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Zonal differences of runoff and sediment reduction effects for typical management small watersheds in China

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Abstract

In this particular study, 99 typical managed small watersheds which representing five water erosion areas in China were selected to study zonality of Runoff Reduction Efficiency (RRE) and of Sediment Reduction Efficiency (SRE). The RRE is the ratio of Effect of Runoff Reduction (ERR) by soil and water conservation measure over management degree in a watershed. And The SRE is the ratio of Effect of Sediment Reduction (ESR) by soil and water conservation measure over management degree in a watershed. First of all, statistical analysis was applied to test the zonal effects of RRE and SRE between different water erosion regions. The results showed that the mean RRE values in northern regions were significantly greater than those of southern regions; and the mean SRE values in northern regions were significantly greater than those in southern regions. Next, the variation of RRE with runoff depth (H) was studied in direction of both latitude and longitude across regions influenced by East Asian Monsoon. Meanwhile, the variation of SRE with specific sediment yield (Y) was studied in direction of both latitude and longitude across regions influenced by East Asian Monsoon. The results showed that RRE had the inverse variation trend as H in both latitude and longitude direction and SRE had the same variation trend as Y in both latitude and longitude direction. Furthermore, the variation of unit management area Runoff Reduction Rate (RRR) with H and RRE was studied in direction of both latitude and longitude. And the variation of unit management area Sediment Reduction Rate (SRR) with Y and SRE was studied in direction of both latitude and longitude. It was found that RRR had the similar variation trend as H in latitude direction and there was critical point around 37°N greater than which RRR began to be equal to H or even larger; RRR had the similar variation trend as H in longitude direction and there was a critical point around 109°E less than which RRR began to equal to or greater than H; SRR had the similar variation trend as Y in latitude direction and there was critical point around 36°N greater than which SRR began to be equal to Y or even larger; SRR had the similar variation trend as Y in longitude direction and there was a critical point around 106°E less than which SRR began to equal to or greater than Y. The zonality of RRE, RRR, SRE and SRR was determined by the combined influence of climate variation and special landform in regions controlled by East Asian Monsoon in China.

Key Words: Zonality, Soil and water conservation, Effects of runoff reduction, Effects of sediment reduction

1 Introduction

Research on soil and water conservation has been developed rapidly during last few decades in China. Before 1980s, the main method to conduct soil and water conservation research was experimental (Wu et al., 2004). Specifically, the recorded data from experimental fields was analyzed to reveal water and sediment reduction effects by single measure in different combination of geology, geomorphology, soil, vegetation and hydrometeorology condi-

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tions. Since 1980s, watershed management has become the research focus. Changjiang Water Resources Committee (CWRC) conducted a research on conditions of incoming water and sediment in the Three Gorges Reservoir; afterwards, CWRC imposed the Chang-Zhi project to study sediment reduction effect in Yangtze River basin. Ministry of Water Resources (MWR) established the Yellow River Water Sediment Research Foundation and the Yellow River Water and Soil Conservation Fund to help advance the research on erosion and sediment yield rule, effects of water and soil reduction and change of runoff and sediment in the Yellow River basin (Ran 2006; Ran et al., 2000). Moreover, many research institutes, universities and provincial soil and water conservation departments have been promoting researches on rules of runoff and sediment change and water and sediment reduction effects by soil and water conservation measures in different regions (Qi et al., 2010; Xia et al., 2007). Especially, typical small watershed management became the research focus during the last few decades and plentiful research results are available and promoting further research endeavors.

Climate, topography, soil, geology, vegetation are basic natural factors controlling the generation and development of the erosion; thus soil and water conservation management applies changing local terrain conditions, improving soil characters and vegetation conditions to reduce soil and water loss. Since the zonality of zonal factors such as rainfall and vegetation have been verified during last few centuries, with more or less the same soil and water conservation measures in different regions. Those zonal factors would lead to zonal differences of water and sediment reduction effects. Previous studies were focusing on runoff and sediment reduction effects in specific region, and few have been conducted to compare effects of water and sediment reduction in different region of China. The main reason was that there was no proper quantitative index which could be used to compare soil and water conservation effects between different water erosion regions. The commonly used indexes to evaluate soil and water conservation measures impact on runoff and sediment yields are Effect of Runoff Reduction (ERR) and Effect of Sediment Reduction (ESR). They are effective when applied to specific watershed assessing how much percentage of runoff or sediment has been reduced after watershed management. However, they cannot be used to compare runoff and sediment reduction effects in different watersheds because they are not functions of management degree. Thus, in order to evaluate the difference of runoff and sediment reduction effects in different watershed after certain degree of management, new quantitative indexes are needed. Qi et al. (2011) firstly used two indexes Runoff Reduction Efficiency (RRE) and Sediment Reduction Efficiency (SRE) to study spatial scale effects of soil and water conservation impact on runoff and sediment reduction between Chabagou, Dalihe and Wudinghe watersheds in loess plateau. This research demonstrated that RRE and SRE could be applied to compare reduction effects of runoff and sediment by soil and water conservation measure in different watersheds. The definition of RRE is the ratio of Effect of Runoff Reduction (ERR) by soil and water conservation measure over management degree in watersheds. And the definition of SRE is the ratio of Effect of Sediment Reduction (ESR) by soil and water conservation measure over management degree in watersheds. RRE and SRE can be calculated as follows:

$$\mathrm{RRE} = \mathrm{ERR}/D \tag{1}$$

$$\mathrm{SRE} = \mathrm{ESR}/D \tag{2}$$

Where RRE stands for Runoff Reduction Efficiency, ERR stands for Effect of Runoff Reduction, SRE stands for Sediment Reduction Efficiency, ESR stands for Effect of Sediment Reduction, and D is the management degree. ERR and ESR can be calculated as follows:

$$\mathrm{ERR} = (R_1 - R_2)/R_1 \tag{3}$$

$$\mathrm{ESR} = (S_1 - S_2)/S_1 \tag{4}$$

Where R_1 is the average annual runoff yield before management, R_2 is the average annual runoff yield after management, S_1 is the average annual sediment load before management, and S_2 is the average annual sediment load after management. D is calculated as follow:

$$D = a/A \tag{5}$$

Where A is the area of the watershed, a is the total management area during comprehensive management period.

Combining (1), (3) and (5) and combining (2), (4) and (5), we have

$$\mathrm{RRE} = (A/R_1) \cdot [(R_1 - R_2)/a] \tag{6}$$

$$\mathrm{SRE} = (A/S_1) \cdot [(S_1 - S_2)/a] \tag{7}$$

Note that A/R_1 is the reciprocal of runoff depth (H, mm) and A/S_1 is the reciprocal of specific sediment yield

(Y, t/km^2) before comprehensive management in watersheds. If we define $R = R_1 - R_2$ and $S = S_1 - S_2$, then R/a should be unit management area Runoff Reduction Rate (RRR, mm) and S/a should be unit management area Sediment Reduction Rate (SRR, t/km^2). Then we have

$$\mathrm{RRE} = \mathrm{RRR}/H \tag{8}$$

$$\mathrm{SRE} = \mathrm{SRR}/Y \tag{9}$$

The equations above can be transformed as follows:

$$\mathrm{RRR} = \mathrm{RRE} \cdot H \tag{10}$$

$$\mathrm{SRR} = \mathrm{SRE} \cdot Y \tag{11}$$

Equations (8) and (9) are showing that RRE is related to H, and SRE is related to Y. If H and Y had zonal effects in different water erosion regions, then RRE and SRE should have the same or inverse patterns. Xu (1995) have conducted a research on zonality of annual runoff depth based on recorded data derived from more than 700 watersheds across areas controlled by eastern monsoon in China. He found that the zonality of annual runoff depth was determined by uneven rainfall distribution and topographical variation across the mainland China. Based on the same dataset, Xu (1994) also studied the zonality of watershed soil erosion and sediment yield. What he found was that the variations of specific sediment yield in different watersheds with longitude and latitude could be explained by Langbein-Schumm law (Langbein et al., 1958). He further analyzed the relationship between specific sediment yield and zonal factors such as annual rainfall, rainfall variability, dry index and forest cover ratio. He concluded that the tension between erosion agents such as rainfall and rainfall variability and resistance agents such as forest cover ratio and composition materials of the soil surface determined the zonality of sediment yield in China. In addition, he pointed that there was a belt of critical water erosion zone existing along the northwestern boundary of monsoon.

The objective of this study is to reveal zonal differences of runoff and sediment reduction effects by soil and water conservation measures for typical management small watersheds in China. Also, this study is attempting to explain the reasons resulting in zonality of runoff and sediment reduction effects.

2 Data and methods

The dataset used in this paper was collected from 99 typical comprehensive management watersheds in five water erosion regions in China. Those typical small watersheds were managed with intense implementation of soil and water conservation measures to reach required reduction effects of runoff and sediment. Those typical watersheds were chosen for they were severely eroded and then successfully managed, and their natural conditions were representative of respective water erosion regions. Those comprehensive managements were conducted by local soil and water conversation projects or experimental purposes that required lots of money and efforts. Most projects lasted for more than one year, and some of them even lasted for more than 10 years. The information collected including the area of the watershed, management degree, ERR and ESR. Since some data was derived from literatures, the management degree and ERR or ESR were estimated according to Equations (3), (4) and (5). With available data for every typical watershed, RRE and SRE values were calculated according to Equations (1) and (2). Among those watersheds, twelve watersheds were chosen in Northeastern Black Earthy Hills region (Ⅰ); seven watersheds were located in Heilongjiang Province, one in Jilin Province and four in Liaoning province. Thirty-nine watersheds were chosen in Northwestern Loess Plateau region (Ⅱ); among them one watershed was located in Henan Province, five watersheds located in Inner Mongolia Autonomous Region, seventeen in Shaanxi Province, four in Shanxi Province, and twelve in Gansu Province. Twenty-eight watersheds were chosen in Northern Earthy Rockies region (Ⅲ); among them five watersheds were located in Beijing, one in Tianjin, five in Hebei Province, nine in Shandong Province and eight in Henan Province. Twelve watersheds were chosen in Southern Red Earthy Hills region (Ⅳ); among them two watersheds were located in Hubei Province, one in Hunan Province, two in Jiangxi Province and five in Fujian Province, one in Guangxi Zhuang Autonomous Region and one in Guangdong Province. Eight watersheds were chosen in Southwest Earthy Rockies region (Ⅴ); among them two watersheds were located in Yunnan province, two in Guizhou province and four in Sichuan province. Among those ninety-nine watersheds, ninety watersheds had ERR results and eight-three watersheds had ESR results. Watersheds in Southwest Earthy Rockies region only had ESR results.

To study the zonal differences of runoff and sediment reduction effects between different water erosion regions in China, firstly the 99 watersheds were categorized according to each water erosion region they were located in. And then statistical methods had been applied to examine the differences of RRE and SRE between five water erosion regions.

3 Data analysis

The statistical analysis results based on the information of 99 watersheds in five water erosion regions were illustrated in Table 1. The average management degrees of five water erosion regions were all above 59% during the comprehensive management periods showing that the watersheds in five water erosion regions had relatively high general comprehensive management level. In addition, the average ERR values of five water erosion regions were all larger than 50% and the average ESR values of five water erosion regions were all larger than 71% showing that the watershed comprehensive management in five water erosion regions had great runoff and sediment reduction effects. The average values of RRE and SRE in Northeastern Black Earthy Hills region were 1.15 and 1.31. The average values for RRE and SRE of watersheds in Northwestern Loess Plateau region were 0.98 and 1.33. The average values for RRE and SRE of watersheds in Northern Earthy Rockies region were 0.83 and 1.07. The average values for RRE and SRE of watersheds in Red Earthy Hills region were 0.62 and 0.91. The average values for RRE and SRE of watersheds in Southwest Earthy Rockies region were 1.29. Note that in Fig. 1, for regions Ⅰ, Ⅱ, Ⅲ and Ⅳ whose watersheds had both RRE and SRE values, the mean SRE and values were all larger than mean RRE values respectively. This showed that the main purpose of intensive soil and water conservation management in those typical watersheds were to reduce soil erosion.

Table 1 **Statistical results of typical small watersheds for five water erosion regions**

	Area (km^2)			Management degree(%)			ERR (%)			ESR (%)			RRE			SRE		
	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave
Ⅰ	6.00	111.67	19.09	40.49	88.68	63.78	36.00	96.35	70.29	41.00	96.36	80.00	0.65	1.63	1.15	0.74	2.35	1.31
Ⅱ	0.13	147.00	22.92	24.30	100.00	62.59	19.9	100	58.18	47	100	74.02	0.38	2.47	0.98	0.68	3.09	1.33
Ⅲ	0.12	114.18	28.63	50.00	97.6	73.94	7.15	85.50	56.84	33.30	99.49	77.58	0.15	1.70	0.83	0.46	1.71	1.07
Ⅳ	7.50	114.75	45.58	53.9	100	80.34	25.60	80.00	49.87	18.70	90.00	73.01	0.28	1.27	0.62	0.22	1.58	0.91
Ⅴ	5.70	84.50	26.38	37.35	100	59.60				33.37	97.00	71.74				0.89	2.12	1.29

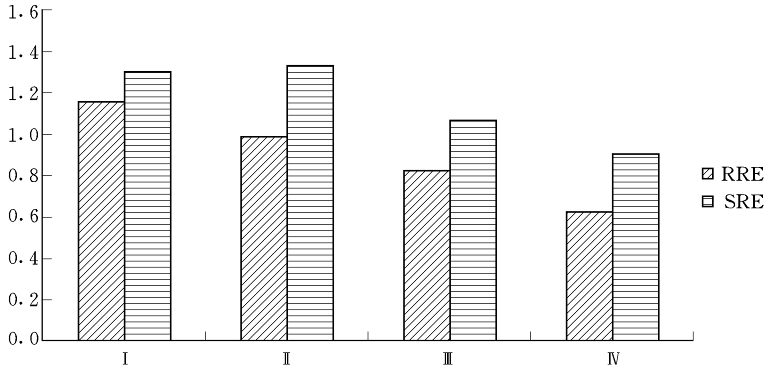


Fig. 1 Contrasting the values of RRE and SRE in four water erosion regions

Before assessing the zonal differences of RRE and SRE for different water erosion regions, RRE and SRE values in different erosion regions should be tested separately to determine their distribution type. Kolmogorov-Smirnov one sample test was applied to check if RRE and SRE were normally distributed in this research. The Null hypothesis is that the sample tested obeys the normal distribution. If the P-value $<\alpha(5\%)$ then the Null hypothesis is invalid, and the opposite hypothesis that the sample is not normally distributed is valid. Table 2 listed the testing results with P-values for each testing samples using SPSS 19. The results demonstrated that all the P-values for tested samples were greater than 5% showing that the probabilities of RRE and SRE values in five water erosion regions were all following the normal distribution were larger than 95%. Thus, the T-test could be validly applied to examine if the mean values of RRE and SRE in five water erosion regions were significantly different. Table 3 listed the P-values of T-test for RRE between four water erosion regions. The difference of RRE between region Ⅰ and Ⅲ was significant at 0.05 significance level. The differences of RRE between region Ⅰ and Ⅳ, region Ⅱ and Ⅳ were also significant at 0.05 significance level. Table 4 listed the P-values of T-test for SRE between five water erosion regions. The differences of SRE between region Ⅰ and Ⅲ, region Ⅳ and Ⅴ were significant at 0.1 confidence level. And the differences of SRE were significant between region Ⅰ and Ⅳ, region Ⅱ and Ⅲ, region Ⅱ and Ⅳ at 0.05 confidence level. Mean values of RRE and SRE for five water erosion regions with 95% confidence level were illustrated in Fig. 2. In Fig. 2(a), the mean values of RRE gradually reduced from region Ⅰ through region Ⅱ and Ⅲ to region Ⅳ showing dramatic zonal differences between those four water erosion regions with the reduction direction from north to south. In Fig. 2(b), mean values of SRE of region Ⅰ, Ⅱ and Ⅴ were not significant different between each other, and mean value of SRE of region Ⅲ and Ⅳ was not significant different from each other either. However, from Fig. 2(b), it was apparent that the difference between regions in the northwestern (Ⅰ, Ⅱ and Ⅴ) and regions (Ⅲ and Ⅳ) in the southeastern was significant. The zonal differences or more specifically, the latitudinal and longitudinal zonality of RRE and SRE would be discussed in next section.

Table 2 Kolmogorov-Smirnov test for RRE and SRE of different water erosions region

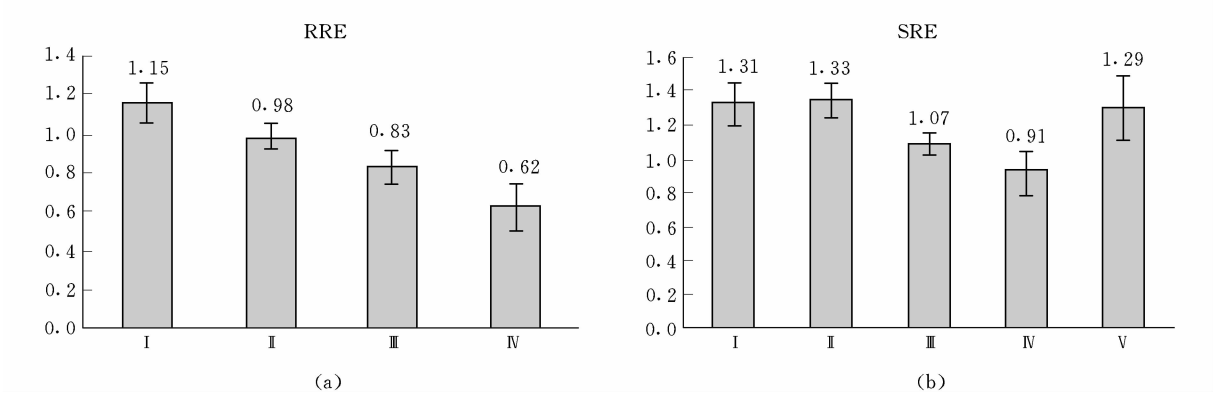
Region	Ⅰ		Ⅱ		Ⅲ		Ⅳ		Ⅴ
P-value	RRE	SRE	RRE	SRE	RRE	SRE	RRE	SRE	SRE
	0.999	0.722	0.397	0.284	0.546	0.943	0.864	0.737	0.616

Table 3 T-test for RRE of five water erosion regions

P-value	Ⅰ	Ⅱ	Ⅲ	Ⅳ
Ⅰ	1			
Ⅱ	0.132	1		
Ⅲ	0.012	0.120	1	
Ⅳ	0.001	0.006	0.128	1

Table 4 T-test for SRE of five water erosion regions

P-value	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ
Ⅰ	1				
Ⅱ	0.850	1			
Ⅲ	0.088	0.024	1		
Ⅳ	0.025	0.010	0.237	1	
Ⅴ	0.925	0.802	0.223	0.071	1



(a) (b)

Fig. 2 Mean RRE and SRE values with 95% confidence level for five water erosion regions

4 Discussion

After the statistical analysis on zonal differences of RRE and SRE in above section, the existence of zonality of RRE and SRE could be verified. However, the zonality was not explicit and the reason of zonality of RRE and SRE was also unknown. Equations (8) and (9) in the introduction section of this paper revealed that RRE was a function of runoff depth (H) and SRE was a function of specific sediment yield (Y). And Xu (1994) and (1995) studied the zonality of H and Y across the areas controlled by East Asian Monsoon in China. So, the zonality of H and Y should have certain relationships with zonality of RRE and SRE.

In this study, 90 watersheds with RRE values scattering in four water erosion regions were chosen firstly. And then all the RRE values were classified with the same interval based on the latitude of each watershed and then the mean values for each class were calculated. Mean H values derived from Xu (1995) for the same latitude classes and mean RRE values were plotted against latitude in Fig. 3(a). With the increase of latitude, H reduced while RRE increased. The inverse tendencies between RRE and H could be expected since RRE was positive correlated with the reciprocal of *H* in Equation(8). In addition, 41 watersheds with RRE values distributed along the belt with the direction from southeast to northwest were chosen to study the variations of RRE and *H* with the change of longitude. With the same method mentioned above, RRE values were classified with equal interval based on the longitude of each watershed and the mean values for each class was calculated. Again, mean *H* values with the same classification derived from Xu(1984) and RRE values had been plotted against longitude in Fig. 3(b). With the increase of longitude, *H* increased while RRE decreased. Fig. 3(a) and (b) verified the existence of zonality of RRE. Generally speaking, RRE had its low values at low latitude and high longitude regions and high values at high latitude and low longitude regions.

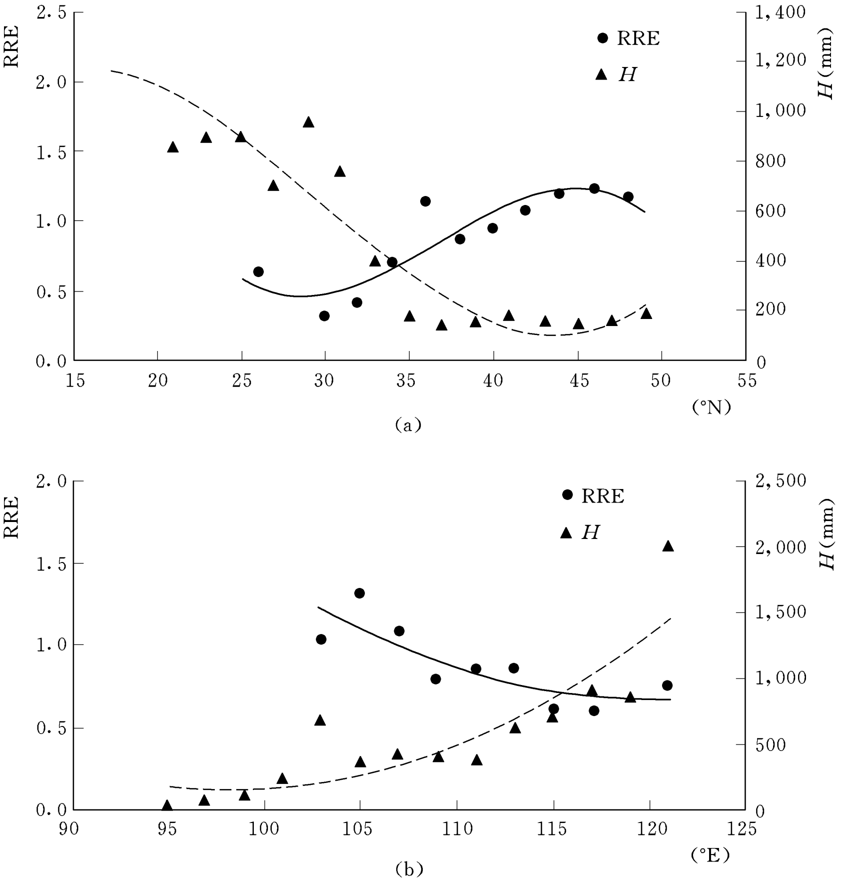


Fig. 3 Variation of RRE with *H* in latitude direction(a). Variation of RRE with *H* in longitude direction(b)

83 watersheds with SRE values distributed in five water erosion regions were chosen to study the variation of SRE with changing of latitude. After classification based on latitude of each watershed the mean SRE values were calculated for each class. Then the mean SRE values and mean *Y* values for each latitude class derived from Xu (1994) were plotted against latitude in Fig. 4(a). With the increase of latitude, *Y* increased gradually with mild slope at first and then a peak suddenly occurred around 35° to 37°N. After that, *Y* decreased dramatically with a steep slope; meanwhile, SRE generally followed the same trend with *Y*, however the peak was not sharp and the values at high latitude were apparently larger than the values at low latitude. Moreover, 35 watersheds with SRE values distributed along the belt with the direction from southeast to northwest were chosen to study the variations of SRE and *Y* with the change of longitude. After classification of SRE based on longitude of each watershed, the calculated mean SRE values for each class were plotted against longitude with the mean *Y* values for the same longitude class in Fig. 4(b). With the increase of longitude, *Y* increased with a mild tail at lower longitude firstly and then rose rapidly reaching the peak around 107°E, and decrease dramatically with a mild tail at higher longitude; at the same time, SRE generally followed the same variation as *Y*, however there was a upwarp at the higher latitude. To sum up, Fig. 4(a) and (b) verified the existence of zonality of SRE. Overall, SRE had its low values at low latitude and high longitude regions and had its high values at middle latitude and middle longitude regions which were located at loss plateau areas.

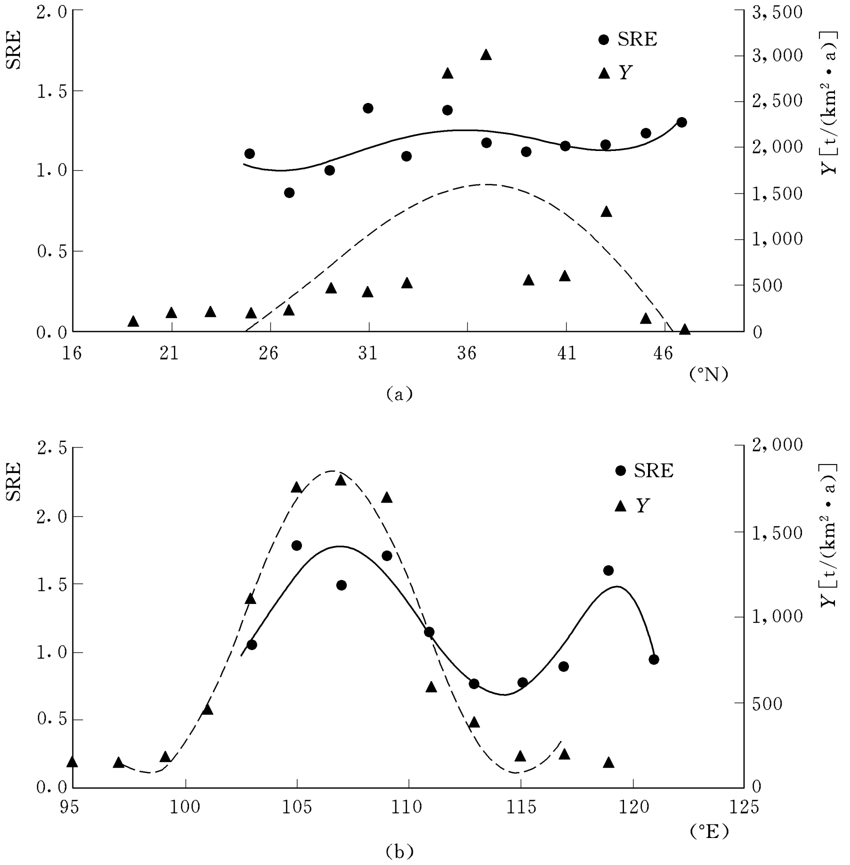


Fig. 4 Variation of SRE with *Y* in latitude direction (a). Variation of SRE with *Y* in longitude direction (b)

The RRR and SRR values were calculated according to Equations (10) and (11) for every typical watershed used in this study. To reveal the relations between RRR, *H* and RRE with change of latitude, those three variables of 90 watersheds in four water erosion regions were classified separately following the same procedure mentioned above. Next, mean values for each class of RRR, *H* and RRE were plotted against latitude in Fig. 5(a). With the increase of latitude, *H* decreased rapidly from low latitude regions to high latitude regions reaching the curve bottom between 40°−45 °N, and then it began to rise with mild slope at higher latitude regions. RRR curve had the same variation trend with *H*, but with milder changing rate and the curve bottom was located around 40°N which was closer to low latitude regions than that of *H*. Note that there was an intersection point of RRR and *H* curves located around 41°N. In regions of latitude lower than this critical point, *H* was greater than RRR, however, RRR was greater than *H* in regions of latitude higher than critical point. In other words, the amount of runoff depth reduced by management on unit controlled area was greater than the runoff depth on unit watershed area in regions of latitude higher than the critical point. Actually, this critical point should be located around 37°N for this was where the first *H* value began to be lower than RRR value. And most importantly, from 37°N to higher latitude the variation of RRR became stable. Using the same dataset and procedure mentioned above, mean values of each class of RRR, *H* and RRE were plotted against longitude in Fig. 5(b). The curve of *H* decreased mildly from low longitude regions at first and then reached the curve bottom around 110°E. After that, it increased rapidly with relatively high gradient. The RRR curve had the similar variation trend but with relatively larger gradient at low longitude regions and lower gradient at high longitude regions. Note that, a critical point occurred too in Fig. 5(b) around 109°E. In regions of longitude higher than this critical point, *H* was greater than RRR, however RRR was greater than *H* in regions of latitude lower than the critical point. As stated above, there was a critical zone existing where the amount of runoff depth reduced by management per unit controlled area was equal to the runoff depth per unit watershed area. Actually, the critical point (37°N, 109°E) in two dimension space was located right in Loess Plateau region. Generally, the mean RRR values in low latitude and high longitude regions were greater than those in high latitude and low longitude regions from Fig. 5(a) and (b). However, the mean RRR values in low latitude and high longi-

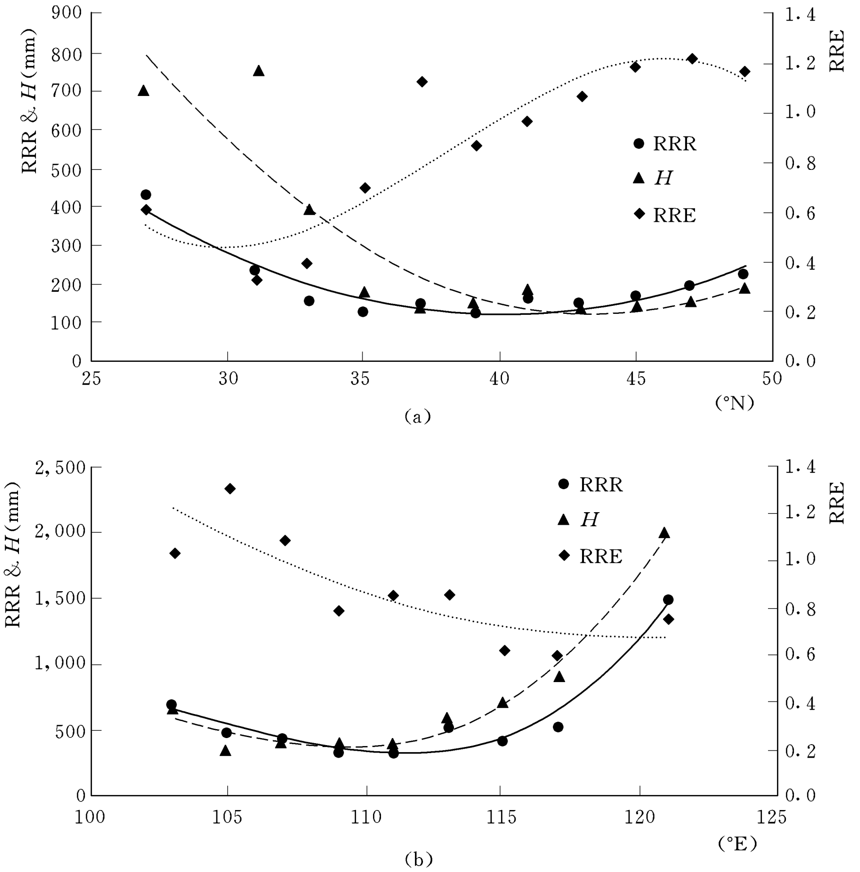


Fig. 5 Variation of RRR with RRE and *H* in latitude direction (a). Variation of RRR with RRE and *H* in longitude direction (b)

tude regions were much less than *H* with RRE less than one, while the mean RRR values in high latitude and low longitude regions were equal or greater than *H* with RRE greater than one. In other words, RRE could be regarded as an index reflecting the relative magnitude of RRR and *H*. If RRE was greater than one, then it was meaning that runoff depth reduced by management per unit controlled area was larger than the runoff depth per unit watershed area. Although mean RRE values in high latitude and low longitude regions were greater than one, but the average RRR values in these regions were less than those in low latitude and high longitude regions. It is worth noting that RRE was not representing the absolute value of runoff reduction amount and should not be confused with RRR. In conclusion, Fig. 5(a) and (b) verified the zonality of RRR and this should be expected since it was the function of RRE and H. Xu (1995) demonstrated that rainfall and runoff were positively related and spatial distribution of rainfall was the determining factor for the zonality of runoff depth in China. Moreover, the rainfall distribution was further influenced by the East Asian monsoon and the special landform in China. Thus, the zonality of RRE and RRR should be explained by the combined influence of climate and topography in China.

To reveal the relations between SRR, *Y* and SRE with changing latitude, those three variables of 83 watersheds in five water erosion regions were classified separately following the same procedure mentioned above. And then, mean values for each class of SRR, *Y* and SRE were plotted against latitude in Fig. 6(a). The curve of *Y* gradually rose until reached its peak around 36°N, and then decreased gradually to the end. SRR curve followed the similar variation manner, but with greater value than that of *Y*. The difference between those two curves reached it biggest value at the peaks of both *Y* and SRR curves. This phenomenon demonstrated that the reduction of sediment yield per unit controlling area was always greater than the sediment yield per unit watershed area in most of the regions and the difference between those two values had its maximum value around 36°N. Using the same dataset and procedure mentioned above, mean values of each class of SRR, *Y* and SRE were plotted against longitude in Fig. 6 (b). *Y* curve rose rapidly at first reaching its peak around 106°E, and then decreased gradually ending with an asymptotic line at higher longitude regions. The curve of SRR had the similar variation trend and shared with *Y* curve the same location of its peak. Note that, the largest difference between those two curves occurred at the

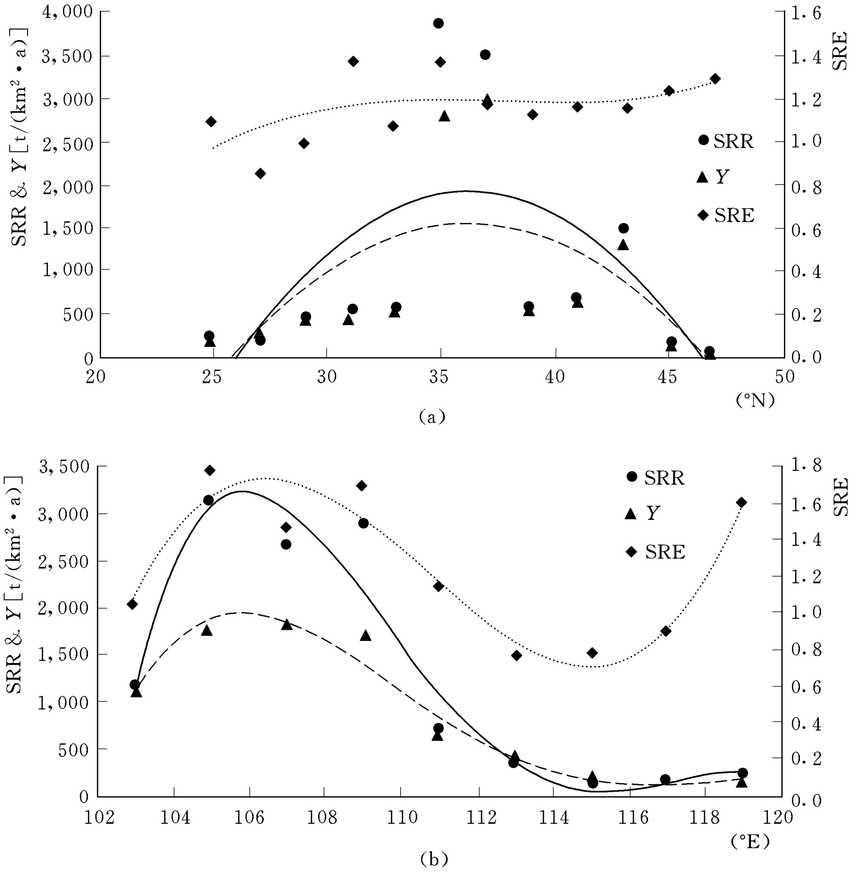


Fig. 6 Variation of SRR with SRE and Y in latitude direction(a). Variation of SRR with SRE and Y in longitude direction(b)

peaks. In other words, for most of the regions, the reduction of sediment yield per unit controlling area was greater than the sediment yield per unit watershed area and the difference between those two values had its maximum value around 106°E. In particular, the variations of SRR, Y and SRE curves in Fig. 6(a) were more dramatic than those in Fig. 6(b). This was due to the calculation of mean values for SRR, Y and SRE in the same latitude classes were accounting for all SRR, Y and SRE values within wide range of longitudes. The average effects made the curves in Fig. 6(a) not as obvious as in Fig. 6(b). In spite of that, the peaks for curves SRR and Y were still distinct. Actually, the SRE curves in Fig. 6(a) and(b) had its peaks where SRR and Y had their largest differences. In addition, when SRR was equal to Y, which indicated in the figures by the intersections of the two curves, SRE was equal to one. Interestingly noticed that the point(36°N, 106°E) where largest differences between SRR and Y occurred in Fig. 6(a) and(b) was very close to the(37°N, 109°E) where RRR began to be equal to H in Fig. 5(a) and(b). Both points were located in Loess Plateau region. In conclusion, Fig. 6(a) and(b) verified the zonality of SRR. Xu(1994) discussed that the tension between erosion agents such as rainfall and rainfall variability and resistance agents such as forest cover ratio and composition materials of the soil surface determined the zonality of specific sediment yield in China. Thus, the zonality of SRE and SRR should be explained by the combined influence of climate and topography conditions in China.

5 Conclusion

In this paper, runoff and sediment reduction effects by soil and water conservation measures for 99 typical managed small watersheds distributed in five water erosion regions in China have been studied. To examine the zonal differences of runoff and sediment reduction effects between different water erosion regions, two new indexes Runoff Reduction Efficiency(RRE) and Sediment Reduction Efficiency(SRE) were introduced. Firstly, Statistical analysis was applied to test the zonal differences of RRE and SRE between different water erosion regions. The results showed that the mean RRE values in northern regions were generally greater those of southern regions; and the mean SRE values in northern regions were generally greater than those in southern regions.

Next, the variation of RRE and unit management area Runoff Reduction Rate (RRR) with runoff depth (H) was studied in direction of both latitude and longitude across regions influenced by East Asian Monsoon. Meanwhile, the zonality of SRE and unit management area Sediment Reduction Rate (SRR) with specific sediment yield (Y) was studied in direction of both latitude and longitude across regions influenced by East Asian Monsoon. The results showed that RRE had the inverse variation trend as H in both latitude and longitude direction and SRE had the same variation trend as Y in both latitude and longitude direction. It was found that RRR had the similar variation trend as H in latitude direction and there was critical point around 37°N greater than which RRR began to be equal to H or even greater; RRR had the similar variation trend as H in longitude direction and there was a critical point around 109°E less than which RRR began to equal to or greater than H; SRR had the similar variation trend as Y in latitude direction and there was critical point around 36°N greater than which SRR began to be equal to Y or even greater; SRR had the similar variation trend as Y in longitude direction and there was a critical point around 106°E less than which SRR began to equal to or greater than Y. The zonality of RRE, RRR, SRE and SRR was result of combined influence of climate variation and special landform in regions controlled by East Asian Monsoon in China.

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