Analysis of Runoff and Sediment Yield Characteristics in Small Watershed of Taihang Mountain Area

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Analysis of Runoff and Sediment Yield Characteristics in Small Watershed of Taihang Mountain Area

Jie Wang, Guangying Zhang and Qiuju Mi, Yong Mi
Baoding Soil and Water Conservation Experimental Station, Baoding, Hebe 074200, China
Corresponding Author: Guangying Zhang; email: 587378168@qq.com;
First Author: Qie Wang; email: 724551200@qq.com.
Second author: Qiuju Mi; email: 1004650668@qq.com.
Third author: Yong Mi; email: 875452137@qq.com.

Abstract: With the small watershed of Chongling in the Taihang Mountain area as the study area, and with the experimental data of the watershed test base collected for years, this paper studies the characteristics of rainfall, runoff and sediment yield of this area. The results show that the adequacy and inadequacy of rainfall in the study area was alternate from 1959 to 2017, and the interannual changes were large, showing non-significant trend of annual rainfall. Vegetation cover can retain surface runoff. When the rainfall was below 250mm in August, the runoff after afforestation was significantly reduced. When the rainfall was over 250mm in August, the runoff quantity changes before and after afforestation were not significant.

1. Study Area Overview and Observation Project
The Chongling small watershed lies in upstream of Xiong’an District, the hilly area in east wing of Yunnmg Mountain in the north offset of Taihang Mountain, possessing the typical natures of vegetation, soil, landform, engineering geology and so on [1]. This paper selects the experimental data collected for years by Chongling small watershed test base in Yi County, Hebei Province, and analyzes the characteristics of runoff and sediment yield of this watershed.

1.1 Study Area Overview
Chongling small watershed is located in Qingxiling, Lianggezhuang Town, Yi County, Hebei Province, shaped like a closed fan, with a maximum length of 4.4 km, an average width of about 1.5 km and covers an area of about 6 km² [2]. It’s between 50-180m above sea level, with gently undulating hills of which most slopes are between 10°-25° [3]. The major type of soil in the gully area is sandy loam, followed by loess [4]. The main tree species in the water conservation forest include arborvitae, poplar, Chinese pine, locust, etc. Most of the economic trees are apples, peaches and pear trees. The herbaceous plants are mainly angelica and red-leaf clovers, etc. The shrubs are mainly wild jujube, vitex negundo, etc. With the temperate continental monsoon climate, the watershed is dry and rainless in spring, hot and rainy in summer, cool in autumn, cold and dry in winter. The distribution of rainfall during the year is uneven to a great extent, with the most amount from July to September.
1.2 Observation Project
Since 1959, Baoding Soil and Water Conservation Experiment Station has carried out manual observations on the hydrological characteristics such as rainfall, runoff and sediment in the Chongling small watershed. At the exit of each channel, control flumes, sediment basins and flow measuring weirs were set for the observation of runoff and sediment, mostly conducted in flood season. However, due to the limitations under some objective conditions at that time, the runoff data of June, July, August and September in the flood season every year are not complete, and some runoff data of large rainfall is missing. Taking into account the integrity and continuity of data, the rainfall data are collected from the Yi County Meteorological Station from 1959 to 2017, and the runoff and sediment data are mainly those observed in Baoding City Soil and Water Conservation Experiment Station from June to September.

2 Results and Analysis

2.1 Rainfall Characteristics of Study Area
The annual average rainfall of Chongling small watershed in 1959-2017 was 526.31mm, with the maximum at 934.2mm in 1963, and the minimum at 206.6mm in 1975. Ratio of the maximum to minimum annual rainfall is 4.52, which shows great difference. The annual rainfall hydrograph and the three-year moving average hydrograph of the Chongling small watershed are shown in Figure 1.

![Annual rainfall hydrograph and three-year moving average hydrograph of Chongling small watershed](image)

**Figure 1** Annual rainfall hydrograph and three-year moving average hydrograph of Chongling small watershed

| P (%) | 1     | 2     | 5     | 10    | 20    | 50    | 70    | 90    | 95    |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| rainfall (mm) | 1089.00 | 1008.61 | 894.25 | 798.79 | 690.79 | 506.57 | 406.07 | 279.27 | 225.73 |

**Table 1** Annual rainfall frequency curve parameters of Chongling small watershed

Analysis of the annual rainfall of Chongling small watershed from 1959 to 2017 is conducted. It can be seen from Figure 1 that during the 59 years, the annual rainfall in the two periods of 1980-1984 and 1997-2006 was continuously inadequate, and that in1994-1996 was continuously adequate. In other years, the annual rainfall was alternately adequate and inadequate, with considerably large difference between years, which was in normal fluctuation.

Using the Kendall rank correlation \(^5\), it is tested whether the trend of rainfall from 1959 to 2017 is significant. The formulas are:

\[ \rho = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n(\sum x^2) - (\sum x)^2][n(\sum y^2) - (\sum y)^2]}} \]

where \(\rho\) is the Kendall rank correlation coefficient, \(n\) is the sample size, and \(x\) and \(y\) are the ranks of rainfall in two different years.
\[ \tau = \frac{4p}{N(N-1)} \quad (1) \]
\[ \sigma^2 = \frac{2(2N+9)}{9N(N-1)} \tau \quad (2) \]
\[ M = \frac{\tau}{\sigma^2} \quad (3) \]

where \( \tau \) is Kendall statistic, \( \sigma^2 \) is variance, M is standardized variable, P is the number of times when \( R_i < R_j \) occurs in all dual observations of runoff data \( (R_i, R_j, i < j) \), and N is series length.

According to the existing observation data, the Kendall standardized variable \( M = -1.81 \). Set the significance level as 0.05, and the corresponding critical value of test \( M = 1.96 \). Since \( 1.96 > 1.81 \), it can be considered that the trend of rainfall of Chongling small watershed from 1959 to 2017 is not significant.

### 2.2 Analysis of Watershed Runoff Characteristics

The rainfall and runoff data of Chongling small watershed in 1961, 1963, 1966, 1985, 1988, 1990, 1995 and 2000 (see Table 2) are used to analyze their characteristics of changes. According to Table 1, the annual rainfall frequency in 1961 was 9.25%, rendering 1961 as a year with adequate rainfall; the one in 1963 was 3.67%, a year with adequate rainfall; 28.01% in 1966, a year with moderate rainfall; 11.99% in 1985, a year with adequate rainfall; 14.77% in 1988, a year with adequate rainfall; 9.99% in 1990, a year with adequate rainfall; 12.98% in 1995, a year with adequate rainfall. 92.54% in 2000, a year with greatly inadequate rainfall. The annual rainfall data of these eight years include the years with adequate, moderate and inadequate rainfall.

#### Table 2 Rainfall and runoff of Chongling small watershed in August in different years

| Year | August Runoff (mm) | August Rainfall (mm) |
|------|--------------------|----------------------|
| 1961 | 137.6              | 213.2                |
| 1963 | 301.6              | 738.6                |
| 1966 | 64.2               | 168.3                |
| 1985 | 5.7                | 168.4                |
| 1988 | 127.5              | 362.4                |
| 1990 | 18                 | 152.4                |
| 1995 | 97.2               | 278.1                |
| 2000 | 3.3                | 155.5                |

The rainfall and runoff data in August in different years are shown in Table 2. To understand the rainfall-runoff changes of Chongling small watershed, the rainfall data were relatively close in August in 1961, 1966, 1985, 1990 and 2000, being between 150mm-220mm; and the rainfall were relatively great in August in 1995, 1998 and 1963, being between 270mm-740mm. In August of 1961, 1966, 1985 and 2000 when the rainfall data were close, the runoff coefficients in August were respectively: 64.5%, 38.1%, 3.4%, 11.8%, 2.1%. We can find that, the runoff coefficients were between 38.1%-64.5% in August in 1961 and 1966, which are in 1960s; After 1985, the runoff coefficients were between 2.1%-11.8% in August in 1990 and 2000, with the ratio of 1:7.4 compared with those in August in 1960s, which means the runoff coefficients in August in 1960s are 7.4 times of those after 1985, and means that the runoff coefficients of Chongling small watershed in August after 1985 were significantly reduced compared with those in 1960s. The vegetation coverage of Chongling small watershed had been low in early years since the founding of the People's Republic of China. With the launch of afforestation projects, especially the implementation of the Taihang Mountain greening project in the mid-to-late 1980s, the vegetation coverage in the watershed increased from 5% in 1982, 8.29% in 1983, to 33.10% in 1989, 38.68% in 1998, and it reached 41.20% in 2000. In the 1960s, the Chongling small watershed had low vegetation coverage and large runoff coefficients, while in the mid-to-late 1980s, the vegetation coverage was significantly increased, but the runoff coefficients were relatively low. For 1963, 1988 and 1995, the runoff coefficients in August were 40.8%, 35.2% and 35.0% respectively, indicating that the monthly runoff coefficient did not significantly decrease with the increase of vegetation coverage when the rainfall was greater than 250mm in August.

In addition, 1966 and 2000 were the years with moderate and inadequate rainfall in the range of 150-220mm in August, and 1985, 1990 and 1961 were the years with adequate rainfall. Though rainfall was different in each year, the data in August were near. Therefore, the differences in monthly...
runoff cannot be seen from whether the rainfall of that year was adequate, moderate or inadequate, while it can be seen from monthly rainfall which has direct effect on runoff.

Through the analysis of the historical rainfall and runoff data of Chongling small watershed, the rainfall in August in 1961, 1990 and 2000 when rainfall was below 250mm, runoff in August was respectively 137mm, 18mm and 3mm, and vegetation coverage increased 35%, with runoff reduced by 92.5% in August, meaning the runoff in August in 1960s was significantly higher than that in 1990s after afforestation. The runoff change was not significant in 1963, 1988 and 1995 when rainfall in August was over 250mm. To sum up, when rainfall in Chongling small watershed in August was below 250mm, the runoff in August in 1960s when afforestation just commenced was significantly higher than that in 1990s after afforestation; and when rainfall in August was over 250mm, the runoff change before and after afforestation was not significant.

2.3 Analysis of Watershed Sediment Yield Characteristics

With typical heavy rain events selected as research object, the process of runoff and sediment yield in zones with different vegetation types of Chongling watershed is analyzed. The rain on August 2nd to 3rd, 1994 lasted 340min, with total rainfall at 78mm, mostly distributed in the first two hours. It can be seen from Figure 2 that the trends of runoff and sediment yield in zones with different vegetation types were similar but different. The sediment yield process in each zone was affected by heavy rain and showed its rise and fall as steep as that of runoff, but the time and quantity of runoff and sediment yield in zones with different vegetation types were different. The time of runoff and sediment yield in Yangshugou grassland zone was about 0.5 hour after rainfall, but the runoff and sediment yield was rapid, with maximum sediment concentration at 3.7kg/m³. The time of runoff and sediment yield in Huyaogou pine and cypress zone appeared later than that of Yangshugou grassland zone, with a lag of about 1 hour after rainfall, and the maximum sediment concentration was at 1.11kg/m³, much less than that of Yangshugou grassland zone. The time of runoff and sediment yield of the Ten thousand-mu forest and water conservation zone was about 1.5 hours after rainfall, and the maximum sediment concentration is the least among the three zones, which was at 0.71 kg/m³; After runoff lasted for some time in these three zones, sediment yield occurred with a lag. Peak sediment appeared some time after the flood peak, and it was in the recession limb, about 0.5 hours after the flood peak. Most of the sediment yield concentrated in the recession limb of runoff, indicating that a large amount of the sediments were those washed off from ditches. After the end of rainfall, there was still a period of runoff in each zone, and it can be seen that certain vegetation coverage can delay the runoff.
3. Conclusion
The adequacy and inadequacy of rainfall in the study area was alternate from 1959 to 2017, and the interannual changes were large, showing non-significant trend of annual rainfall. In the typical heavy rain event, most of the sediment yield concentrated in the recession limb of runoff, indicating that a large amount of the sediments were those washed off from ditches. After the end of rainfall, there was still a period of runoff in each zone, and it can be seen that certain vegetation coverage can delay the runoff.

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