Responses of runoff and soil loss to rainfall regimes and soil conservation measures on cultivated slopes in a hilly region, northern China

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Abstract: Cultivated land plays an important role in water and soil loss in the earth-rocky mountainous region, northern China, however, its responses to soil control measures and rainfall characteristics are still not fully understood. In this study, 85 erosive rainfall events in 2011-2019 were grouped into three types, and the responses of runoff and soil loss on five cultivated plots with different slopes in the upstream catchment of the Miyun Reservoir to soil conservation measures and rainfall regimes were evaluated. Results found that event-averaged runoff depths and soil loss rates on the five plots ranged from 7.05 mm to 0.03 mm and from 300.51 t km^{-2} to 0.37 t km^{-2} respectively, depending on rainfall regimes, soil conservation measures, and slope gradients. The high occurring frequency (i.e., 72.94%) rainfall regime A with short rainfall duration (RD), low rainfall amount (P), and high mean rainfall intensity (I_m) yielded lower runoff depth and higher soil loss rate. Rainfall regime B with longer RD, and higher P and I_m, however, produced higher rainfall depth and lower soil loss rate. Terraced plot had the highest runoff and soil loss reduction efficiencies of over 96.03%. Contour tillage had comparable sediment reduction efficiency to that of the terraced plot on gentle slopes (gradient less than 11.0%), while its runoff reduction efficiency was less than 13.11%. This study implies that in the Miyun Reservoir catchment and similar regions in the world, contour tillage should be promoted on gentle slopes, and terrace construction should be given enough attention since it can greatly reduce water quantity and cause water shortage in downstream catchments.

Keywords: cultivated land; rainfall regime; soil conservation measure; reduction efficiency; northern China

1. Introduction

Soil erosion is an expansive environmental problem with significant ecological implications. It is associated with on-site land degradation, off-site sediment siltation in rivers, reservoirs, lakes, and water resource use [1-3]. Thus, it directly and indirectly influences water, soil, and organism health as well as other earth surface processes [3].

It is widely recognized that land use affects soil loss. Among all the land use types, sloping cultivated land usually suffers higher soil loss and acts as an important sediment source area [4-5]. In the Ethiopian Plateau of Africa, the average soil erosion intensity of sloping farmland is around 8000 t km^{-2} yr^{-1}, which is the land use type suffering the highest soil loss in sub-Saharan Africa [6]. In China, sloping farmland covers an area of around 24.5 million ha, occupying approximately a fifth of the cultivated land, and annual soil loss from sloping farmland is approximately 1.5×10^9 t yr^{-1}, contributing around 30% of total soil loss in China [7]. On the

Loess Plateau, soil erosion intensity can be up to 9700-21700 t km^{-2} yr^{-1}, and even to 6.94×10^3-95.89×10^3 t km^{-2} under extreme rainstorms, which is even dozens of times those on grass and forest lands [8]. In the Sichuan Basin of China, soil erosion intensity on sloping farmlands can also reach 3000-5000 t km^{-2} yr^{-1}, and soil loss from the cultivated land accounts for 60-80% of the total [9]. Therefore, soil and water resources protection and the corresponding scientific research on sloping farmland are particularly important and necessary.

The Miyun Reservoir is an important source of drinking water for people in Beijing, 70% of which is provided by the Miyun Reservoir [10-13]. Therefore, the water quality and quantity of the Miyun Reservoir and its upstream catchment have attracted much attention by local government and research scholars. In recent years, many studies have been conducted in this region, mainly focusing on water pollution [14], water purification [15], nitrogen and phosphorus loss [16-17], and soil pollution [11,18]. In the process of soil erosion, the dissolved pollutants in runoff and/or those adsorbed onto the sediments can be routed out, resulting in downstream water pollution [19]. Therefore, soil erosion in the upper reaches of the reservoir has also attracted the attention, and a large number of soil conservation measures have been implemented in the mountainous areas, including contour tillage, terrace, tree planting, and dams in gullies and/or rivers [11-13, 20].

In recent two decades, researches on soil erosion and its response to soil conservation measures have been done in this region. At the catchment scale, studies on the effect of land use change and soil conservation measures on runoff and sediment transport dynamics have been conducted [12-13, 21-23]. At the slope scale, the characteristics of water and soil loss and their responses to soil conservation measures were also analyzed [19, 21, 24-25]. Nowadays, cultivated lands in the upstream catchment of the Miyun Reservoir still act important sediment and pollution source areas, and contour tillage and terrace have been widely implemented in this region ([21, 12-13]. The intensive anthropogenic activities and lasting dry years result in dramatically reduced streamflow into the Miyun Reservoir [23, 26]. Thus, comparisons of runoff and soil loss from cultivated lands in this region have important implications. However, evaluations of runoff and soil loss on cultivated lands to different rainfall characteristics and soil conservation measures are scare. This study is also necessary to cope with future extreme rainstorms through managing land use in the hilly regions around the capital city of China [13, 23].

Therefore, runoff and soil erosion data from 85 rainfall events over five cultivated plots were used to explore the responses of runoff and soil loss to soil conservation measures and rainfall characteristics in the upstream catchment of the Miyun Reservoir, northern China. The specific aims were to (i) compare the differences in surface runoff and soil loss under different soil conservation measures, (ii) identify their responses to different types of rainfall events, and (iii) give suggestions to implement reasonable soil conservation measures in the study area.

2. Materials and methods

2.1. Study site

The study area is located in the Shixia catchment (E117°4′30″ and 40°34′40″N) (Figure 1), some 90 km northeast of Beijing. The catchment lies in the Yanshan Mountains, and has a temperate territorial monsoon climate with annual precipitation ranging from 300 mm to 700 mm, 70% of which falls from June to August.

Figure 1 is about here.

The catchment has an area of 33 km^2 with elevations of 130-390 m a.s.l.. It exhibits an earth-rock hilly geomorphology. The lithology is dominated by gneiss, scattered with granite and limestone. The soil is developed on alluvial and diluvial parent materials. The catchment is mostly covered by artificial *Robinia pseudoacacia*, *Pinus tabulaeformis*, and economic forest. The major crops are corn (*Zea mays*) and wheat (*Triticum aestivum*).

2.2. Description of the selected runoff plots

There are 22 runoff plots in the catchment (Figure 1). The boundaries of each plot were made of bricks and cement to prevent runoff

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from leaving or entering the plot. The plots are bare, covered with different types of vegetation, or implemented with different soil conservation measures. In order to specifically study the effect of soil conservation measures on runoff and soil loss from cultivated slopes, five plots planted with corn were selected, consisting of one plot without soil conservation measure, three plots with contour tillage, and one plot with 4-m wide terrace. Each plot was 50 m^2 in area and 5 m in width. The slope gradients range from 6.1% to 29.6% with soil thickness of around 30 cm. Detailed information of the plots was given in Table 1.

Table 1 is about here

2.3. Data collection

Surface runoff and soil loss were collected and measured after each rainfall event in 2011-2019. A nine-hole diversion bucket and a tank were used to collect runoff mixed with sediment from the plot. The runoff amount was calculated and sampled with 1000-ml flasks after each rainfall. After settling for 24 h, sediment was separated from the water, dried in an over at a temperature of 105℃, and subsequently weighted to determine the sediment concentration. Soil loss of each plot was calculated by multiplying the average sediment concentration and the runoff volume. The runoff depth (H; mm) of runoff plot after each rainfall event was calculated by using total runoff amount and plot area. Soil loss rate (SLR; t km^{-2} $event^{-1}$) was obtained by using soil loss and plot area.

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Annual runoff depth and annual soil loss rate of each plot were obtained by summing the event-derived ones.

Self-recording rain gauge and rain barrel were installed near the plots to monitor rainfall process and rainfall amount. According to the records, rainfall duration (RD), rainfall amount (P), mean rainfall intensity (I_m), maximum intensities at 30-min (I_{30}), and at 60-min (I_{60}) were obtained. Annual rainfall amount (AP) was obtained by summing event P.

Soils from the runoff plots were collected, and soil texture and soil organic matter in Table 2 were obtained by Wang et al. [19]. Soil samples for moisture measurements before a rainfall event were taken using drilled soil cores, 20 cm depth from slope surface at an interval of 10 cm thickness in profiles. Sampling time intervals depended on the occurring frequency of rainfall events. All the samples were transported to the laboratory, and soil moistures were obtained by subtracted weight of water from that of fresh soils.

Table 2 is about here

2.4. Data treatment and statistical analysis

In order to study the effect of rainfall characteristics on surface runoff and soil loss, K-means clustering method was used to group the erosive rainfall events in 2011-2019. To determine the number of groups, many criteria were used. Normally, the classification must meet the

ANOVA criterion of significant level (p < 0.05). In the present study, rainfall eigenvalues of P, RD, I_m, I_{30}, and I_{60} were employed to group the erosive rainfall events.

In the present study, erosive rainfall was defined as the rainfall that induces runoff and soil loss. Event-averaged runoff reduction efficiency (ARRE) of soil conservation measure was calculated as follows:

$$\mathrm{ARRE} = \frac{AH_0 - AH_i}{AH_0} \quad (i = 2,3,4, or\ 5) \tag{1}$$

Where AH_0 represents averaged runoff depth on plot 1 (without soil conservation measure), and AH_i represents event-averaged runoff depth on the ith plot with soil conservation measure. Similarly, event-averaged soil loss reduction efficiency (ASLRE) was calculated as follows:

$$\mathrm{ASLRE} = \frac{ASLR_0 - ASLR_i}{ASLR_0} \quad (i = 2,3,4, or\ 5) \tag{2}$$

Where $ASLR_0$ represents averaged soil loss rate on plot 1, and SLR_i represents envent-averaged soil loss rate on the ith plot with soil conservation measure.

Pearson correlation analysis was performed to assess the relationships between H, SLR, and their influencing factors. Fisher's protected least significant difference (LSD) test was conducted to compare the means of Hs and SLRs on the plots. Treatments were considered significantly if P < 0.05.

3. Results

3.1. Rainfall characteristics

In 2011-2019, mean AP was 507 mm, ranging from 410 to 579 mm. In contrast, mean annual erosive rainfall amount was 326 mm, ranging from 249 to 434 mm. There were 85 erosive rainfall events in the study period, ranging from seven to eleven rainfall events per year (Figure 2a). Most erosive rainfalls occurred in July and August (Figure 2b).

Figure 2 is about here

K-means clustering classification result indicated that RD, P, and I_m were the significant rainfall eigenvalues to group the 85 rainfall events (Table 3), resulting in three rainfall regimes (Table 4). Rainfall regime A occurred 62 times, occupying 72.9% of the total. Rainfall regime B occurred 20 times, and the occurring frequency occupied of 23.5% of the total. Rainfall regime C had 3 rainfall events (Table 4). In accordance with the occurring frequency, regime A had the shortest average RD of 176 minutes, the lowest average P of 26 mm, and the highest average I_m of 14.18 mm h^{-1}. Inversely, rainfall regime C had the longest average RD, the highest average P, and the smallest average I_m of 3.30 mm h^{-1}. These three rainfall regimes had comparable I_{30} and I_{60} values, without significant differences at the 0.05 level (Table 4). In respect of the 85 rainfall events, the average P, I_m, I_{30}, and I_{60} were 33.51 mm, 11.45 mm h^{-1}, 28.73 mm h^{-1}, and 20.77 mm h^{-1}, respectively. Average RD of the 85 rainfall events was 354.77 minutes, ranging from 20 to 1940 minutes (Table 4).

Table 3 is about here

Table 4 is about here

3.2. Surface runoff

During the study period, average AH differed greatly. Plot 1 had the highest AH ranging from 28.41 to 103.51 mm with an average of 71.30 mm, followed by plot 2 with contour tillage measure ranging from 32.28 to 98.30 mm with an average of 63.07 mm. The AHs on the contour tillage plots 5 and 4 were 62.74 mm and 61.95 mm, respectively. The terraced plot 3 yielded the lowest AH ranging from 0 to 11 mm with an average of 2.86 mm, which was significantly different from those on other plots at the 0.05 level (Figure 3a).

Figure 3 is about here

The number of runoff-soil loss events differed among the plots. 77 events occurred plot 1, and 71, 67, 63, and 9 events occurred on plots 2, 5, 4, and 3 respectively. For each plot, more runoff-soil loss events were caused by rainfall regime A, followed by regimes B, and C (Figure 3b). The average Hs of the 85 rainfall events presented the same sequence (Figure 3c). Plot 1 yielded the highest runoff depth, and plot 3 yielded the lowest one. Rainfall regimes affected H on each plot. Under rainfall regime A, the Hs decreased from 7.03 mm on plot 1, 6.35 mm on plot 2, 6.29 mm on plot 5, 6.19 mm on plot 4, to 0.2 mm on plot 3. Under rainfall regime B, Hs decreased from 8.09 mm on plot 1, 6.66 mm on plot

2, 6.44 mm on plot 5, 6.23 mm on plot 4, to 0.23 mm on plot 3. However, under rainfall regime C, plot 4 had the highest H of 16.4 mm and plot 3 had the lowest one of 2.94 mm. For each plot, rainfall regimes B and C had higher H, and rainfall regime A had lower H. For example, on plot 1, the Hs were 7.03 mm, 8.09 mm, and 4.42 mm under rainfall regimes A, B, and C, respectively. The average Hs on plots 1, 2, 4, and 5 under each rainfall regime were insignificant and they all significantly higher than that on plot 3 at the 0.05 level.

3.3. Soil loss

Soil losses from the plots had almost the same changing patterns to the counterparts of Hs at both annual and event scales. Mean annual SLRs decreased from 2838.11 t km^{-2} on plot 1, 2033.83 t km^{-2} on plot 2, 455.94 t km^{-2} on plot 5, 160.60 t km^{-2} on plot 4, to only 3.49 t km^{-2} on plot 3 (Figure 4a). Mean annual SLRs on plot 1, plot 2, and those on other plots were significantly different at the 0.05 level. Similarly, the event-averaged SLR decreased from 300.51 t km^{-2} on plot 1, 215.35 on plot 2, 47.22 on plot 5, 7.00 on plot 4, to approached zero on plot 3.

Figure 4 is about here

Different from event-averaged H under the three rainfall regimes, event-averaged SLR under rainfall regime A were insignificantly higher than that under rainfall regimes B for individual plot (Figure 4b). However, event-averaged SLRs under regime C were significant higher than those under regimes A and B at the 0.05 level. For example, SLRs on plot 1 were 319.54 t km^{-2}, 225.39 t km^{-2}, and 408.00 t km^{-2} under rainfall regimes A, B, and C, respectively. This changing pattern of SLR under different rainfall regimes also occurred on other plots.

3.4. Runoff-soil loss relationship

Runoff and soil loss relationships for each plot under different rainfall regimes were shown in Figure 5. The scattered points were fitted with linear regressions. The slope b of the linear regression function y=a+bx reflects the sensitivity of soil to be eroded. For all the erosive rainfall events, the b value on plot 1 was the highest of 35.39, followed by those of 30.82 on plot 2, 9.04 on plot 5, and 1.94 on plot 4. However, there was no apparent relationship between runoff and soil loss on plot 3. For individual runoff plot, the b values was usually less under rainfall regime A, and higher under rainfall regimes B and C. For example, for plot 1, the b value was 25.16 under rainfall regime A, the b values were 38.14 and 28.04 under regimes B and C, respectively.

Figure 5 is about here

4. Discussion

4.1. Effect of antecedent soil moisture and soil crust

Soil moisture is an important factor in influencing surface runoff and soil loss, and higher antecedent soil moisture content (ASMC) usually induces more runoff and soil loss [27]. However, there were no significant correlations between ASMC, H and SLR in the present study (Table 5). This could result from the interactions of soil curst and rills as affected by ASMC and the runoff generation type in the study area. Under the impact of rainfall, encrusted soil surface can greatly reduce infiltration rate [28-30]. The presence of only 0.1 mm thick of crust may reduce the infiltration rate from 800 cm day^{-1} to 70 cm day^{-1} [31]. Qinna and Awwad [32] found that the permeability of deep soils was up to 2000-fold higher than that of the surface soil crust. However, when rainfall intensity is high enough, the encrusted soil can be destroyed and rills and/or even ephemeral gully develop that can increase infiltration rate [33-35]. Soils with higher ASMC can accelerate the formation and destructive processes of soil crust [36], resulting in its complex effect on H and soil loss. Field investigation demonstrated that sometimes rills developed on the lower section of the plots after a high intensity rainfall event. The changes of soil crust and rills with rainfall duration make a complex relation of ASMC and runoff [34-35]. The special runoff generation type in this region that will be discussed below could also induce insignificant correlations of ASMC and H. Under the shorter RD and high rainfall intensity conditions, infiltration excess runoff dominates, resulting in a lower H. However, the longer RD rainfall and higher P events yielded a higher H (Figure 3b), due to the dominant saturation excess runoff. Affected by the complex interactions of soil crust and rills development, and the changes in runoff generation type with time duration, the ASMC did not significantly affect H and SLR on the plots in the study area.

Table 5 is about here

4.2. Effect of rainfall regimes

In the present study, P, I_{30}, and I_{60} were positively correlated with H and SLR at the 0.01 level, and RD was also positively correlated with H at the 0.01 or 0.05 levels (Table 5). However, H and SLR were not significantly correlated with I_m although it was an efficient indicator to group the rainfall events (Table 3), implying that rainfall eigenvalues I_{30} and I_{60} were more efficient than I_m in influencing runoff and soil loss [34, 37].

In the study area, rainfall regime A is the most frequently occurring rainfall events, with short RD, low P and high I_m. This type of rainfall regime has been proved to produce more surface runoff and soil loss than those by regimes B and C (e.g., Wei et al., 2007; Fang et al., 2008; Chen et al., 2018). However, in the present study, rainfall regime A induced a lower H (Figure 3c). In the earth-rocky hilly region, infiltration excess runoff dominates the early stage of a rainfall event. However, with time duration, the runoff generation type turns from infiltration excess runoff into saturation excess runoff [38]. Different from that on the Loess Plateau where infiltration excess runoff dominates [34, 37, 39], this kind of runoff generation type resulted in a significantly positive correlations between RD and H (Table 5), inducing a higher H on the plots under rainfall regimes B and C with long PD and high P (Figure 3b).

Consistent with previous studies [34, 37, 39], higher SLR occurred under rainfall regime A (Figure 4b), resulting from its significantly higher I_m and comparable I_{30} and I_{60} in comparison to the counterparts under rainfall regime B (Table 4). As mentioned above, soil curst usually develops under rain drop impact [29, 34]. However, the encrust soil developed on the coarse-texture soil (Table 2) can easily be destroyed when higher rainfall intensity occurs, and more loose soil underneath is readily available to be eroded, resulting in higher sediment concentration and SLR [35, 40]. This inference can be verified from the fitting lines of H versus SLR under different rainfall regimes (Figure 5). For example, according to the regression functions of the fitting lines for regimes A and B, the average H of 7.03 under rainfall regime A (H_A in Figure 5a) corresponds to an SLR of 292.00 t km^{-2} $event^{-1}$, which is larger than the SLR of 225.36 m^{-2} $event^{-1}$ derived from the average H of 8.09 under rainfall regime B (H_B in Figure 5a). Rainfall regime C had a similar I_{30} and I_{60} to those of rainfall regime A, but with a much longer RD of 1171 min and higher P 96.37 mm (Table 4), resulting in the highest H and SLR (Figure 3c and Figure 4b). However, because rainfall regime C consisted of only three rainfall events, most of soil loss from plots was still induced by rainfall regime A.

4.3. Effect of slope gradient

Slope gradient is an important factor in influencing surface runoff and soil loss [41-43]. As slope gradient increases, the runoff-holding capacity of soil conservation measure will decrease. Zhao et al. [43] found that the benefit of soil loss reduction by contour tillage decreased by 3.08% with an increment of one degree. In the RUSLE2 model, the effect of slope gradient is regarded as the greatest among the influencing factors before contour failure [44]. In the present study, plots 2, 4 and 5 had the same soil conservation measure (i.e., contour tillage). Affected by slope gradients (Table 1), the average Hs on the plots decreased with deceasing slope gradient although their differences were insignificantly at the 0.05 level (Figure 3b). However, the average SLR on plot 2 was significantly higher than those on plots 4 and 5 (Figure 4b). This result is consistent with the published literatures [45-46]. Therefore, the resultant ASLREs of contour tillage measure on the plots 4 (94.34%) and 5 (84.29%) with gentle slope were quite higher than that on plot 2, although their ARREs differed little, ranging from 11.52% to 13.11% for the 85 rainfall events. It has also been confirmed that contour tillage has greater sediment reduction effect than runoff reduction effect by Jia et al. [7] through a meta-analysis in China.

4.4. Effect of soil conservation measures

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Contour tillage and terrace are the two mostly implemented soil conservation measures in China and the world [7, 47-48]. In the present study, the selected runoff plots are nearby with the same soil type and rainfall characteristics. The primary differences lie in the implemented soil conservation measures and slope gradients. The terraced plot 3 yielded the least number of runoff events (i.e., 9 times; Figure 3b), and intercepted around 98% of runoff and sediment. Similar conclusions were also reported in studies [49-51]. Interestingly, the number of runoff events on the contour tillage plots 4 was 6-fold higher than that on terraced plot 3, however, plot 4 had a comparable ASLRE to that of plot 3 although its ARRE of 13.11% was much lower than that of plot 3 (i.e., 96.03%). Similarly, plot 5 with contour tillage also had a higher ASLRE of 84.29% and a much lower ARRE of 12.05%. However, both of the ARRE (11.52%) and ASLRE (28.34%) of the contour tillage plot 2 were much lower (Figure 6), due to its higher slope gradient of 25.7%. These comparisons imply that contour tillage is efficient to control soil loss but cannot efficiently intercept runoff on gentle slopes.

Figure 6 is about here

In recent years, the deterioration in water quality and shortage of water supply in the Miyun Reservoir have threatened Beijing's drinking water supply [12, 23], and thus "water saving" soil conservation measures should be promoted in this region, as pointed out by Li et al. [52]. In the present study, the terraced plot can concurrently effectively intercept runoff and sediment that could greatly prevent runoff from entering into Miyun Reservoir, affecting the amount of drinking water for the people in Beijing. Furthermore, terrace construction is of high cost, and occupies a large part of field. Therefore, terraces should be cautiously implemented in the study area. On gentle slopes, contour tillage should be promoted because it allows more runoff to route downstream when it can efficiently control soil loss.

5. Conclusions

In this study, surface runoff and soil loss from five cultivated slopes were monitored in 2011-2019 in the hilly region, northern China, and 85 runoff-soil loss events occurred during the study period. The 85 erosive rainfall events were grouped into three regimes based on K-means cluster classification, and the effects of rainfall regimes and soil conservation measures (i.e., contour tillage and terrace) on runoff and soil loss of the cultivated plots were evaluated.

Responses of runoff and soil loss to the three rainfall regimes were different. The frequently occurred rainfall regime A with short RD, low P and high I_m produced higher SLR and lower H. However, rainfall regime B with higher RD, P, and low I_m yielded higher H and lower SLR. The terraced plot can concurrently intercept runoff and sediment, resulting in the highest ARRE (i.e., 96.03%) and ASLRE (i.e., 99.88%) on gentle slopes. Although contour tillage measure had comparable ASLRE to that on terraced plot 3, its ARRE was much smaller than that by terrace on gentle slopes. The effects of rainfall characteristics and soil conservation measures increased with decreasing slope gradients.

In the Miyun reservoir catchment where water-shortage exists, water-saving soil conservation measures should be given priority to. Therefore, contour tillage should be promoted on gentle slopes, and terrace should be given enough attention in the study area and similar regions in the world because it can intercept a large portion of surface runoff which could greatly reduce downstream water quantity, exacerbating water storage and drinking water safety in downstream areas.

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References

1. Damnati, B.; Ibrahimi, S.; Radakovitch, Q. Quantifying erosion using ^{137}Cs and ^{210}Pb in cultivated soils in three Mediterranean watershed: Synthesis study from El Hachef, Raouz and Nakhla (North West Morocco). *J. Afr. Earth Sci.* **2013**, 79, 50-57.
2. Wuepper, D.; Borrelli, P.; Finger, R. Countries and the global rate of soil erosion. *Nat. Sustain.* **2020**, 3, 51-55.
3. Borrelli, P.; R4obinson, D.A.; Fleischer, L.R.; Lugato, E.; Ballabio, C.; Alewell, C.; Meusburger, K.; Modugno, S.; Schutt, B.; Ferro, V.; Bagarello, V.; van Oost, K.; Montanarella, L.; Panagos, P. An assessment of the global impact of 21st century land use change on soil erosion. *Nat. Commun.* **2017**, 8, 1-13.
4. Alatorre, L. C.; Beguería, S.; Lana-Renault, N.; Navas, A.; García-Ruiz, J. M. Soil erosion and sediment delivery in a mountain catchment under scenarios of land use change using a spatially distributed numerical model. *Hydrol. Earth Sys. Sci. Dis.* **2012**, 16, 1321-1334.
5. Didoné, E.J.; Minella J.P.G.; Evrard, O. Measuring and modelling soil erosion and sediment yields in a large cultivated catchment under no-till of Southern Brazil. *Soil Tilla. Res.* **2017**, 174, 24-33.
6. Aneseyee, A.B.; Elias, E.; Soromessa, T.; Feyisa, G.L. Land use/land cover change effect on soil erosion and sediment delivery in the Winike watershed, Omo Gibe Basin, Ethiopia. *Sci. Tot. Environ.* **2020**, 728, 138776.
7. Jia, L.Z.; Zhao, W.W.; Zhai, R.J.; An, Y.M.; Pereira, P. Quantifying the effects of contour tillage in controlling water erosion in China: A meta-analysis. *Catena* **2020**, 195, 104829.
8. Bai, L.C.; Wang, N.; Jiao, J.Y.; Chen, Y.X.; Tang, B.Z.; Wang, H.L.; Chen, Y.L.; Yan, X.Q.;

Wang, Z.J. Soil erosion and sediment interception by check dams in a watershed for an extreme rainstorm on the Loess Plateau, China. *International J. Sedi. Res.* **2020**, 35, 408-416.

9. Ge, F.L.; Zhang, J.H.; Su, Z.G.; Nie, X.J. Response of changes in soil nutrients to soil erosion on a purple soil of cultivated sloping land. *Acta Ecol. Sin.* **2007**, 27(2), 459-464.
10. He, Y.Y.; Wang, X.Y.; Duan, S.H. Characteristics of runoff and sediment during individual rainfall in upper area of Miyun Reservoir. Transac. *Chin. Soc. Agr. Engi.* **2015**, 31(24),134-141.
11. Han, L.F.; Gao, B.; Lu, J.; Zhou, Y.; Xu, D.Y.; Gao, L.; Sun, K. Pollution characteristics and source identification of trace metals in riparian soils of Miyun Reservoir, China. *Ecotox. Environ. Safe.* 2017, 144, 321-329.
12. Qiu, J.L.; Shen, Z.Y.; Hou, X.S.; Xie, H.; Leng, G.Y. Evaluating the performance of conservation practices under climate change scenarios in the Miyun Reservoir Watershed, China. *Ecol. Eng.* **2020**, 143, 105700.
13. Qiu, J.L.; Shen, Z.Y.; Huang, M.Y.; Zhang, X.S. Exploring effective best management practices in the Miyun reservoir watershed, China. *Ecol. Eng.* **2018**, 123, 30-42.
14. Li, H.Y.; Di, Y.M.; Li, D.Q.; Liang, J.; Guo, X.Y. Spatial and temporal variations of water quality in a wetland-reclaimed water-supplied purification urban river: case study in Chaobai River of Beijing. *Res. Environ. Sci.* **2007**, 30(10), 1542-1552.
15. Wang, P.J.; Rene, E.R.; Yan, Y.L.; Ma, W.F.; Xiang, Y.Y. Spatiotemporal evolvement and factors influencing natural and synthetic EDCs and the microbial community at different groundwater depths in the Chaobai watershed: A long-term field study on a river receiving reclaimed water. *J. Enviro. Manage.* **2019**, 246, 647-657.

16. Wang, S.F.; Wang, X.K.; Ouyang, Z.Y. Effects of land use, climate, topography and soil properties on regional soilorganic carbon and total nitrogen in the Upstream Watershed of Miyun Reservoir, North China. *J. Environ. Sci.* **2012**, 24(3), 387-395.
17. Xu, E.Q.; Zhang, H.Q. Relationship between land use and nutrients in surface runoff in upper catchment of Miyun Reservoir, China. *J. Appl. Ecol.* **2018**, 29(09), 2869-2878.
18. Wei, J.; Zheng, X.G.; Wang, C.L.; Zhang, G.X.; Liu, J.T. Soil arsenic content and environmental quality assessment in the upstream basin of Guanting Reservoir and Miyun Reservoir. *Environ. Chem.* **2019,** 38(1), 71-77.
19. Wang, X.Y.; Hu, Q.J.; Zhu, F.Y.; He, W. Loss of nutrients in runoff and soil in the watershed of Miyun Reservoir-as a example of Shixia experimental area. *J. Capi. Nor. Uni.* **2001**, 22(2), 79-85.
20. Li, Z.J. Impacts of different allocation plans as soil and water conservation measures on annual runoff in the Chaohe River basin. *Bull. Soil Water Conserv.* **2010**, 30(01), 108-112.
21. He, J.J.; Cai, Q.G.; Wang, X.Q. Research on paradigm of soil erosion comprehensive control about Shixia small watershed in the upstream of Miyun Reservoir. *J. Nat Resour.* **2009**, 24(04), 585-593.
22. Feng, J.J.; Shi, M.C.; Jiang, Q.E. Influence of land use/cover change on soil erosion in Chaobai River basin. *Science of Soil and Water Conservation* **2019**, 17(03), 121-132.
23. Yan, T.Z.; Bai, J.W.; Arsenio, T.; Shen, Z.Y. Future climate change impacts on streamflow and nitrogen exports based on CMIP5 projection in the Miyun Reservoir Basin, China. *Ecohydrol. Hydrobiol.* **2019**, 19, 266-278.
24. Cai, X.G. Benefits from soil and water conservation measures on reducing runoff and

sediments in Shixia small watershed. *Res. Sci.* 2001, (2), 79-85.

25. Gao. Y. Study on the effect of different soil conservation measures on soil erosion in Shixia catchment. *Dev. Inno.* **2018**, 29(13), 255-256.
26. Pang, S.J.; Wang, X.Y.; Melching, C.S.; Feger, K.H. Development and testing of a modified SWAT model based on slope condition and precipitation intensity. *J. Hydrol.* **2020**, 588, 125098.
27. Meißl, G.; Zieher, T.; Geitner, C. Runoffresponse to rainfall events considering initial soil moisture–Analysis of 9-year records in a small Alpine catchment (Brixenbach valley, Tyrol, Austria. *J. Hydrol.:Reg. Stud.* **2020**, 30, 100711.
28. Vandervaere, J.P.; Peugeot, C.; Angulo Jaramillo, R.; Vauclin, M.; Lebel, T. Estimating hydraulic conductivity of crusted soils by using disc infiltrometers and micro-tensiometers. *J. Hydrol.* **1997**, 188-189, 203-223.
29. Esteves, M.; Lapetite, J.M. A multi-scale approach of runoff generation in a Sahelian gully catchment: a case study in Niger. *Catena* **2003**, 50, 255–271.
30. Hardie, M.; Almajmaie, A. Measuring and estimating the hydrological properties of a soil crust. J. *Hydrol.* 2019, 574, 12-22.
31. McIntyre, D.S. Permeability measurements of soil crusts by raindrop impact. *Soil Sci.* **1958**, 85, 185-189.
32. Qinna, M.I.A.; Awwad, A.M.A. Infiltration rate measurements in arid soils with surface crust. *Irri. Sci.* **1998**, 18, 83-89.
33. Peugeot, C.; Esteves, M.; Rajot, J.L.; Vandervaere, J.P.; Galle, S. Runoff generation processes: results and analysis of field data collected at the central supersite of the Hapex-Sahel

experiment. *J. Hydrol.* **1997**, 188-189, 179-202.

34. Fang, H.Y., Cai, Q.G., Chen, H., Li, Q.Y., 2008. Effect of rainfall regime and slope on runoff in a gullied loess region on the Loess Plateau in China. *Environ. Manage.* **2008**, 42, 402-411.
35. Fang, H.Y.; Sun, L.Y.; Tang, Z.H. Effects of rainfall and slope on runoff, soil erosion and rill development: an experimental study using two loess soils. *Hydrol. Process.* **2015**, 29, 2649-2658.
36. Le Bissonnais, Y.; Renaux, B.; Delouche, H. Interactions between soil properties and moisture content in crust formation, runoff and interrill erosion from tilled loess soils. *Catena* **1995**, 1-4, 33-46.
37. Wei, W.; Chen, L.D.; Fu, B.J.; Huang, Z.L.; Wu, D.P.; Gui, L.D. The effect of land uses and rainfall regimes on runoff and soil erosion in the semi-arid loess hilly area, China. *J. Hydrol.* **2007**, 335, 247-258.
38. He, P.; Zhang, G.S.; Bian, R.Y. A study of runoff yield in mid-area of Haihe basin. *Hydr. Sci. Technol.* **2001**, 22(1), 45-50.
39. Chen, H.; Zhang, X.P.; Alba, M.; Yan, R.; Ren, Q.F.; Ren, Z.Y.; Yang, Y.H.; Zhao, W.H.; Lin, P.F.; Liu, B.Y.; Yang, X.H. Effects of vegetation and rainfall types on surface runoff and soil erosion on steep slopes on the Loess Plateau, China. *Catena* **2018**, 170, 141-149.
40. Hu, Y.X.; Fister W.; He, Y.; Kuhn, N.J. Assessment of crusting effects on interrill erosion by laser scanning. *Peerj* **2019**, 8, e8487.
41. Guo, J.Z. Discussion on the issue of the relations of slope gradient and runoff amount and sediment production. *Yel. Riv.* **1958**, 3, 47-49.
42. Fox, D.M.; Bryan, R.B.; Price, A.G. The influence of slope angle on final infiltration rate for

interrill conditions. *Geoderma* **1997**, 80,181-194.

43. Zhao, L.S.; Hou, R.; Wu, F.Q.; Dai, Q.H. Effect of slope gradient on soil and water conservation benefit of tillage practices in agriculture lands. *J. Soil Water Conserv.* **2017**, 31 (03), 69-72, 78.
44. Hessel, R.; Messing, I.; Liding, C.; Ritsema, C.; Stolte, J. Soil erosion simulations of land use scenarios for a small Loess Plateau catchment. *Catena* **2003**, 54 (1), 289-302.
45. Zhao, L.; Liang, X.; Wu, F. Soil surface roughness change and its effect on runoff and erosion on the Loess Plateau of China. *J. Arid Land* **2014**, 6 (4), 400-409.
46. Wu, Q.J; Wang, L.H.; Wu, F.Q. Effects of structural and depositional crusts on soil erosion on the Loess Plateau of China. *Arid Land Res. Manag.* **2016**, 30 (4), 432-444.
47. Chen, D., Wei, W., Chen, L.D. Effects of terracing practices on water erosion control in China: A meta-analysis. Earth-Sci. Rev. **2017**, 173, 109-121.
48. Xin,Y.; Liu, G.; Xie, Y.; Gao, Y.; Liu, B.Y.; Shen, B. Effects of soil conservation practices on soil losses from slope farmland in northeastern China using runoff plot data. *Catena* **2019**, 174, 417-424.
49. Zhao, J.L.; Yang, Z.Q.; Gover, G. Soil and water conservation measures reduce soil and water losses in China but not down to background levels: Evidence from erosion plot data. *Geoderma* **2019**, 337, 729-741.
50. Chen, J.; Xiao, H.B.; Li, Z.W.; Liu, C.; Tang, C.J. How effective are soil and water conservation measures (SWCMs) in reducing soil and water losses in the red soil hilly region of China? A meta-analysis of field plot data. *Sci. Tot. Environ.* **2020**, 735, 139517.
51. Fernandes, A.C.S.A.; Gontijo, L.M. Terracing field slopes can concurrently mitigate soil

erosion and promote sustainable pest management. *J. Environ. Manage.* 2020, 269, 110801.

52. Li, X.B.; Ma, Z.Z.; Yao, X.Y.; Jing, K.; Zhu, H.Y. Current status and comprehensive control strategies of soil erosion for rocky mountain areas in the Northern China. *Sci. Soil Water Conserv.* **2008**, 6(1), 9-15.

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Table 1. Description of the selected runoff plots.

No.	Gradient (%)	Length（m）	Width (m)	Area（m^2）	Aspect	Type	Crop	Measure
1	29.6	10	5	50	Sunny	Cultivated	Corn	-
2	25.7	10	5	50	Semi-shady	Cultivated	Corn	Contour tillage
3	6.1	10	5	50	Sunny	Cultivated	Corn	Terrace (4-m wide)
4	6.1	10	5	50	Sunny	Cultivated	Corn	Contour tillage
5	11.0	10	5	50	Semi-sunny	Cultivated	Corn	Contour tillage

Table 2. Soil properties of the runoff plots in the study area.

	SOM (%)	Texture				
		>0.05	0.05-0.01	0.01-0.005	0.005-0.001	<0.001
Mean	1.57	60.9	15.00	3.22	6.00	14.88
St.D	0.69	-	4.36	1.53	1.00	2.55

Table 3. Result of analysis of variance (ANOVA) using K-means clustering classification method.

	Cluster		Error		F	Sig.
	Mean square	df	Mean square	df		
RD	4980828.25	2	23349.50	82	213.32	0.00
P	9573.87	2	434.34	82	22.04	0.00
I_m	854.79	2	121.57	82	7.03	0.00
I_{30}	270.12	2	222.84	82	1.21	0.30
I_{60}	59.44	2	162.97	82	0.37	0.70

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Table 4. Statistical features of the erosive rainfall events and their rainfall regimes in 2011-2019.

Rainfall regime	Eigenvalue	Mean	Range (min-max)	Standard deviation	Variation of coefficient	Number
A	*P* (mm)	26.01	4.80-105.20	16.52	0.64	62
	RD (min)	176.03	20.00-498.00	138.04	0.78	
	I_m (mm min^{-1})	14.18	2.07-69.6	12.68	0.89	
	I_{30} (mm min^{-1})	29.70	6.00-75.80	15.85	0.53	
	I_{60} (mm min^{-1})	21.17	3.60-69.60	12.76	0.60	
B	*P* (mm)	47.32	10.60-123.60	31.21	0.66	20
	RD (min)	705.30	500.00-1060.00	188.27	0.27	
	I_m (mm min^{-1})	4.20	1.03-11.36	2.84	0.68	
	I_{30} (mm min^{-1})	23.90	6.40-37.40	10.29	0.43	
	I_{60} (mm min^{-1})	18.74	4.50-57.20	12.44	0.66	
C	*P* (mm)	96.37	82.50-108.10	12.93	0.13	3
	RD (min)	1711.67	1580.00-1940.00	198.52	0.12	
	I_m (mm min^{-1})	3.30	3.07-3.74	0.34	0.10	
	I_{30} (mm min^{-1})	31.6	15.20-56.00	21.54	0.68	
	I_{60} (mm min^{-1})	23.77	14.40-42.00	15.79	0.66	
Total	*P* (mm)	33.51	4.80-123.60	25.53	0.76	85
	RD (min)	354.76	20.00-1940.00	376.01	1.06	
	I_m (mm min^{-1})	11.45	1.03-69.60	14.98	1.31	
	I_{30} (mm min^{-1})	28.40	6.00-75.80	14.95	0.53	
	I_{50} (mm min^{-1})	20.69	3.60-69.60	12.67	0.61	

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Table 5. Pearson correlation coefficients between runoff, soil loss rate, and their influencing factors for the five runoff plots.

		RD	P	I_m	I_{30}	I_{60}	ASMC
Plot 1	H	0.224*	0.607**	0.098	0.528**	0.487**	-0.050
	SLR	-0.019	0.304**	0.280**	0.448**	0.416**	0.011
Plot 2	H	0.235*	0.518**	0.180	0.586**	0.486**	-0.060
	SLR	0.132	0.349**	0.186	0.404**	0.381**	-0.096
Plot 3	H	0.402**	0.521**	0.024	0.286**	0.284**	0.002
	SLR	-0.004	0.282**	0.127	0.245*	0.320**	0.049
Plot 4	H	0.316**	0.581**	0.061	0.514**	0.441**	0.003
	SLR	-0.100	0.219*	0.181	0.281**	0.287**	0.112
Plot 5	H	0.220*	0.521**	0.182	0.542**	0.491**	0.006
	SLR	0.315**	0.426**	0.070	0.321**	0.345**	0.134

Note: SLR is soil loss rate; ASMC is antecedent soil moisture content. * represents significance at 0.05 level, and ** represents significance at the 0.01 level.

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Figure captions:

Figure 1. Location of the study area and the cultivated runoff plot selected. The red figures represent the plots in Table 1.

Figure 2. Annual total and erosive rainfall amounts in 2011-2019 (a) and monthly distributions of the numbers of the erosive rainfall events in the study period (b).

Figure 3. Average annual runoff depth (AH) (a), number of runoff events induced by rainfall regimes A, B, and C on the five plots (b), and event-averaged runoff depth (H) under each rainfall regime. Note: Average values in (a) and (c) on the columns with the same letter are not significant different at the 0.05 level (LSD). Vertical bars represent standard deviation.

Figure 4. Average annual soil loss rate (SLR) (a) and event-averaged SLR for the 85 rainfall events under each rainfall regime. Note: Average values on the columns with the same letter are not significant different at the 0.05 level (LSD). Vertical bars represent standard deviation.

Figure 5. Relationships runoff depth (H) and soil loss rate (SLR) under different rainfall regimes from plot 1 (a), plot 2 (b), plot 3 (c), plot 4 (d), and plot 5 (e). In (a), HA (7.03 mm) and HB (8.09) are the mean rainfall depths on plot 1 under rainfall regimes A and B in Figure 3b, SLRA and SLRB are the corresponding SLR.

Figure 6. Event-averaged runoff reduction efficiency (ARRE) and soil loss reduction efficiency (ASLRE) of the soil conservation measures on the selected plots.

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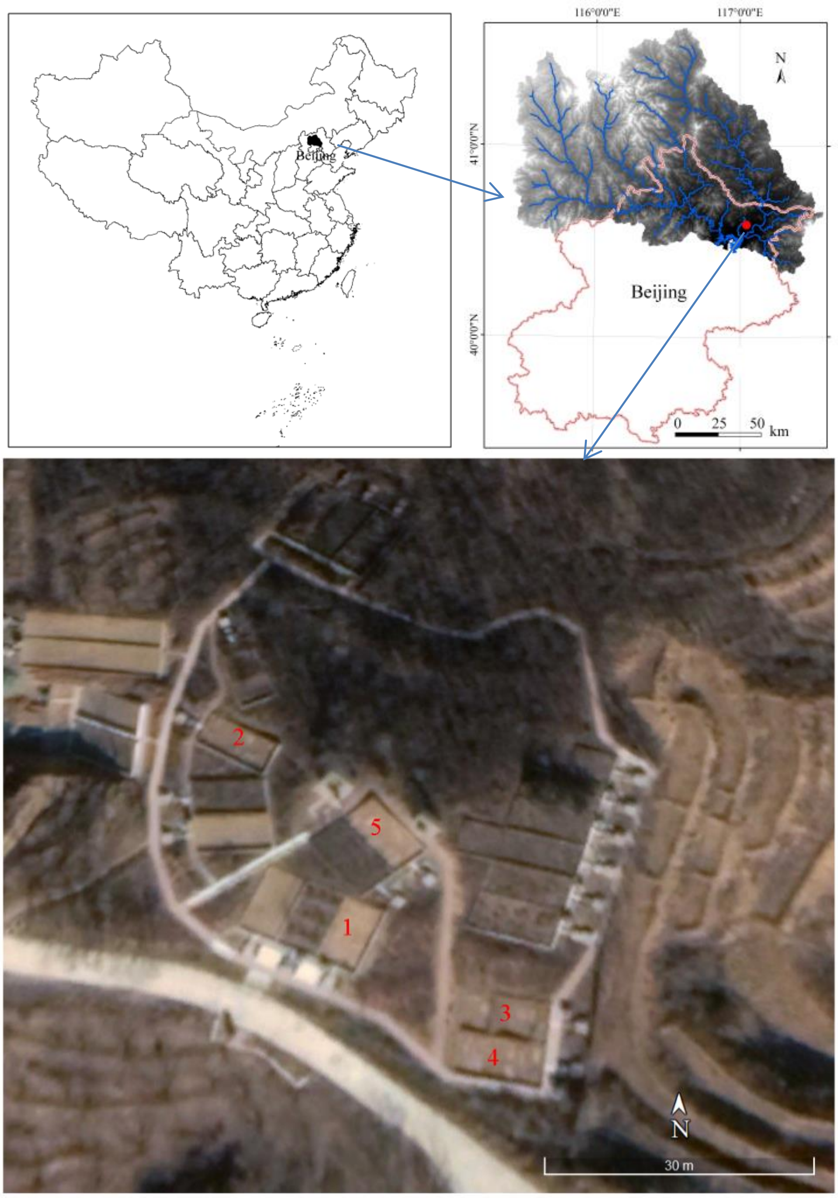

Figure 1.

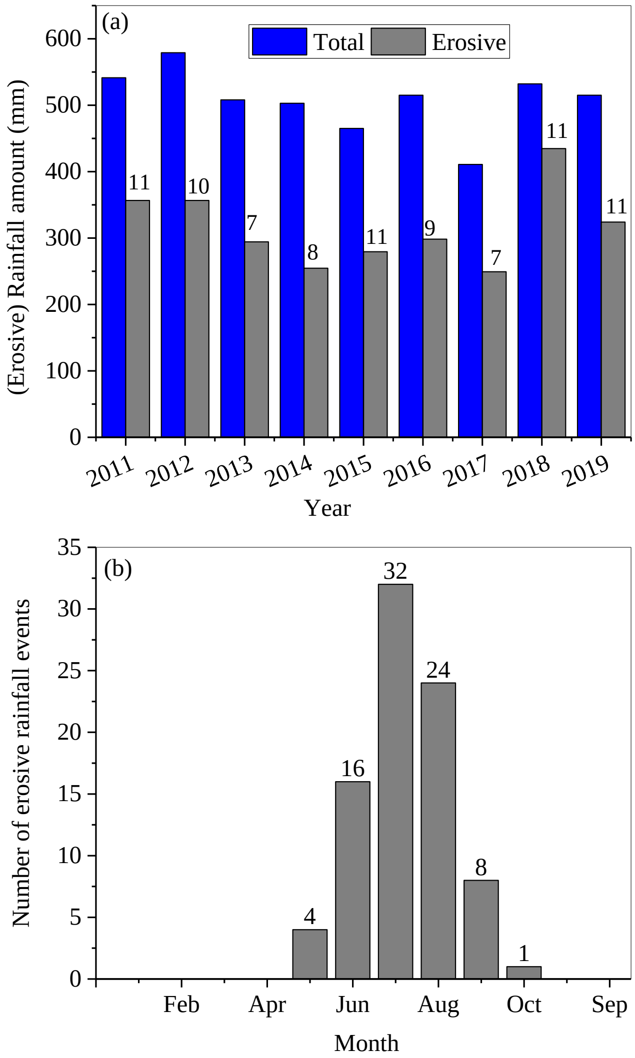
(a)
Total
Erosive
(Erosive) Rainfall amount (mm)
0
100
200
300
400
500
600
11
10
7
8
11
9
7
11
11
2011
2012
2013
2014
2015
2016
2017
2018
2019
Year
(b)
Number of erosive rainfall events
0
5
10
15
20
25
30
35
4
16
32
24
8
1
Feb
Apr
Jun
Aug
Oct
Sep
Month

Figure 2.

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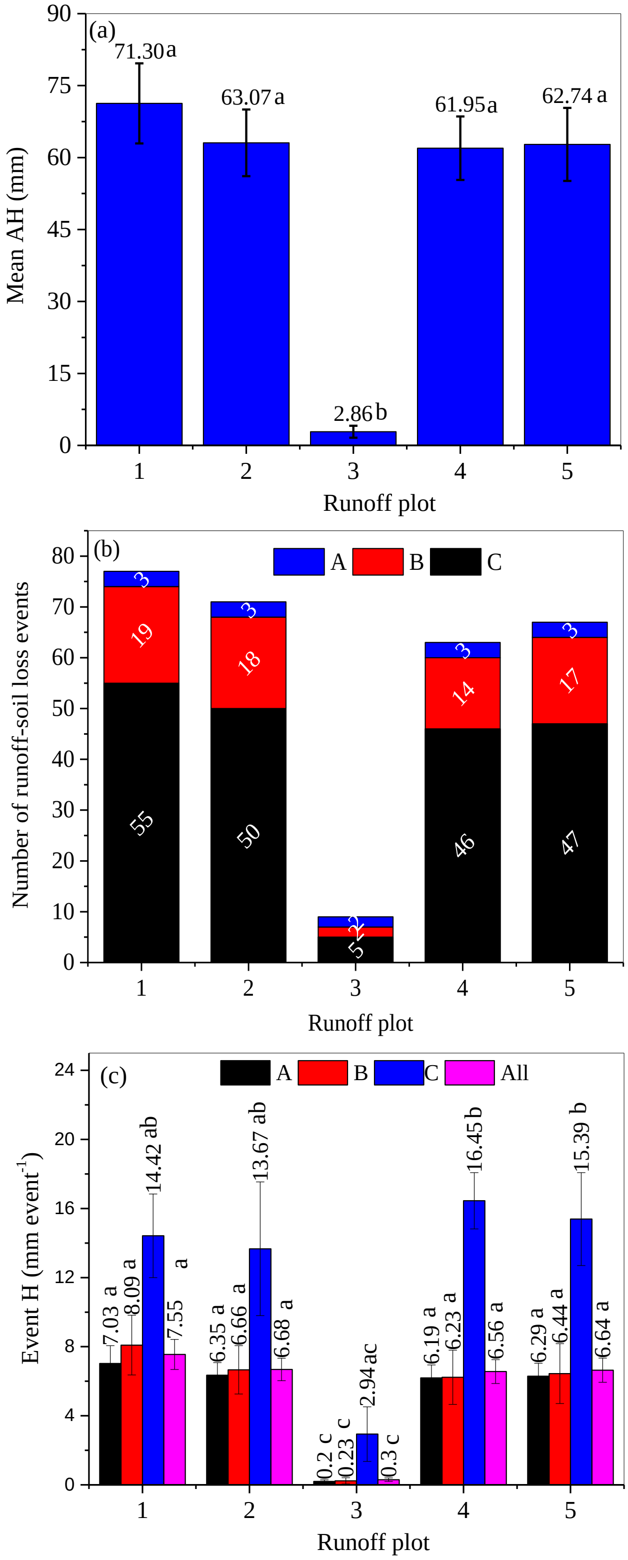

Figure 3.

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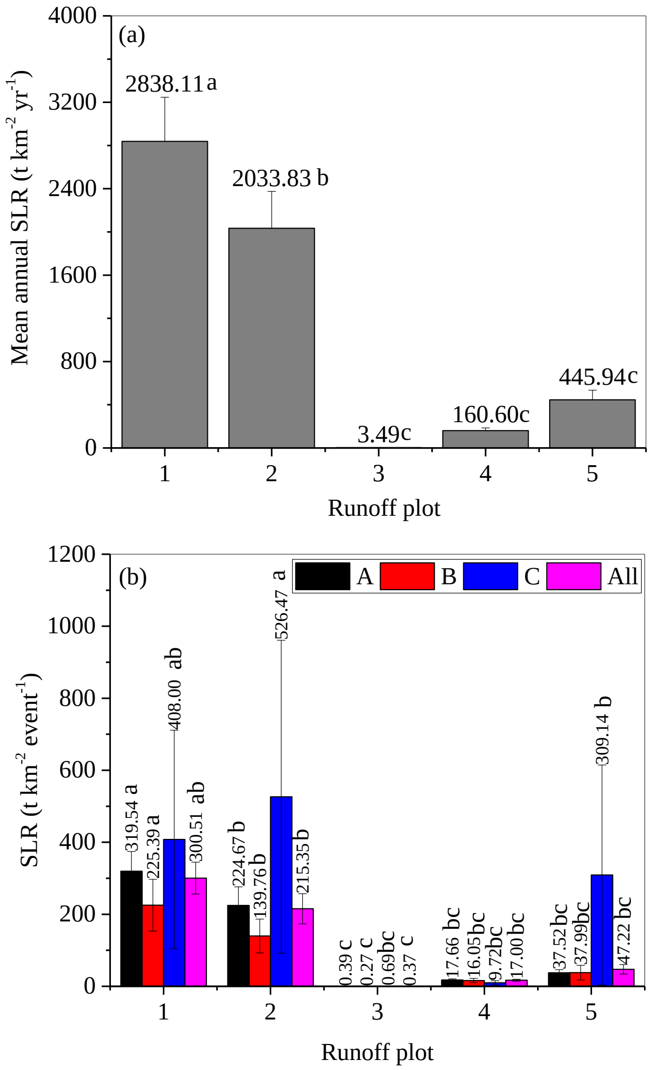

Figure 4.

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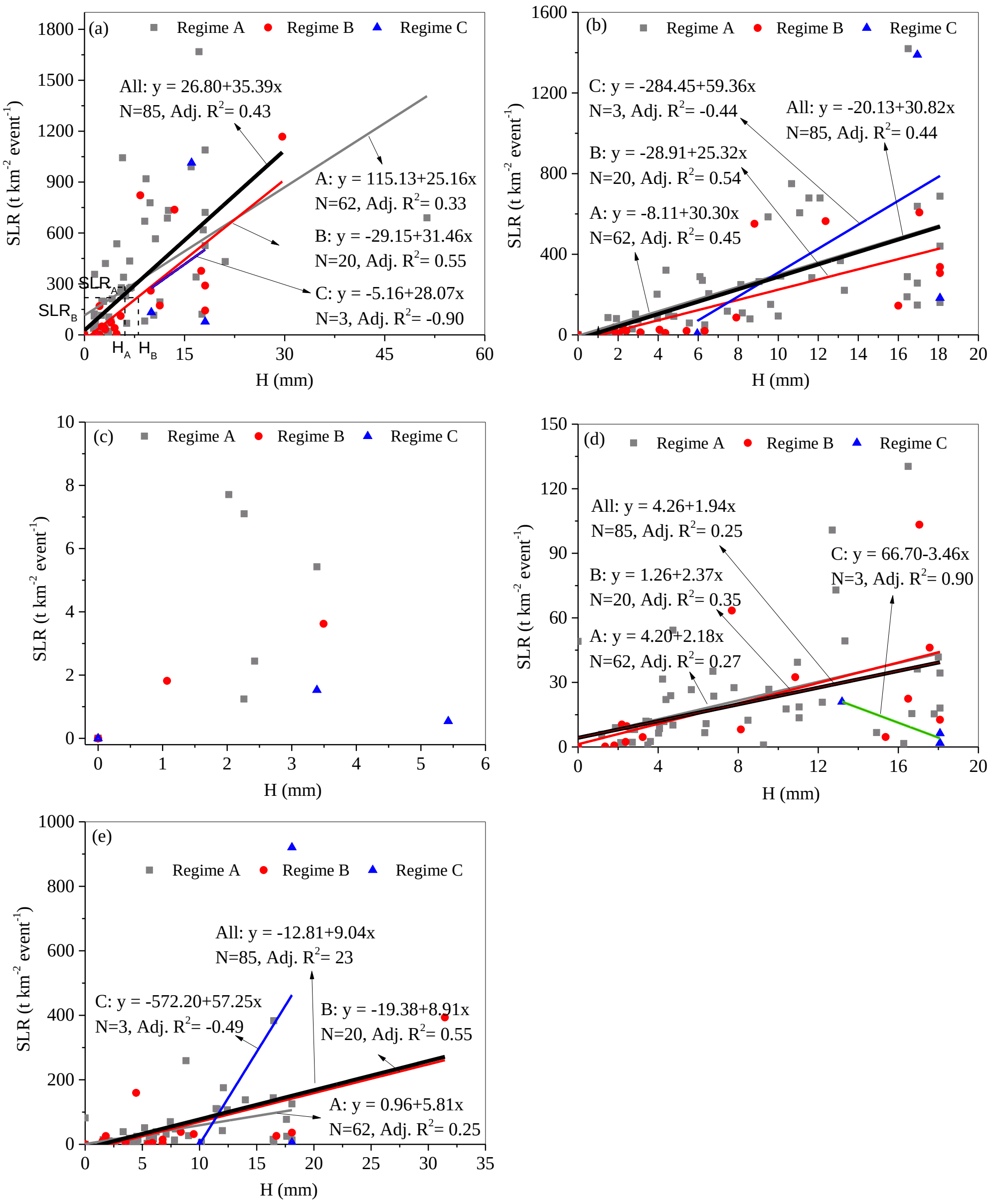

Figure 5.

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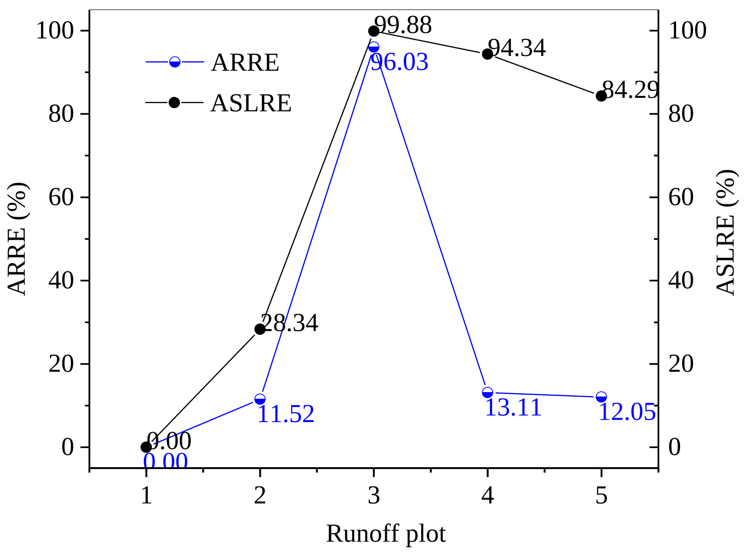

Figure 6.