Influence of slope on runoff process in typical soil unit, North China

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Abstract. Runoff is a crucial process of water cycle and the related research is also important for hydrology. In this study, an experiment of artificial rainfall runoff was conducted on the Linmingguan Test Base of Hebei University of Engineering, China. The results show that the typical rainfalls runoff process in flood season and non-flood season are different on the same slope units; the initial time of runoff yield, the peak time & discharge and recession hydrograph of surface runoff and interflow are various on different slope units. This research can sustain development of principle analysis of runoff yield and concentration and provide technical support for parameter optimization of hydrological model in unsaturated zone of North China.

1. Introduction
Slope-runoff is a complicated process, and its influencing factors include soil properties, soil moisture, surface slope and rainfall [1]. Many scholars have conducted detailed research on the rule of slope-runoff process by means of field test, rainfall simulation experiment and numerical simulation. Some scholars have studied and observed that the increased slope would make the runoff larger [2-4]. Similarly, Chaplot and Bissonnais obtained the runoff increases with slope between 2% and 8% on silt loam soil through field test [5]. However, some scholars have found that the increase of slope increases the amount of erosion, which leads to the decrease of runoff [6]. Increased slope has a negative effect on runoff [7]. Nevertheless, some scholars have found that the effect of slope on runoff is not obvious [8]. From the reports of those who have reported well about the slope runoff, it can be concluded that there are various impacts of slope on runoff are various.

The North China Plain is a typical semi-humid and semi-arid region. However, its runoff generation process model has not been clarified. The influence of slope on regional runoff is more important for the study of regional runoff and confluence principle. In this study, an experiment of artificial rainfall runoff was conducted on the Linmingguan Test Base of Hebei University of Engineering, China, to explore the influence of slope on the runoff process under typical soil component. The purpose of this study is to analyse the rule of runoff process on the piedmont unsaturated zone and provide the basis and reference for the confluence rules and parameter optimization of hydrological model in the North China region.
2. Methodology

2.1. Experimental area
The Linmingguan Test Base is located in the south of Hebei Province (figure 1) and is affiliated to Hebei University of Engineering. It has typical units with two different slopes and rainfall devices required for this experiment, shown in figure 2. Both typical soil components’ sizes are 9 m (length) × 3 m (width) × 3 m (height), and it’s slopes are 1/36 (a in figure 2) and 1/13 (b in figure 2) respectively. The soil types of small slope component are sandy loam, loam and silty clay from top to bottom; those of the large slope component are sandy loam, silty clay and loam, respectively.

![Figure 1. The location of experiment station.](image1)

![Figure 2. The experiment units and rainfall device.](image2)

2.2. Triangular weir and its calibration
Each typical soil unit is equipped with five triangular weirs for collection and measurement of channel runoff, surface runoff, 1st interflow, 2nd interflow and deep interflow (figure 3), of which the corresponding letter is a, b, c, d and e and the corresponding soil deep is river, surface, less than 1m, 1–2 m and 2–3 m, respectively. In this study, only surface runoff and 1st interflow (interflow for short) has been monitored, i.e., only b and c triangular weir were used. The relationship between discharge and water-level of triangular weirs were calibrated based on the theory of water balance through measuring the steady flow volume of a large bucket in each minute (figure 4).
2.3. Experiment design
We have completed the design and verification of regional typical rainfall process in advance. In this study, we set up three types of artificial rainfall. The rainfall intensity was 40 mm/h, 60 mm/h and 40 mm/h from Type 1 to Type 3, and the duration was 1h. Since the rainfall experiment is carried out continuously, the soil moisture of Type 2 and Type 3 are larger than Type 1. During the experiment, we have measured the rainfall intensity and we monitored the runoff process of surface runoff & interflow with b and c triangular weir. In order to improve the accuracy of the test and the reliability of the results, we conducted a second repeated experiment.

3. Result

3.1. Experiment design
The observed rainfall intensity is shown in table 1. During the first experiment, the relative error between observed and designed rainfall intensity is 25.25% ~ 45.75% at the Type 1. The error is 0.75%~22.33% at Type 2 and Type 3. In the second experiment, the error of all kind types is 10.83%~73%. In general, the observed rainfall intensity of the first artificial rainfall experiment was uniform compared to the second time. Moreover, in the second experiment, the relative error of Type 1 of rainfall is too large, and it in the small slope unit reaches 73%, the observed rain intensity of the small slope unit is significantly greater than that of the large slope unit. This will affect the runoff
process.

Table 1. Rainfall error.

| Rainfall type | Type 1 | Type 2 | Type 3 |
|---------------|--------|--------|--------|
| Designed rainfall intensity (mm/h) | 40 | 60 | 40 |
| Experiment Unit | Small | Large | Small | Large | Small | Large |
| First experiment measured rainfall (mm/h) | 55.4 | 50.1 | 65.5 | 57.3 | 47.9 | 39.7 |
| Relative error (%) | 38.5 | 25.25 | 9.17 | 4.5 | 19.75 | 0.75 |
| Second experiment measured rainfall (mm/h) | 69.2 | 49.7 | 76 | 66.5 | 49.9 | 53.9 |
| Relative error % | 73 | 24.25 | 26.67 | 10.83 | 24.75 | 34.75 |

3.2. Runoff type analysis
The three types of runoff processes in the first experiment are shown in figures 5~7, and the second times shown in figures 8~10. The rainfall intensity is constant in each type of each experiment. There was no runoff at the beginning, and all the rainfall was used for infiltration. As the water content increases, the infiltration capacity decreases rapidly. This makes the flow quickly become larger and gradually stabilizes. Finally, the recession hydrograph of runoff begins after the end of the rain.

Figure 5. The runoff process of Type 1-rainfall.

Figure 6. The runoff process of Type 2-rainfall.

Figure 7. The runoff process of Type 3-rainfall.

Figure 8. The runoff process of Second experiment Type 1- rainfall.
3.3. **Slope impact analysis**

During the two experiments, due to the different slopes of the two soil units, the initial time of runoff yield, the peak time & discharge and recession hydrograph of surface runoff and interflow are different.

### 3.3.1. **Initial time of runoff yield**

The initial time of different experiments is shown in table 2. At first experiment, the results illustrate that the initial time of runoff in the large slope unit is 1 minute earlier than that in the small slope unit. But in the second experiment, the small slope unit is 1~3 minutes earlier than large slope unit. We think the result in second experiment is due to rainfall error, the greater the rainfall intensity, the earlier the initial time.

![Figure 9](image1.png)

**Figure 9.** The runoff process of Second experiment Type 2- rainfall.

![Figure 10](image2.png)

**Figure 10.** The runoff process of Second experiment Type 3- rainfall.

| Time (min)            | Small slope unit | Large slope unit | Small slope unit | Large slope unit |
|-----------------------|------------------|------------------|------------------|------------------|
| First Experiment of Type 1 | 35               | 58               | 34               | -                |
| First Experiment of Type 2 | 8                | 17               | 7                | -                |
| First Experiment of Type 3 | 9                | 16               | 8                | -                |
| Second Experiment of Type 1 | 22               | 45               | 25               | -                |
| Second Experiment of Type 2 | 6                | 8                | 7                | 29               |
| Second Experiment of Type 3 | 7                | 9                | 10               | 16               |

### 3.3.2. **Peak time & discharge**

The peak time appears at 9-10 minutes after the initial time of runoff yield during the experiment, but the initial time is different.

The discharge data is stable runoff intensity, as shown in table 3. From the comparison of Type 2 and Type 3, in the case of high soil moisture, the discharge of small slope unit is greater than large slope unit. We can also find this situation during the second experiment. However, the discharge of the large slope unit is greater at Type 1. This phenomenon is due to soil moisture.

| Discharge(ml/s) | Small slope unit | Large slope unit | Small slope unit | Large slope unit |
|-----------------|------------------|------------------|------------------|------------------|
|                 | Surface Runoff   | Interflow        | Surface Runoff   | Interflow        |
| First Experiment of Type 1 | 38.4             | 11.78            | 52.02            | -                |
| First Experiment of Type 2 | 116.29           | 18.76            | 95.03            | -                |
| First Experiment of Type 3 | 67.6             | 18.76            | 59.55            | -                |
3.3.3. **Recession hydrograph** The recession hydrograph of surface runoff and interflow shown in figures 5~10, it begins to appear after the end of the rain, but this is a slow process. Small slope unit is reduced faster, but the effect is very small. This requires further testing to prove.

### 4. Conclusion

This research was conducted on typical units with two different slopes in Linmingguan Experimental Base of North China. The influence principle of slope on the rainfall runoff was illustrated through two artificial rainfall experiments: the trends of surface runoff and interflow in the same slope are similar whether the rainfall is in the flood season or in the non-flood season; Under the same rain type, the surface runoff and interflow initial time are advanced with the slope becoming larger; When the soil moisture is small, the discharge increases with the increase of the slope, but when the soil moisture is large, the opposite result is presented. The effect of slope on the recession hydrograph was not evident in this experiment. The purpose is to sustain development of principle analysis of runoff yield and concentration and provide technical support for parameter optimization of hydrological model in unsaturated zone of North China.

Since the artificial rainfall experiment is carried out in the field, the wind speed has a great influence. In the future, when the experiment is involved, the artificial rainfall device is improved to minimize the influence of wind speed on artificial rainfall and increase the reliability of the test results.

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