

4.1. The Spatial Distribution Characteristics of Precipitation

4.1.1. The Spatial Distribution of Total Precipitation

The average precipitation of 37 stations in the shiyang River basin in summer is 136.8 mm, including the precipitation of 183.8 mm, 84.1 mm and 91.1 mm at the upper, middle and lower reaches respectively (**Figure 2(a)**). The maximum precipitation (262.1 mm) appears in the high-altitude mountainous area Tanshanling Town at the upper reaches, and the minimum precipitation occurs in the low-altitude Hongshagang Town at the lower reaches (46.9 mm), with a gap of 215.2 mm between them. As for the percentage of total precipitation between 0.1 and 19.9 mm a day in the total precipitation in summer, it is 74.0% (101.2/136.8) on average across the whole basin, and 73.8% (135.7/183.8), 81.9% (68.9/84.1) and 67.3% (61.3/91.1) at the upper, middle and lower reaches respectively. The precipitation of more than ≥ 20.0 mm a day accounts for 26.0% (35.7/136.8) on average in total average precipitation, and makes up 26.2%

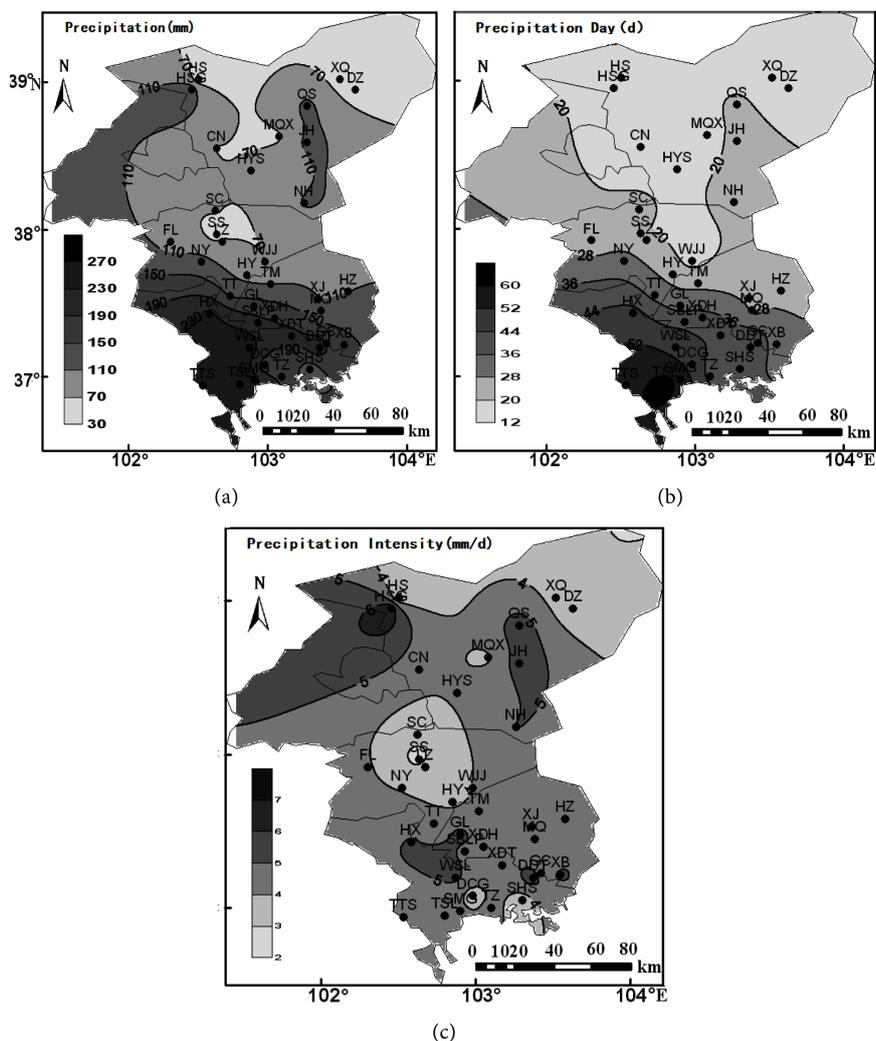


Figure 2. Spatial distribution of precipitation parameters in summer over the Shiyang River Basin.

(48.1/183.8), 18.1% (22.2/84.1) and 22.7% (22.8/91.1) at the upper, middle and lower reaches respectively.

4.1.2. The Spatial Distribution of the Number of Days with Precipitation in Summer

The number of days with precipitation shows a decline trend from the upper reaches to the lower reaches of the Shiyang River basin in summer. The number of days with precipitation is 31.1 d on average at the 37 stations across the whole basin in summer, including 40.7 d, 24.2 d and 20.4 d at the upper, middle and lower reaches (**Figure 2(b)**). The maximum value appears in Tanshanling Town (62.2 d) at the upper reaches, while the minimum value appears Xiqu Town (14.8 d) at the lower reaches. The number of days with daily precipitation of 0.1 - 19.9 mm is 29.9d on average across the whole area, with 39.2 d, 23.5 d and 19.6 d at the upper, middle and lower reaches, and the maximum and minimum values seen at Tanshanling Town (61 d) and Xiqu Town (14.2 d) at the lower

reaches; the number of days with daily precipitation of 20 mm or more is 1.2 d on average across the whole area, with 1.6 d, 0.8 d and 0.8 d at the upper, middle and lower reaches, and the maximum and minimum values appearing at Wushao Ridge (2.8 d) and Hongshagang Town (0.2 d).

4.1.3. The Spatial Distribution of Precipitation Intensities

In the Shiyang River basin, the high value center ($6.7 \text{ mm}\cdot\text{d}^{-1}$) of daily precipitation intensities is at Hongshagang town of Minqin County at the lower reaches, while the minimum value center ($2.6 \text{ mm}\cdot\text{d}^{-1}$) is at Shuangshu Township of Liangzhou District at the middle reaches (Figure 2(c)). The average daily precipitation intensity is $4.3 \text{ mm}\cdot\text{d}^{-1}$ at the 37 stations across the basin, and is $4.5 \text{ mm}\cdot\text{d}^{-1}$, $4.5 \text{ mm}\cdot\text{d}^{-1}$ and $3.7 \text{ mm}\cdot\text{d}^{-1}$ at the upper, lower and middle reaches respectively. The intensity of daily precipitation of 0.1 - 19.9 mm is $3.3 \text{ mm}\cdot\text{d}^{-1}$ on average, and $3.4 \text{ mm}\cdot\text{d}^{-1}$, $3.4 \text{ mm}\cdot\text{d}^{-1}$ and $2.9 \text{ mm}\cdot\text{d}^{-1}$ at the upper, lower and middle reaches respectively. The maximum value of $5.1 \text{ mm}\cdot\text{d}^{-1}$ appears in Hongshagang Town at the lower reaches, while the minimum value of $2.2 \text{ mm}\cdot\text{d}^{-1}$ occurs in Shuangshu Township at the middle reaches; The intensity of daily precipitation of 20 mm or more is $30.6 \text{ mm}\cdot\text{d}^{-1}$ on average, and $32.4 \text{ mm}\cdot\text{d}^{-1}$, $31.5 \text{ mm}\cdot\text{d}^{-1}$ and $29.6 \text{ mm}\cdot\text{d}^{-1}$ at the lower, upper and middle reaches respectively. The maximum value of $48.7 \text{ mm}\cdot\text{d}^{-1}$ appears in Songshan, while the minimum value of $20.9 \text{ mm}\cdot\text{d}^{-1}$ is seen in Hongshagang Town at the lower reaches.

In the Shiyang River basin, the total precipitation and the spatial distribution of the number of days with precipitation in summer generally show a close relationship to the geographical location, altitude and latitude of this area. First, the total precipitation and the number of days with precipitation in summer are obviously in a positive correlation with the altitude (passed the 99% reliability test), and in a negative correlation with the latitude (passed the 99% reliability test), increasing with the increase of the altitude but decreasing with the increase of the latitude (Table 1), with greater correlation with the altitude than with the latitude. Moreover, the lower the precipitation intensity is, the better the correlation will be. More significant correlation is seen with the precipitation of 0.1 - 19.9 mm than with heavy precipitation. The high-altitude and low-latitude upper reaches are on the northeastern flank of the Qilian Mountains, where the average total precipitation and the number of days with precipitation are greater

Table 1. Correlation coefficients among precipitation parameters, latitude and elevation over Shiyang River Basin.

	Precipitation		Precipitation Frequency		Precipitation Intensity	
	elevation	latitude	elevation	latitude	elevation	latitude
0.1 - 19.9 mm	0.81**	-0.73**	0.87**	-0.83**	0.25	-0.10
≥20 mm	0.65**	-0.54**	0.65**	-0.53**	0.09	-0.14
all	0.84**	-0.75**	0.88**	-0.83**	0.20	-0.07

than those at the middle and lower reaches, with large value centers of precipitation across all magnitudes appearing in the upper reaches of the mountainous area. Additionally, the precipitation distribution across the Shiyang River Basin is also related to the weather systems affecting the locality. Apart from large-scale westerly wind currents, the study area is also under the influence of meso- and micro-scale systems arising from the topography of the Tibetan Plateau. The middle and lower reaches are mainly affected by the westerlies circulation system, so there is relatively less water vapor in the atmosphere at the middle and lower reaches, resulting in less total precipitation and fewer days of precipitation. The upper reaches are on the northeastern flank of the Qilian Mountains and affected significantly by the southwest monsoon, which together with the thermal and dynamic lifting effect of the plateau itself results in frequent activities of vortex and shear, warm and moist southwest currents, more water vapor in the atmosphere and the greater precipitation and number of days with precipitation in this area. The spatial distribution of precipitation intensities is not significantly related to altitude and latitude but caused by complex factors. As the observational data retrieved from the regional station covers a relatively short time span, it needs further empirical studies and analysis based on data in a longer time span.

4.2. The Diurnal Variation Characteristics of Precipitation

4.2.1. The Diurnal Variation of Hourly Precipitation

The cumulative hourly precipitation in the past 5 years shows obvious fluctuations in the Shiyang River basin in summer. The diurnal variation of total precipitation across the basin is in bimodal distribution (**Figure 3(a)**), with the precipitation mainly concentrating between 03:00 and 08:00, and between 14:00 and 21:00, accounting for 21.8% and 37.9% of the 24-hour total precipitation respectively. The maximum precipitation accumulates between 18:00 and 19:00, contributing 6.3% of the daily total precipitation; the minimum precipitation accumulates between 10:00 and 13:00, making up 8.5% of the 24-hour total precipitation, during which there is the least hourly precipitation from 11:00 to 12:00, accounting for 2.7% of the 24-hour total precipitation. The precipitation of 0.1 - 19.9 mm per hour is also embodied in bimodal distribution, mainly appearing between 02:00 and 09:00 and between 14:00 and 22:00, which contributes 30.4% and 40.5% of the 24-hour total precipitation respectively. The maximum precipitation occurs in the period from 18:00 to 19:00, accounting for 6.2% of the daily total precipitation, and the period with minimum precipitation is from 10:00 to 13:00, with the precipitation making up 8.5% of the 24-hour total precipitation. The minimum precipitation appears in the periods from 11:00 to 12:00 and from 12:00 to 13:00, accounting for 2.8% of the 24-hour total precipitation respectively. The heavy precipitation of 20.0 mm or more per hour mainly occurs between 12:00 and 21:00, making up 32.4% of the 24-hour total precipitation, with the maximum precipitation in the period from 17:00 to 18:00 and

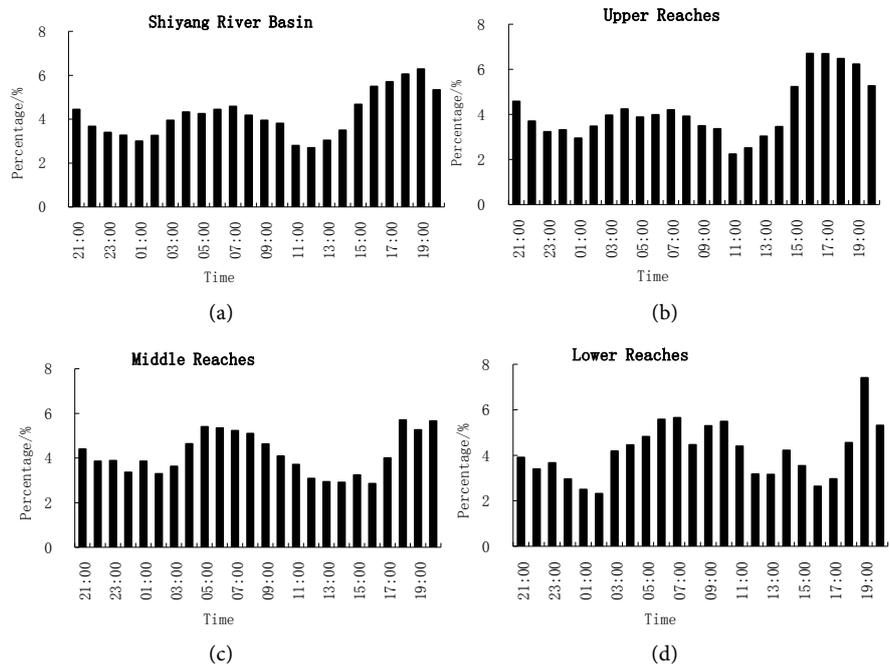


Figure 3. Distribution of hourly precipitation in summer over Shiyang River Basin

contributing 22.7% of the daily total precipitation. In the periods from 01:00 to 02:00 and from 02:00 to 03:00, heavy precipitation occurs once respectively, accounting for 3.0% and 3.2% of the 24-hour total precipitation, and there is no heavy precipitation in other periods.

The mountainous upper reaches of the Shiyang River basin and the whole basin share the same periods of major precipitation contributing to total precipitation, with the precipitation also in bimodal distribution (**Figure 3(b)**). The daily total precipitation at the upper reaches also concentrates mainly between 02:00 and 08:00, and between 14:00 and 21:00, with the precipitation of each period accounting for 24.2% and 41.0% of the 24-hour total precipitation respectively. There is maximum precipitation in the periods from 15:00 to 16:00 and from 16:00 to 17:00, making up 6.7% of daily precipitation respectively, while minimum precipitation accumulates between 10:00 and 13:00, accounting for 7.7% of the 24-hour total precipitation, of which the period from 10:00 to 11:00 is that with the minimum precipitation, which makes up 2.2% of the 24-hour total precipitation. The precipitation of 0.1 - 19.9 mm per day also concentrates between 02:00 and 08:00 and between 14:00 and 21:00, the precipitation during which accounts for 20.9% and 39.9% of the 24-hour total precipitation respectively. The period from 15:00 to 16:00 is that with maximum precipitation, which contributes 6.6% of the daily total precipitation; the period from 10:00 to 13:00 is that with minimum precipitation that accounts for 7.6% of the 24-hour total precipitation, during which minimum precipitation accumulates from 10:00 to 11:00, making up 2.3% of total precipitation. The precipitation of 20.0 mm or more concentrates mainly between 12:00 and 21:00, accounting for 91.8% of the 24-hour total precipitation, with maximum precipitation occurring between

16:00 and 17:00, which contributes 18.3% of the daily total precipitation, and heavy precipitation appearing once in the periods from 01:00 to 02:00 and from 02:00 to 03:00 respectively.

On the oasis plain at the middle reaches of the Shiyang River basin, major precipitation constituting total precipitation occurs mainly in the periods from 03:00 to 10:00 and from 16:00 to 21:00, accounting for 34.4% and 25.0% of the 24-hour total precipitation. The periods with the maximum precipitation are 17:00-18:00 and 19:00-20:00, contributing 5.7% of daily precipitation respectively, while the minimum precipitation mainly appears between 11:00-14:00, making up 8.9% of the 24-hour total precipitation, with the minimum precipitation in the periods from 12:00 to 13:00 and from 13:00 to 14:00, accounting for 2.9% of the 24-hour total precipitation respectively (**Figure 3(c)**). Here, the periods with major precipitation constituting daily precipitation of 0.1 - 19.9 mm and the percentage of such precipitation in the 24-hour total precipitation are the same as the performance of the total precipitation. The periods from 17:00 to 18:00 and from 19:00 to 20:00 are also periods with maximum precipitation, accounting for 5.7% of the 24-hour total precipitation respectively; there is less precipitation between 11:00 and 16:00; heavy precipitation of 20.0 mm or more per hour is not seen at the middle reaches.

On the desert plain at the lower reaches of the Shiyang River basin, hourly total precipitation fluctuates greatly, but precipitation mainly occurs between 03:00 and 11:00, and between 17:00 and 20:00, accounting for 35.7% and 17.3% of total daily precipitation respectively. The maximum precipitation appears between 18:00 and 19:00, contributing 7.4% of daily precipitation, while there is less precipitation during the periods from 00:00 to 02:00 and from 16:00 to 17:00, making up 7.8% and 5.6% of the 24-hour total precipitation, in which it is the period with the minimum precipitation from 01:00 to 02:00 in a day, accounting for 2.3% of the 24-hour total precipitation (**Figure 3(d)**). The daily precipitation of 0.1 - 19.9 mm and total precipitation basically share the same periods with larger amounts of precipitation, namely the periods from 03:00 to 11:00 and 18:00 to 20:00. The precipitation of the two periods contributes 41.4% and 11.3% of the daily total precipitation, with the accumulation of maximum precipitation from 18:00 to 19:00, accounting for 6.3% of daily precipitation; the periods from 01:00 to 02:00 and 16:00 to 17:00 are the two with minimum precipitation, making up 5.0% and 5.1% of the 24-hour total precipitation respectively. The periods with minimum precipitation are from 01:00 to 02:00 and 16:00 to 17:00, with the precipitation accounting for 2.4% of the 24-hour total precipitation respectively. Heavy precipitation of 20.0 mm and more occurs five times, concentrating between 16:00 and 20:00, with the accumulation of maximum precipitation from 18:00 to 19:00, which is 52.3 mm, and no heavy precipitation in other periods.

4.2.2. The Diurnal Variation of Hourly Precipitation Frequency

The accumulative hourly precipitation frequency is shown in bimodal distribu-

tion in the Shiyang River basin, but fluctuates less significantly compared with the diurnal variation of precipitation (**Figure 4**). Higher total precipitation frequency across the whole basin basically concentrates in the periods from 04:00 to 10:00 and 14:00 to 23:00, accounting for 26.2% and 41.4% of the total precipitation frequency. The highest precipitation frequency appears between 18:00 and 19:00, making up 5.2% of the daily total precipitation frequency; the lowest precipitation frequency appears between 11:00 and 14:00, accounting for 10.4% of the total precipitation frequency (**Figure 4(a)**). The frequency of precipitation of 0.1 - 19.9 mm also concentrates between 04:00 and 10:00, and between 14:00 and 23:00, which contributes 26.2% and 41.4% of the total precipitation frequency respectively. The highest precipitation frequency appears between 18:00 and 19:00, making up 5.2% of the daily total precipitation frequency; the lowest precipitation frequency is in the period from 11:00 to 14:00, accounting for 10.4% of the total precipitation frequency. The frequency of heavy precipitation of 20 mm and more mainly concentrates between 12:00 and 21:00, contributing 84.0% of the 24-hour total precipitation frequency. The highest frequency occurs between 16:00 and 17:00, making up 20.0% of the daily total precipitation frequency; in the periods from 01:00 to 02:00 and 02:00 to 03:00, heavy precipitation occurs once respectively, and there is no heavy precipitation in other periods.

At the mountainous upper reaches of the Shiyang River basin, the accumulative frequency of hourly precipitation is also embodied in bimodal distribution, mainly concentrating between 04:00 and 09:00 and between 14:00 and 23:00, and accounting for 20.9% and 44.1% of the total precipitation frequency. The highest

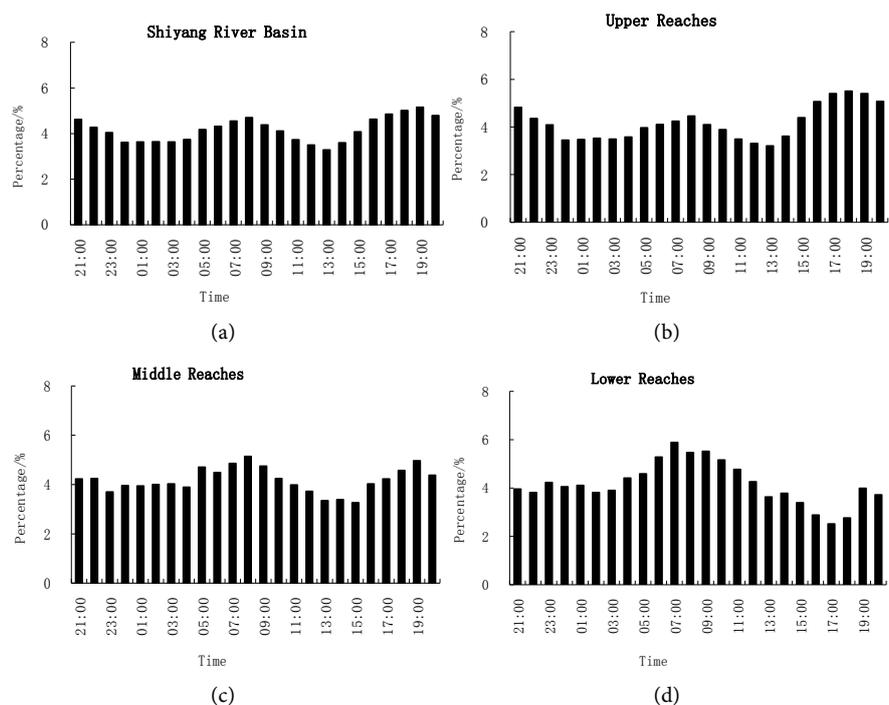


Figure 4. Distribution of hourly precipitation frequency in summer over Shiyang River Basin.

precipitation frequency occurs between 17:00 and 18:00, contributing 5.5% of the daily total precipitation frequency; the lowest precipitation frequency appears in the period from 10:00 to 13:00, making up 10.0% of the total precipitation frequency (**Figure 4(b)**). Besides, the frequency of daily precipitation of 0.1 - 19.9 mm also concentrates between 04:00 and 09:00 and between 14:00 and 23:00, which accounts for 20.9% and 44.1% of the total precipitation frequency. The highest precipitation frequency appears between 17:00 and 18:00, making up 5.5% of the daily total precipitation frequency; the lowest precipitation frequency occurs in the period from 10:00 to 13:00. In the period from 12:00 to 13:00, there is the lowest precipitation frequency, which is 618.0 times and accounts for 3.2% of the total precipitation frequency. The frequency of heavy precipitation of 20.0 mm or more mainly concentrates between 12:00 and 21:00, contributing 90.0% of the total precipitation frequency. The highest frequency appears between 16:00 and 17:00, making up 20.0% of the daily total precipitation frequency; heavy precipitation occurs once respectively in the periods from 01:00 to 02:00 and 02:00 to 03:00, and there is no heavy precipitation in other periods.

The accumulative frequency of hourly precipitation is in even distribution at the middle reaches of the Shiyang River basin, with relatively higher precipitation frequency in the periods from 04:00 to 10:00 and 16:00 to 22:00, which contributes 28.2% and 26.6% of the total precipitation frequency. The highest precipitation frequency appears between 07:00 and 08:00, which is 235.0 times and makes up 5.1% of the total precipitation frequency (**Figure 4(c)**). The frequency of daily precipitation of 0.1 - 19.9 mm mainly concentrates between 04:00 and 11:00 and between 15:00 and 22:00, which accounts for 62.8% of the 24-hour total precipitation frequency. The highest precipitation frequency appears between 07:00 and 08:00, making up 5.1% of the daily total precipitation frequency; the lowest precipitation frequency occurs between 12:00 and 15:00, only accounting for 10.0% of the daily total precipitation frequency. There is the lowest frequency of precipitation during the periods from 12:00 to 13:00 and 14:00 to 15:00, which makes up 3.3% of the total precipitation frequency respectively. There is no heavy precipitation of 20.0 mm or more per hour.

The accumulative frequency of hourly precipitation shows unimodal distribution at the lower reaches of the Shiyang River basin, mainly concentrating between 03:00 and 11:00, and accounting for 41.1% of the total precipitation frequency. The highest precipitation frequency occurs between 06:00 and 07:00, which is 196.0 times and contributes 5.9% of the total precipitation frequency. It is different from maximum precipitation that appears between 18:00 and 19:00. The period from 15:00 to 18:00 is that with lower precipitation frequency, accounting for 8.0% of the total precipitation frequency, with the lowest frequency appearing between 16:00 and 17:00, which is 84.0 times and makes up 2.5% of the total precipitation frequency (**Figure 4(d)**). The frequency of daily precipitation of 0.1 - 19.9 mm mainly concentrates between 03:00 and 12:00, which accounts for 45.5% of the 24-hour total precipitation frequency. The highest preci-

precipitation frequency appears between 06:00 and 07:00, making up 5.9% of the daily total precipitation frequency; the lowest precipitation frequency appears between 15:00 and 18:00, only accounting for 8.1% of the daily total precipitation frequency. In the period from 16:00 to 17:00, there is the lowest precipitation frequency, which is 83.0 times and makes up 2.5% of the total precipitation frequency. Heavy precipitation of 20.0 mm and more occurs 5 times in total, with the highest precipitation frequency in the periods from 16:00 to 20:00 and 18:00 to 19:00, which is twice, and there is no heavy precipitation in other periods.

4.2.3. The Diurnal Variation of Hourly Precipitation Intensities

Relatively higher precipitation intensities appear in the same periods as greater precipitation and higher precipitation frequency, mainly concentrating between 02:00 and 07:00 and between 13:00 and 21:00, accounting for 60.0% of the total precipitation intensity. The highest intensity of precipitation appears between 17:00 and 19:00, which contributes 10.2% of the total; the lowest intensity occurs between 10:00 and 12:00, which makes up 1.4% of the total (**Figure 5(a)**). Relatively higher intensities of daily precipitation of 0.1 - 19.9 mm mainly concentrate in the periods from 13:00 to 20:00 and 02:00 to 07:00, accounting for 33.0% and 22.8% of the total respectively. The highest intensity of precipitation is seen between 18:00 and 19:00, accounting for 5.1% of the total; the period with the lowest intensity of precipitation is from 10:00 to 13:00 at noon, making up 10.2% of the 24-hour total precipitation intensity. Relatively higher intensities of heavy precipitation of 20.0 mm or more mainly appear between 12:00 and 21:00, contributing 83.7% of the total, with the occurrence of a peak between 17:00 and 18:00, which makes up 14.9% of the total.

Higher total precipitation intensities mainly appear in the periods from 01:00 to 07:00 and 12:00 to 21:00 at the upper reaches of the Shiyang River basin, contributing 68.5% of the total precipitation intensity. The highest precipitation intensity appears in the period from 15:00 to 16:00, accounting for 5.6% of the daily total precipitation intensity; the lowest precipitation intensity is seen between 10:00 and 11:00, making up 2.7% of the total (**Figure 5(b)**). As for the precipitation of 0.1 - 19.9 mm, the periods with higher intensities are from 13:00 to 20:00 and 01:00 to 07:00, which contributes 33.6% and 26.8% of the total precipitation intensity respectively. The peak intensity appears in the period from 15:00 to 16:00, making up 5.5% of the daily total precipitation intensity; the intensity drops to the lowest point between 10:00 and 11:00, accounting for 2.8% of the total. Heavy precipitation of 20.0 mm or more shows higher intensities mainly between 12:00 and 21:00, which accounts for 81.2% of the 24-hour total precipitation intensity. The peak intensity of such precipitation appears between 20:00 and 21:00, making up 15.3% of the daily total precipitation intensity.

At the middle reaches of the Shiyang River basin, the highest precipitation intensity appears between 16:00 and 20:00, contributing 15.1% of the total, and the period from 02:00 to 06:00 is another period with a relatively higher intensity, making up 14.8% of the total; the lowest intensity appears between 15:00 and

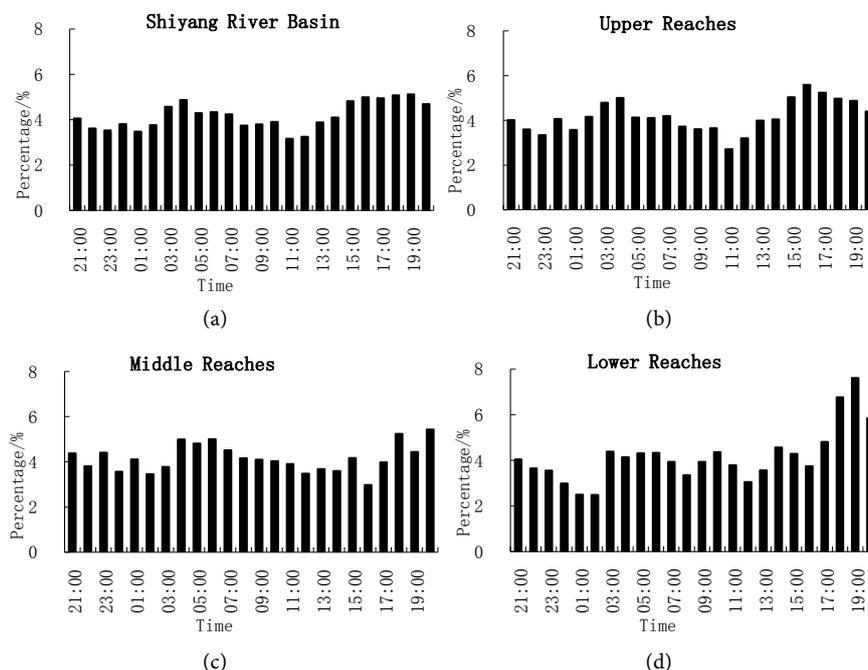


Figure 5. Distribution of hourly precipitation intensity in summer over Shiyang River Basin.

16:00, accounting for 3.0% of the total (Figure 5(c)). The intensities of daily precipitation of 0.1 - 19.9 mm mainly concentrate between 03:00 and 10:00 and between 16:00 and 21:00, constituting 55.1% of the 24-hour total precipitation intensity, with the peak appearing during the period from 03:00 to 06:00 and making up 10.0% of the daily total precipitation intensity, and the lowest value seen between 15:00 and 16:00 and accounting for 3.0% of the total precipitation intensity.

The hourly total precipitation intensities fluctuate greatly at the lower reaches of the Shiyang River basin, with the occurrence of a peak intensity between 17:00 and 19:00, which is the same as the period with maximum precipitation and accounts for 7.6% and 14.4% of the total precipitation intensity; in the period from 00:00 to 02:00, the precipitation intensity drops to the lowest point, making up 5.0% of the total (Figure 5(d)). As for the daily precipitation of 0.1 - 19.9 mm, its peak intensity appears between 17:00 and 19:00, contributing 12.7% of the daily total precipitation intensity; the precipitation intensity is the lowest in the period from 00:00 to 02:00, making up 5.2% of the total precipitation intensity. Heavy precipitation of 20.0 mm or more occurs 5 times in total, mainly concentrating between 16:00 and 20:00, with a peak intensity appearing between 16:00 and 17:00 and accounting for 27.2% of the 24-hour total precipitation intensity.

4.3. The Variation Characteristics of Precipitation for Different Duration

4.3.1. The Diurnal Variation of Precipitation for Different Duration

On the whole, there is a larger amount of short precipitation lasting for 1 - 3 h in

the Shiyang River basin, accounting for 30.3% of total precipitation for all duration, with the amount of precipitation lasting for 3 h, 1 h and 2 h declining in sequence, while the precipitation processes lasting for more than 10h all create less precipitation. The large values of precipitation lasting for 1 - 6 h appear between 13:00 and 20:00, making up 55.9% of the total precipitation lasting for 1 - 6 h. The large values of precipitation lasting for more than 7 h are seen between 17:00 and 20:00, and between 23:00 and 05:00, contributing 64.4% of the total precipitation lasting for over 7 h (**Figure 6(a)**).

At the upper reaches of the Shiyang River basin, the amount of precipitation lasting for 3 h is also the largest, followed by the precipitation lasting for 2 h and 4 h successively, while there is a smaller amount of precipitation lasting for more than 10h. The large values of precipitation for 1 - 6 h mainly appear between 13:00 and 20:00, contributing 61.7% of total precipitation lasting for 1 - 6 h; the high values of precipitation lasting for more than 7 h are seen between 14:00 and 20:00 and between 23:00 and 05:00 (**Figure 6(b)**).

In the Shiyang River basin, the largest amount of precipitation comes from the precipitation process lasting for 4 h, followed by that lasting for 3 h, 2 h and 5 h, while that lasting for more than 10 h creates a smaller amount of precipitation. The high values of precipitation lasting for 1 - 6 h mainly appear between 16:00 and 19:00, making up 31.0% of the total precipitation; the high values of precipitation lasting for more than 7 h are seen between 17:00 and 20:00 and between 22:00 and 05:00, which account for 76.0% of precipitation lasting for over 7 h (**Figure 6(c)**).

At the lower reaches of the Shiyang River basin, there is a larger amount of

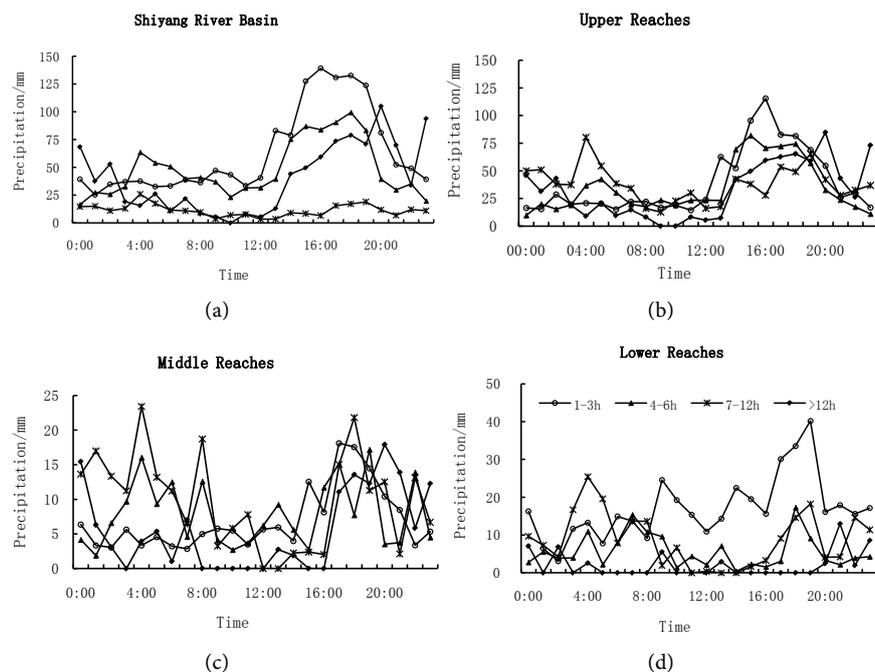


Figure 6. Hourly variation of continuous precipitation of different duration in summer over Shiyang River Basin.

short precipitation, of which that lasting for 1 h creates the largest amount, followed by that lasting for 2 h. The high values of precipitation lasting for 1 - 6 h appear between 17:00 and 19:00, which account for 24.5% of the total precipitation lasting for 1 - 6 h; the high values of precipitation lasting for 7 - 12 h are seen between 18:00 and 08:00, which make up 87.9% of the total precipitation lasting for more than 7 h (**Figure 6(d)**).

4.3.2. The Diurnal Variation of the Frequency of Precipitation for Different Hours

In the Shiyang River basin, short precipitation occurs most frequently, with 76.5% of the total precipitation frequency from the precipitation lasting for 1 - 3 h, in which that lasting for 1 h occurs most frequently, followed by that lasting for 2 h, while that lasting for more than 10 h only makes up 3.5%. The high values of frequency of precipitation lasting for 1 - 6 h are seen between 14:00 and 20:00, making up 37.3% of the total frequency of precipitation lasting for 1 - 3 h within 24 hours. The high values of frequency of precipitation lasting for over 7 h appear between 17:00 and 20:00 and between 23:00 and 05:00, contributing 59.2% of the total frequency of precipitation lasting for more than 7 hours (**Figure 7(a)**).

At the upper reaches of the Shiyang River basin, the frequency of precipitation lasting for 1 - 3 h accounts for 76.18% of the total precipitation frequency, which is in the sequence of the precipitation lasting for 1 h that occurs most frequently, followed by that lasting for 2 h and 3 h successively. The high values of frequency of precipitation lasting for 1 - 6 h appear between 14:00 and 20:00, making up 39.9% of the total frequency of precipitation lasting for 1 - 6 h. The high values of frequency of precipitation lasting for more than 7 h are seen in the periods from 14:00 to 20:00 and 23:00 to 05:00, contributing 71.3% of the total frequency of precipitation lasting for over 7 h (**Figure 7(b)**).

At the middle reaches of the Shiyang River basin, the frequency of precipitation lasting for 1 - 3 h constitutes 74.9% of the total precipitation frequency, of which the sequence is the precipitation lasting for 1 h occurring most frequently followed by that lasting for 2 h and 3 h successively. The high values of frequency of precipitation lasting for 1 - 6 h appear in the period from 16:00 to 19:00, which make up 21.5% of the total frequency of precipitation lasting for 1 - 6 h. The high values of frequency of precipitation lasting for over 7 h are seen between 17:00 and 20:00 and between 23:00 and 05:00, accounting for 63.9% of the total frequency of precipitation lasting for more than 7 h (**Figure 7(c)**).

At the lower reaches of the Shiyang River basin, the highest frequency of precipitation comes from that lasting for 1 h, followed by the frequency of that lasting for 2 h and 3 h. In this area, the high values of frequency of precipitation lasting for 1 - 6 h appear between 06:00 and 11:00, constituting 30.9% of the total frequency of precipitation lasting for 1 - 6 h. The high values of frequency of precipitation lasting for over 7 h are seen in the period from 19:00 to 08:00, making up 84.5% of the total frequency of precipitation lasting for more than 7 h (**Figure 7(d)**).

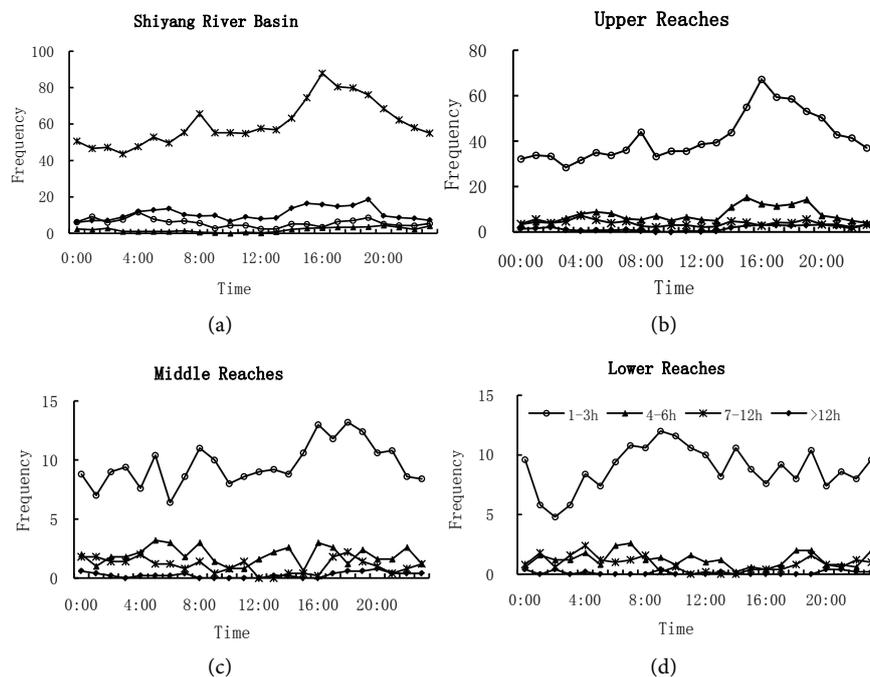


Figure 7. Hourly variation of continuous precipitation frequency of different duration in summer over Shiyang River Basin.

5. Conclusions

On the whole, the total precipitation and the spatial distribution of days with precipitation are closely related to the geographical location, altitude, latitude and influencing systems in the Shiyang River basin in summer. They both show a decline trend from the upper reaches to the lower reaches, with the total precipitation at the upper reaches higher than that at the lower reaches and that at the middle reaches successively, and the number of days with precipitation at the upper reaches larger than that at the middle reaches and that at the lower reaches successively. The precipitation intensities are $4.5 \text{ mm}\cdot\text{d}^{-1}$, $4.5 \text{ mm}\cdot\text{d}^{-1}$ and $3.7 \text{ mm}\cdot\text{d}^{-1}$ at the upper reaches, lower reaches and middle reaches, respectively, which shows a relatively complex spatial distribution and an insignificant correlation with altitude and latitude.

The hourly precipitation is in bimodal distribution in the Shiyang River basin in summer, with precipitation peaks mainly occurring between 03:00 and 08:00 and between 14:00 and 21:00, during which the highest peak appears between 18:00 and 19:00. The heavy precipitation of 20 mm or more per hour shows unimodal distribution and occurs between 12:00 and 21:00. The occurrence of the peak in the afternoon may be related to the frequent moist convection activities during this period [14] [23].

The hourly precipitation frequency is in bimodal distribution at the upper and middle reaches of the Shiyang River basin in summer, with the peaks mainly occurring in the periods from 04:00 to 10:00 and 14:00 to 23:00, and the peaks of heavy precipitation of 20 mm and more concentrating between 12:00 and 21:00.

The frequency of precipitation of different intensities shows unimodal distribution at the lower reaches, with peaks mainly appearing between midnight and the period of 04:00-11:00 in the morning, and heavy precipitation of 20 mm or more occurring most frequently between 16:00 and 20:00.

The hourly precipitation intensities of the Shiyang River basin are in bimodal distribution, with peaks mainly concentrating between 02:00 and 07:00 and between 13:00 and 21:00, and the heavy precipitation of 20 mm or more shows a higher intensity between 12:00 and 21:00.

In the Shiyang River basin in summer, there is a larger amount and higher frequency of short precipitation lasting for 1 - 3 h, but a smaller amount and lower frequency of precipitation lasting for more than 10 h. The short precipitation lasting for 1 - 6 h tends to reach a peak of precipitation during the period from the afternoon to the evening, while the long precipitation lasting for over 6 h usually creates a peak of precipitation in the midnight and in the period from the afternoon to the evening.

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