May 8, 2017

Memorandum

To: Pro. Nunzio Romano, Editor of *Hydrology and Earth System Sciences*

Subject: Revision of hess-2016-654

Dear Pro. Nunzio Romano:

We have carefully addressed all the comments made by the two anonymous reviewers on our manuscript hess-2016-654 entitled "Spatio-temporal patterns of the effects of precipitation variability and land use/cover changes on long-term changes in sediment yield in the Loess Plateau, China". The comments have helped us improve the overall quality of the manuscript. The following is the point-point response to all the comments.

Response to Anonymous Referee #1:

General comments:

The authors investigated the effects of precipitation variability and land use/cover changes (LUCC) on sediment yield in the Loess Plateau (LP), China. The author presents a detailed examination of the relationship between precipitation/LUCC and sediment yield in different catchments in the middle part of the LP during three periods. However, there are quite a few issues in this manuscript, hence I suggest some major revisions.

Reply: *All the issues have been carefully considered and modifications have been done accordingly (see the following point-to-point replies to the comments).*

My major concerns are:

1. Comment:

About the linear regression model for attribution analysis, nearly half of the catchments do not show statistically significant relationship between precipitation and sediment load during the reference period (Table 3). Therefore, it is very questionable to apply these linear regression models to the validation period for detecting the precipitation-induced (or LUCC-induced) sediment load change.

Reply: *We have changed the linear regression model (SSY=aP+b) for attribution analysis. Rustomji et al. (2008, Water Resources Research, 44, W00A04, doi:10.1029/2007WR006656) found that the square root of sediment yield could be linearly fitted well with the precipitation in the catchments of the Loess Plateau, which was used in this study to develop precipitation-sediment yield relationship during the reference period:*

$$\sqrt{SSY} = aP + b \quad (1)$$

Within this new regression model, the sediment yield was correlated with precipitation at 0.05 level in twelve catchments and 0.1 level in eleven catchments, and the R^2 value also improved much compared to the original linear regression model (see Table 1). Therefore, this new regression model was satisfactory to detect the precipitation-induced (or LUCC-induced) sediment load change.

Table 1. The linear regression equations between square root of specific sediment yield and annual precipitation ($\sqrt{SSY} = aP + b$) during the reference period (1961-1969).

ID	Catchment	Regression equation	R^2	p
1	Huangfu	$y = 0.341x+12.041$	0.78	0.002
2	Gushan	$y = 0.349x+8.237$	0.84	0.001
3	Kuye	$y = 0.323x+9.939$	0.67	0.007
4	Tuwei	$y = 0.218x+12.635$	0.87	0.000
5	Jialu	$y = 0.382x+6.976$	0.78	0.004
6	Wuding	$y = 0.174x+20.544$	0.53	0.027
7	Qingjian	$y = 0.232x+20.923$	0.48	0.040
8	Yanhe	$y = 0.243x+0.741$	0.39	0.070
9	Shiwang	$y = 0.070x+10.935$	0.27	0.150
10	Qiushui	$y = 0.257x+30.738$	0.60	0.014
11	Sanchuan	$y = 0.191x+15.053$	0.36	0.089
12	Quchan	$y = 0.202x+34.590$	0.72	0.016
13	Xinshui	$y = 0.202x-6.593$	0.71	0.004
14	Zhouchuan	$y = 0.207x+20.226$	0.33	0.090
15	CSHC	$y = 0.218x+5.689$	0.70	0.005

2. Comment:

Even though this is just a "preliminary" study, as the author mentioned, I do not feel it is a complete work presented in this manuscript. There is a need for further discussion or analysis at some places. If the focus of this paper is on both spatial and temporal pattern of precipitation/LUCC-sediment relationships, there is lack of discussion on possible reasons for the spatial variability. Also, is it possible to investigate the effect of intra-annual variability of precipitation (or precipitation extremes) on sediment load since the authors have noted the effect is important (L328-330; L369-385)? Additionally, what are equation 6 and 7 for?

Reply: *This is a good comment.*

First, we have showed the spatial distribution of catchment characteristics (including precipitation, soil, slope, LAI and LUCC), which are the possible reasons for the spatial variability of precipitation/LUCC-sediment relationships (see Figs. 1-3). The precipitation/LUCC-sediment relationships were also presented in maps to indicate spatial pattern rather than grouped scatter plots used in the original version (see Figs. 4-5).

Second, we have compared the precipitation/LUCC-sediment relationships in different parts of the study area, and discussed the effects of catchment characteristics on the variability of relationships among catchments. We have also investigated the effects of potential factors (precipitation, percentage area of forestland, grassland, construction land, terracing and check-dams, and LAI) on sediment yield change in different stages. It was found that check-dam construction was the dominant factor for sediment yield reduction from reference period to period-2, and pasture plantation and check-dam construction acted the dominant factors for sediment yield from reference period to period-3 (see Table 2). The increase of precipitation mitigated the reduction of sediment yield to some degree from period-2 to period-3 (see Table 2).

Third, for the effect of intra-annual variability of precipitation (or precipitation extremes) on sediment load, we have investigated the correlation between sediment yield and storm events (including storm numbers, precipitation amount of storms) in the study area during different decades. The analysis showed that the sediment yield was significantly correlated with storm numbers in 1960s, 1970s and 1980s ($p<0.05$), and precipitation amount of storms in 1960s and 1970s ($p<0.05$) (see Table 3). This result indicated the critical role of storm events in sediment yield, especially during the periods before substantial LUCC took effect. Furthermore, we have chosen a catchment as an example and compared the within-year rainfall pattern and sediment load in nearby two years (see Fig. 6). The comparison also indicated the important role of distribution of storm events in sediment yield.

Fourth, we have deleted equations 6 and 7 which are somewhat misleading, and reframed the analysis about the spatio-temporal patterns of the impacts of precipitation and LUCC on sediment yield. We divided the study period into three stages including reference period and validation periods (period-2 and period-3). We used the maps to show the spatial distribution of precipitation-sediment relationships in the three stages and investigated the reason for the spatial-temporal variability (see Figs. 4-5). In the reference period before LUCC took effect, the variation of SSY mainly depends on precipitation, and any spatial patterns of SSY among catchments was controlled by differences in annual precipitation and land surface conditions. During the validation period (period-2 and period-3) with LUCC increased and took effect, the temporal changes of SSY depend more on the fraction of treated surface area and precipitation played a secondary role. The spatial pattern of the impacts of precipitation on sediment yield was dependent on the landscape properties among catchments, and it changed considerably especially in period-3 as the combined effects of engineering measures and vegetation restoration project.

Finally, it should be noted that the focus of this study is to present the spatio-temporal patterns of effects of precipitation variability and LUCC on long-term changes in sediment yield, and it is a "preliminary" study to investigate the detailed effects of intra-annual variability of precipitation and catchment characteristics on sediment yield, which need more detailed processes-based studies on fine scales. This is the next immediate step in our investigations.

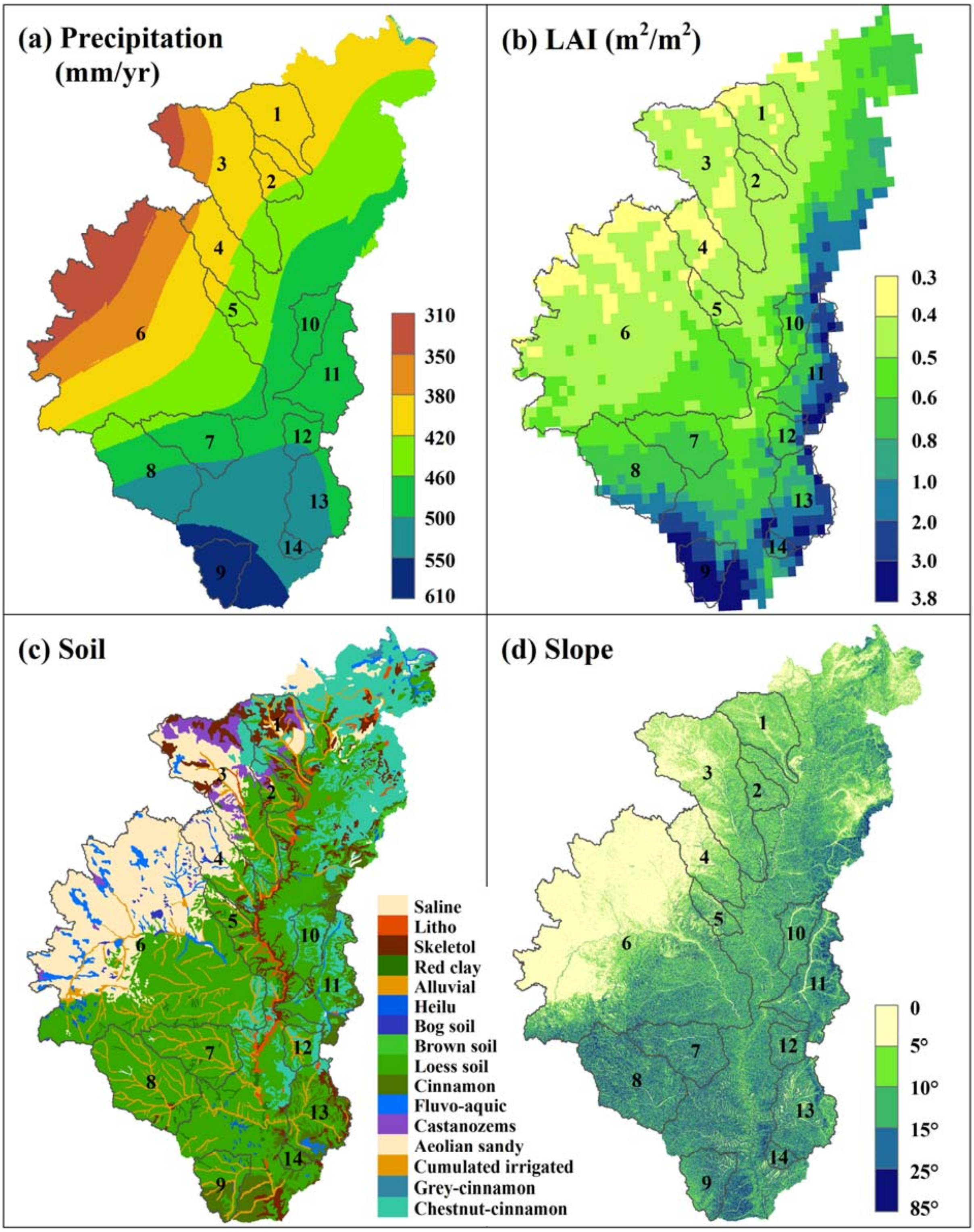

Figure 1. Spatial distribution of (a) annual mean precipitation (1961-2011), (b) growing season leaf area index (LAI, 1982-2011), (c) soil type and (d) slope in the study area.

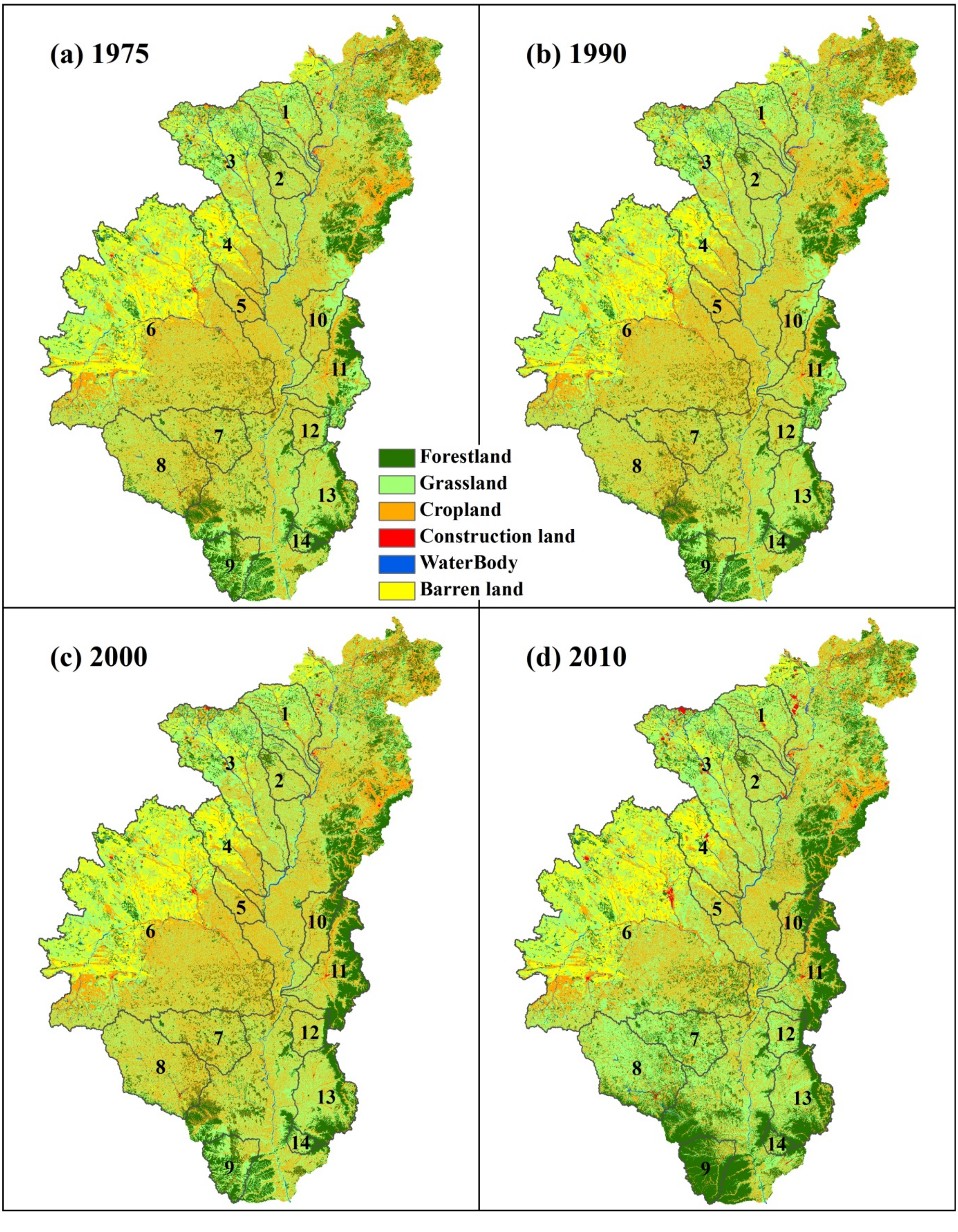

Figure 2. Land use and cover of the study area in (a) 1975, (b) 1990, (c) 2000 and (d) 2010.

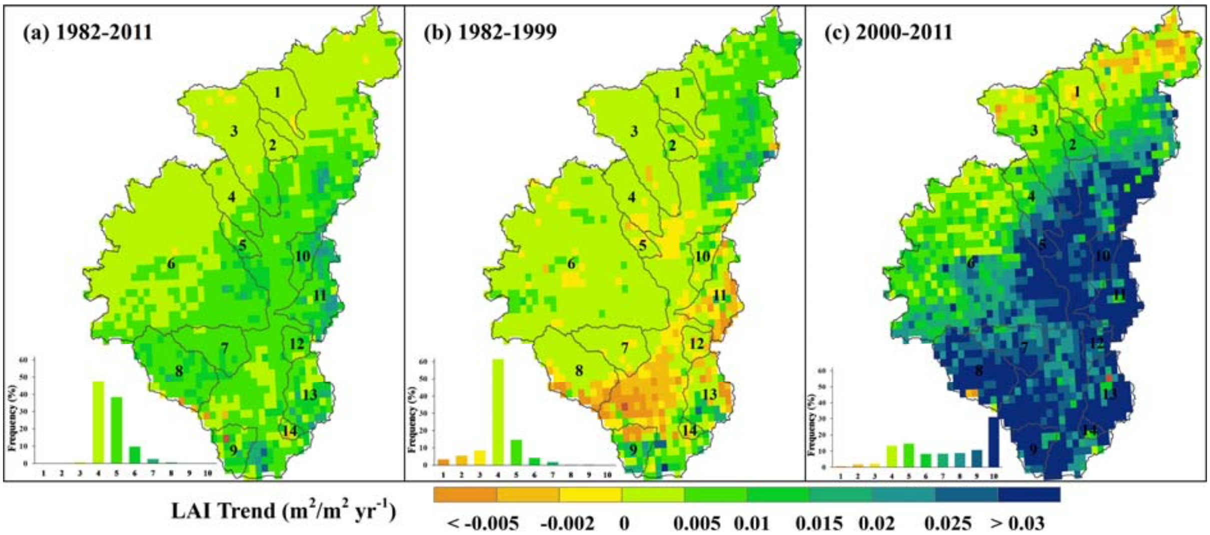

Figure 3. Long-term trends in growing season LAI changes over (a) 1982-2011, (b) 1982-1999 and (c) 2000-2011 in the study area. Inset in each figure shows the frequency distribution of the LAI trends.

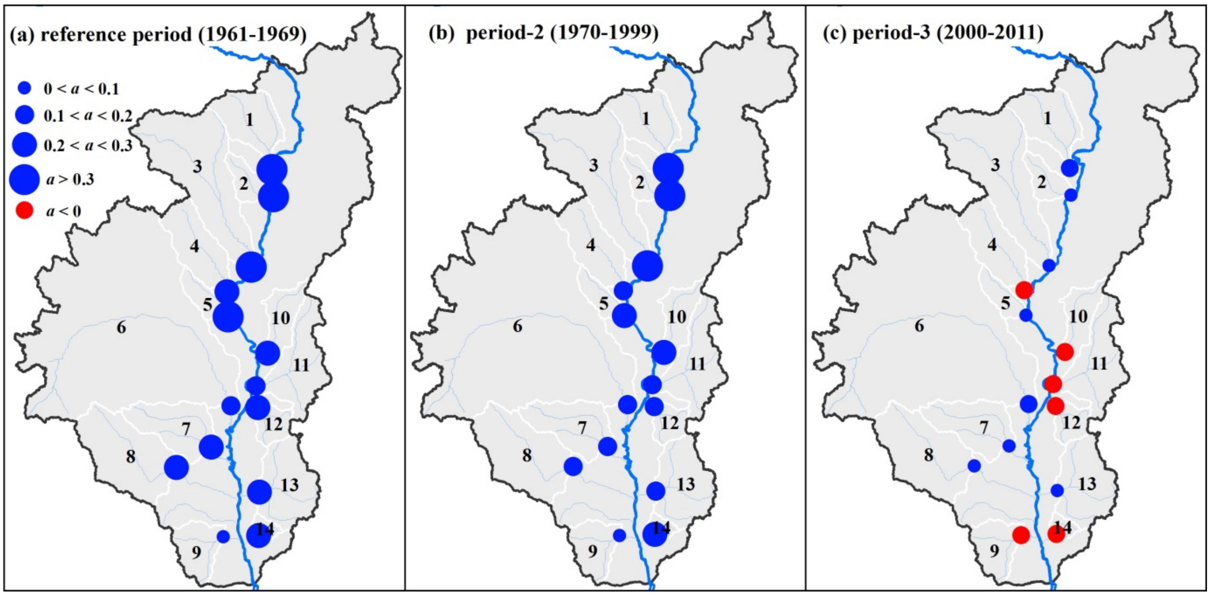

Figure 4. Spatial distribution of slope *a* in the regression equation $\sqrt{SSY} = aP + b$ during (a) reference period (1961-1969), (b) period-2 (1970-1999) and (c) period-3 (2000-2011). *SSY* is specific sediment yield, and *P* is precipitation.

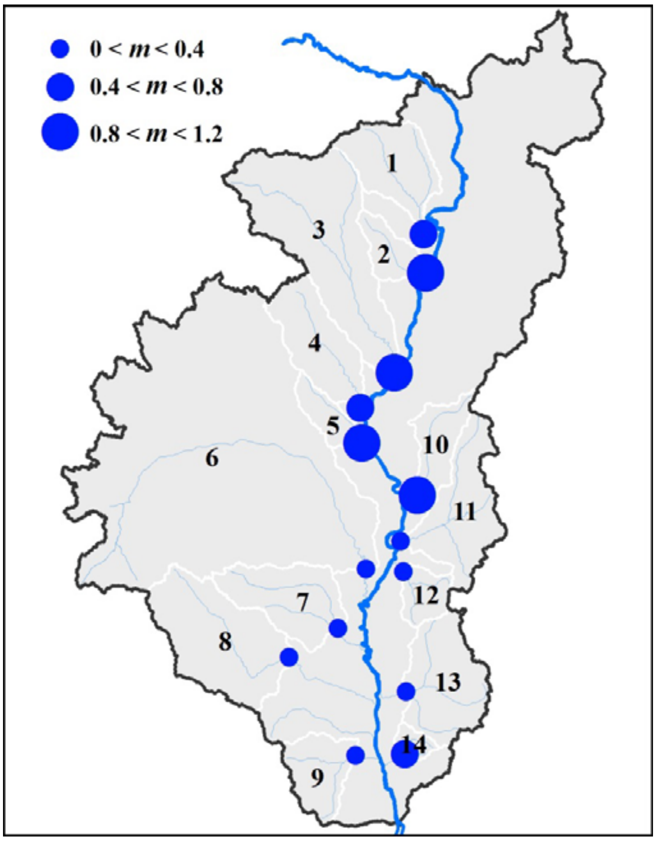

Figure 5. Spatial distribution of slope *m* in the regression equation $\overline{SC} = -mA_c + n$. $\overline{SC}$ is the decadal average sediment coefficient, and A_c is the fraction area treated with soil and water conservation measures.

Table 2. The regression models for sediment yield change (Δ*SSY*) in different stages.

Period	Regression model	R^2	*p*
Reference period vs. Period-2	ΔSSY=-0.135-0.850 ×ΔDam	0.886	0.000
Reference period vs. Period-3	ΔSSY=-0.067-0.659 ×ΔDam-0.081 ×ΔPasture	0.928	0.023
Period-2 vs. Period-3	ΔSSY=-0.105-0.488 ×ΔDam+0.058×ΔP-0.129 ×ΔPasture	0.905	0.003

ΔDam and ΔPasture are changes in percentage area of check-dams and pasture plantation, respectively. ΔP is changes of annual precipitation over the two compared periods.

Table 3. Pearson correlation coefficients (*r*) and two-tailed significance test values (*p*) between sediment yield and annual precipitation (*P*), number of storms (N_{storm}) and precipitation amount of storms (P_{storm}) during different decades of the CSHC region.

Decades	*P*		N_{storm}		P_{storm}	
	r	*p*	*r*	*p*	*r*	*p*
1960s	0.772	0.015*	0.808	0.008**	0.718	0.029*
1970s	0.266	0.458	0.714	0.020*	0.695	0.026*
1980s	0.775	0.009**	0.633	0.050*	0.527	0.117
1990s	0.865	0.001***	0.591	0.072	0.572	0.084
2000s	0.118	0.715	0.006	0.986	0.138	0.669

***, ** and * indicate the significance levels of 0.001, 0.01 and 0.05, respectively.

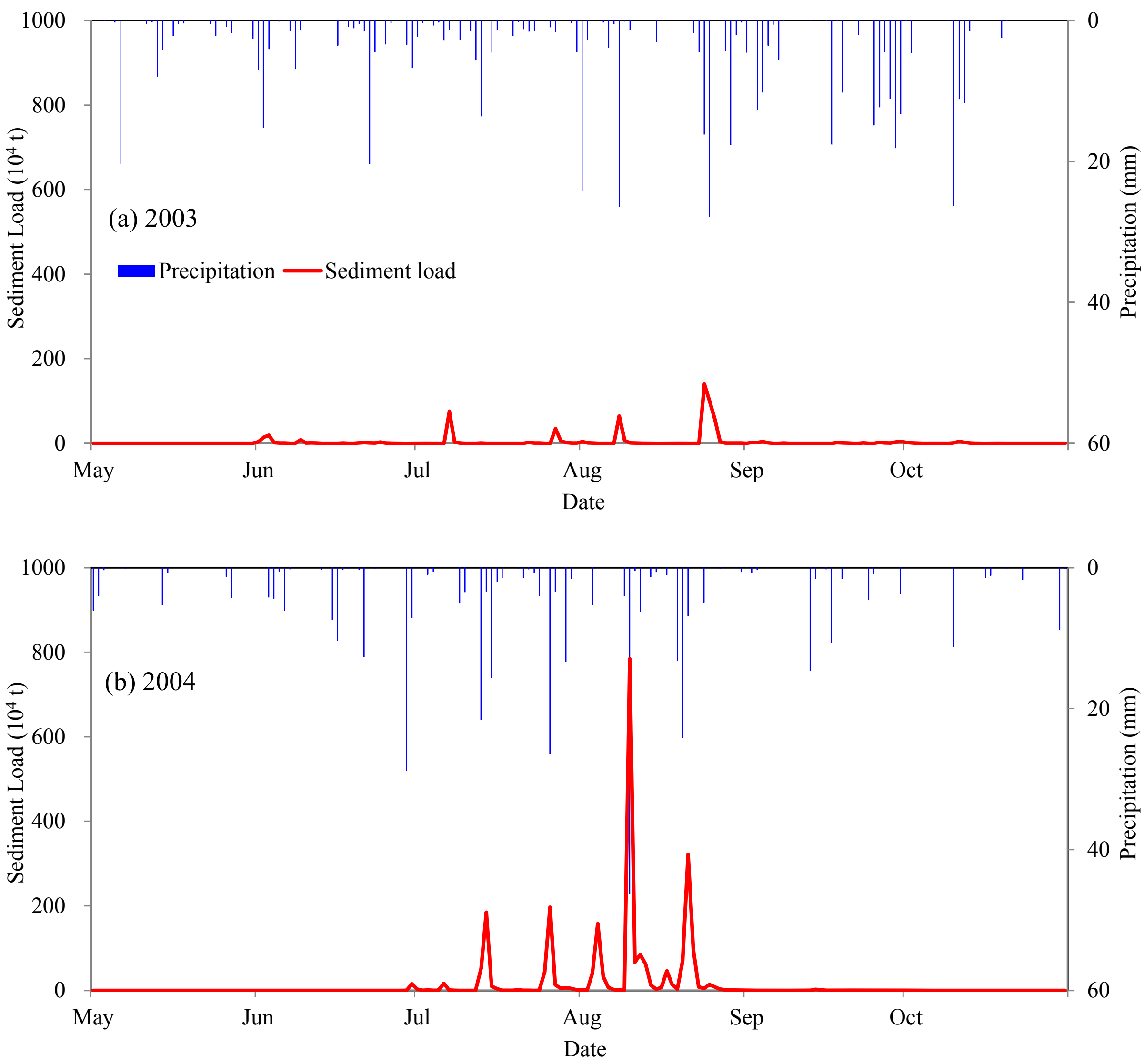

Figure 6. Daily precipitation and sediment load of the Yanhe catchment during rainy season (May-October) in (a) 2003 and (b) 2004.

3. Comment:

As the spatial pattern is the focus in section 3.4-3.6, I suggest to present the precipitation/LUCC-sediment relationships in maps rather than grouped scatter plots.

Reply: *This is a good suggestion. We have used maps to present the spatial pattern of the precipitation/LUCC-sediment relationships (see Figs 4-5).*

Specific comments:

1. Comment:

P1, L22-23: Is the "70%" and "30%" a part of the conclusion in this study? If yes, I didn't see any of them in the results (section 3.3). Figure 5 does not support this statement either. If not, where are the numbers from? It would be better to also include it in the introduction.

Reply: *The attribution analysis indicated that the contribution of LUCC to sediment load was 74.39% from the reference period to period-2, and it was 88.67% from the reference period to period-3. Therefore, it can be considered that "The human induced land use/cover change (LUCC) was the dominant factor with contributing over 70% of the sediment load reduction, whereas the contribution of precipitation was less than 30%".*

2. Comment:

P5, L106: The introduction above is mainly about the whole TP, why is only the middle part of LP investigated?

Reply: *Most of sediment yield of the LP was produced in the Coarse Sandy Hilly Catchments (CSHC) region in the central region of the LP, which supplied over 70% of total sediment load in the YR, especially coarse sand. The CSHC region was the focus to investigate the variation of sediment load in the LP.*

3. Comment:

P6, L129: Any reference?

Reply: *These two percentages were determined with the observed hydrological data during 1961-2011 by us.*

4. Comment:

P7, L139-140: It would be better to describe the data first, then show the figure.

Reply: *We have described the changes of annual precipitation, streamflow and sediment load of the CSHC region with the data first, and then showed the figure.*

5. Comment:

P7, L146-150: The whole sentence is a little bit confusing. SSY, SC, and Cs were estimated based on P, Q, and A?

Reply: *We have rephrased this sentence. The SSY, SC and* C_s was estimated based on the observed P, Q, S and A ($SSY=S/A$, $SC=S/(Q.A)$, $C_s=SSY/P$).

6. Comment:

P8, L158: What does vegetation cover mean? The vegetation fraction in each grid cell?

Reply: *The LAI was used in this study to indicate vegetation cover.*

7. Comment:

P13, L287-301: I am very confused that the authors proposed this "framework" but didn't show any results of it. What is its purpose here?

Reply: *We have reframed the analysis about the spatio-temporal patterns of precipitation and LUCC impacts on sediment yield. Please see the fourth point of the response to #2 main comment.*

8. Comment:

P15, L313-316: It would be better to describe the grouping at the beginning of this paragraph.

Reply: *We have described the spatial distribution and grouping of the precipitation-sediment yield relationships at the beginning of the paragraph.*

9. Comment:

P17, L355-356: Does this indicate that the precipitation-sediment relationship gets stronger in some regions but weaker in some other regions? Is the strengthened (or weakened) relationship related to the SWCM or vegetation change in these catchments?

Reply: *We have deleted this misleading sentence. In period-3, as a result of the combined effects of SWCM and vegetation restoration project, the precipitation-sediment relationship became much weaker in all the catchments, and slope of the regression equation decreased sharply in all the catchments, especially for some catchments the slope was even negative (see Fig. 5). Furthermore, the spatial pattern of precipitation-sediment relationship had somewhat change compared to that in the reference period and period-2.*

10. Comment:

P20, L425: The same issue as (P13, L287-301). What is k0 and k1?

Reply: *We have deleted this misleading equation and the related statements.*

Response to Anonymous Referee #2:

1. Comment:

The author's attempt to determine the drivers of changes in sediment yield within the Coarse Sandy Hill Catchments region of the Loess Plateau. The authors attribute changes in sediment yield to both land-use change and changes in precipitation. Although the authors do a great job characterizing changes in precipitation, land cover, and sediment yield, their statistical analysis leaves much room for improvement and many of their figures could be clarified.

Reply: *We have improved the statistical analysis (see response to the main comment #1 of reviewer #1), clarified many figures in map not in bar graphs or scatter plots (see Figs. 1-5), and addressed all the following comments.*

2. Comment:

While land-use change (specifically crop to forest) and precipitation change are certainly major drivers in changes in sediment yield, soil properties, topography, and changes in urban cover must also play some role, and thus warrant some discussion as to their exclusions, or what excluding them might mean for the paper's results. Moreover, as the author's bring up, the intensity of certain storms are not always captured when one looks at annual average precipitation, but these intense storm greatly affect sediment yield. Thus, analyzing the number of intense events along with average precipitation may prove insightful.

Reply: *We have investigated the possible effects of catch characteristics (soil, slope, LUCC and LAI) on the changes of sediment yield (see the second point of the response to #2 main comment of reviewer*

#1). We have also investigated the effects of storm events on sediment yield and (see the third point of the response to #2 main comment of reviewer #1).

3. Comment:

Lines 35-36. The effect of precipitation is also temporally variable, yet it is framed in the abstract and throughout most of the paper as only being spatially variable.

Reply: *Yes, the effect of precipitation was both temporally and spatially variable. We have reframed the analysis about the spatio-temporal patterns of precipitation impacts on sediment yield (see the fourth point of the response to #2 main comment of reviewer #1).*

4. Comment:

Lines 144-145. Although the author's provided a robust motivation for their analysis of the their 14 chosen catchments within the CSHC, a sentence or two explaining why they are studying the CSHC would be useful.

Reply: *We have explained the reason for focusing on the CSHC region in this study (see the response to #2 specific comment of reviewer #1).*

5. Comment:

Line 179. Why resample the AVHRR data?

Reply: *We have changed the data source of LAI data. LAI was derived from the Global Land Surface Satellite (GLASS) NDVI series with spatial resolution of 1 km.*

6. Comment:

Lines 179-185. What is meant by vegetation cover? Do the authors estimate vegetation cover using NDVI or a different vegetative index?

Reply: *The LAI was used in this study to indicate vegetation cover.*

7. Comment:

Lines 183-185. It seems as though the authors have useful spatial information regarding the total areas impacted by conservation measures (the Yao et al. 2011) dataset, yet it's unclear where this comes into play in their analysis.

Reply: *We only had the total area of conservation measures, not the spatial information. It is necessary to obtained them with field survey and high-resolution satellite data, and investigate the detailed effects of conservation measures on streamflow and sediment yield.*

8. Comment:

Lines 192-194. Did you test your variables after performing the TFPW to see if any residual autocorrelation remained?

Reply: *There was no residual autocorrelation remained after performing the TFPW.*

9. Comment:

Lines 220-226. What was the land-cover during the study period which the authors consider their reference period where "the effects of human activities were slight and could be mostly ignored." Here and throughout, presenting the spatial data as maps rather than bar graphs or scatter plots will more clearly to the audience. Especially given in the results and discussion where the authors often reference the differences in spatial patterns.

Reply: *The land use and cover in 1975, 1990, 2000 and 2010 was shown in this study, and the land use in 1975 was thought to be the substitute during the reference period (see Fig. 2). We have presented the spatial data including the catchment characteristics (see Figs. 1-3) and the precipitation/LUCC-sediment relationships (see Figs. 4-5) as maps.*

<u>10. Comment:</u>

Line 254. As mentioned above, need to be clear about the proxy used for vegetation cover.

Reply: *The LAI was used as the proxy for vegetation cover.*

<u>11. Comment:</u>

Line 260, 263. Average annual LAI?

Reply: *The growing season (April-October) LAI was used as nearly all the sediment yielded during this period.*

<u>12. Comment:</u>

Line 278-288. Why use the coefficient of variation and not standard deviation? What do these results tell us?

Reply: *The coefficient of variation is equal to the ratio of standard deviation and average value, and it is better to compare the inter-annual variability of precipitation, streamflow and sediment load among the catchments with distinct different average value. The results indicated that both the annual value and variability of precipitation decreased, and the annual value of streamflow and sediment load decreased significantly, whereas their inter-annual variability presented somewhat increase, especially for sediment load.*

<u>13. Comment:</u>

Section 3.3. In Equation 6, precipitation is also a temporally variable component, and 'area treated with erosion control measures' is also a spatially variable component. And it seems as though other factors (steeper slopes, soil properties, impermeable surface area, etc) may also play a role in affecting SSY. Moreover, it seems likely that changes in precipitation and land-use change may interact to affect sediment yield. The authors may want to rethink the way they've framed their analysis. Especially as 6/14 catchments in their analysis exhibited no significant correlation. A multiple regression analysis with an interaction term may be a more appropriate means of analysis.

Reply: *First, we have used new regression model to analyze the precipitation-sediment relationship and it improved much compared to the original linear regression model (see response to the main comment #1 of reviewer #1).*

Second, we have deleted Eq. (6) and reframed the analysis about the spatio-temporal patterns of the impacts of precipitation and LUCC on sediment yield (see the fourth point of the response to the main comment #1 of reviewer #1). Both the temporally variability of precipitation and spatial variability of fraction of area treated with erosion control measures were included in the framework. Furthermore, we *have also investigated the possible effects of catch characteristics on the changes of sediment yield (see the second point of the response to #2 main comment of reviewer #1).*

14. Comment:

Lines 387 and throughout: Authors often discuss a 'clear spatial pattern' present in their results, thus maps would be more useful as figures than scatter plots.

Reply: *We have used maps as figures (see Figs. 1-5).*

15. Comment:

Line 393 and 419. Remove undoubtedly.

Reply: *We have removed it.*

16. Comment:

Lines 449-454. Not quite sure how this resulting empirical relationship follows from the preceding analysis. What are k0 and k1. Also, once better explained, the authors could prove this empirical relationship is robust by showing how accurately it predicts SSY when they input observational data.

Reply: *We have deleted this empirical equation and the related statements.*

17. Comment:

Table 2: Add an ID column.

Reply: *The ID column has been added in Table 2.*

If you have any further questions about this revision, please contact us.

Sincerely Yours,

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Pro. Bojie Fu (bjf@rcees.ac.cn)

Pro. Murugesu Sivapalan (sivapala@illinois.edu)