Point–by–point responses to the reviewer's comments/questions:

Dear reviewer #1:

General Comment: The manuscript quantified suspended sediment concentration dynamics under the influence of the "Household Contract Responsibility System" and Grain-for-Green projects in China. The paper is well written. The content is interesting and scientifically sound. It is a useful contribution to research in the field of catchment geomorphology. However, the manuscript in current version could not meet the standard of the journal, and moderate modification should be performed.

Reply: Thank you very much for your time on our manuscript and the opportunity to revise the work. We took these comments and suggestions seriously and addressed each of them in every detail.

Comment1. Specific comments: The results are based on one study case. How the results are anticipated to change for different catchments for other case studies? The authors need to add some text regarding this in the conclusion section to show the scope of this research results.

Reply: Thank you for your comment. We added information in the section of discussion. We compared our results with other studies.

Comment2. For the discussion, an objective and open–minded consideration of multiple possible explanations could provide a theoretical dimension and bolster the geomorphic aspects of the paper. Given that speculation about watershed processes is likely the best that can be done, the paper should employ the method of multiple working hypotheses.

Reply: Thank you for your comment. Thank you for your comment. We added information in the section of discussion and added more possible explanations.

Comment3. Line 28: The unit of annual suspended sediment yield should be kg.

Reply: We have used kg as the unit of annual suspended sediment yield in the revised manuscript.

Comment4. Line 34~35: The standard deviation should be noted for 1990s and 2000s.

Reply: Thank you for your comment. We added the standard deviation in the revised manuscript.

Comment5. (Line 110) Line 122: Why the forestland of sub-catchment changed different from the Du catchment?

Reply: Thank you for your comment. Forestland changed a lot under the influence of the "Household Contract Responsibility System'' and Grain-for-Green projects. Flat land and land near the river are more likely cultivated during 1990s. Farmland with slopes >25° was restored to forest during 2000s. Thus, the change of forestland was influenced by slope as well as the distance to river.

Comment6. Line 140: At the end of the study area, what about population in the watershed? (number of villages, total population and trend, population density).

Reply: Thank you for your comment. The study area contains Zhenping county, Zhuxi county, 2/3 of Zhushan county, and parts of Fang county. There are 1002 villages with total population of 1.9×10^6 based on the fifth population census of China in 2000.

Comment7. Line 152: Variable D should be italic.

Reply: We apologize for our mistake and we used italic in the revised manuscript.

Comment8. Line 172: Please note the threshold values of Mann-Kendall statistical test.

Reply: Thank you for your comment. The threshold is ±1.96 for significant difference. We indicated the threshold in Figure 5.

Comment9. Line 185: No need indicate excel 2010 and SPSS17.0.

Reply: Thank you for your comment. We deleted the information in the revised manuscript.

Comment10. Line 191: Consider use kg as the unit for SSY.

Reply: We used kg in the revised manuscript.

Comment11. Line 234: Is 1980-1989 the same as 1980s? please use a uniform expression.

Reply: We used 1980s in the revised manuscript.

Comment12. Line 237: “max Qx”, add “the”.

Reply: We added the before max.

Comment13. Line 241: It should be Figure 7.

Reply: We apologize for our carelessness. It should be Figure 7.

Comment14. Line 254: Why use 25%, 50% and 75% as threshold?

Reply: Thank you for your comment. The thresholds are subjective. Similarly, we can use 33% and 77% as the threshold. However, during rainfall event, large runoff caused by peak flow or low runoff which can load sediment is relatively scarce. Most SSC data were acquired from moderate flow. Thus, we classified moderate flow to have more number of samples.

Comment15. Line 259: Figure 8 presents box plots for SSCz and “SSCx”?

Reply: Thank you for your comment. It should be “SSCx”.

Comment16. Line 317: “Cultivation or reforestation alter the slope surfaces but do not remove gullies and channels. Thus, the max SSCx is greater than the max SSCz”. This is speculative and only one of many possible explanations. The difference of the max SSC could be caused by rainfall regimes.

Reply: We agree with your opinion. We changed the expression in the revised manuscript: “The max SSCx is greater than the max SSCd (31800 vs. 22400 g m^{-3}). One possible explanation is…” (see P13. L329)

Comment17. Line 458, 462, 485 and 489: Delete the “-”.

Reply: We apologize for our carelessness. We corrected this mistake.

Thank you for your time and instructive advice.

Point–by–point responses to the reviewer's comments/questions:

Dear reviewer #2:

General Comment: The topic of this paper is of particular interest not only in China but also in many places where land use changes have occurred as a result of socio-economic development. This paper by Fang et al., is well written and based on a vast number of paired *Q-SSC* samples collected over 30 decades. Such dataset is usually difficult to find and this is one of the strengths of the paper. However, some changes should be made before publication of this manuscript, which I specify in the following points.

Reply: Thank you very much for your time on our manuscript and the opportunity to revise the work.

Specific Comment: I would change the units used in the paper. Consider using tons/year (or kg/year) for the SSY and mg/l (or g/l) for the SSC. - If you mention the Du basin before specifying that the station's name in this basin is Zushan, I would use the sub-index D in the subsequent variables (i.e. QD,SSYD,etc). I think that would help the reader which is not familiar with the names. - Be consistent and use Figure or Fig. throughout the manuscript.

Reply: Thank you for your good suggestions. We used kg/year (kg yr^{-1}) for *SSY*, sub-index d for Zhushan station (i.e. *SSCd*, *SSYd*, and *Qd*), and consistent used Figure throughout the revision. However, the g m^{-3} is the original unit for SSC. The g l^{-1} is good for large values of *SSC* but not very good for low values. We still use g m^{-3} in the revised manuscript.

Comment1: P7585-L15-16. Could you provide more details on the sampling frequency? What do you mean by "the sampling measurement frequency was increased several times each day"?

Reply: Suspended sediments were collected by manual samples. During rainfall events, samples were collected based on the variation of the discharge and magnitude of *SSC*. Generally, samples collected frequently during events with high value of *SSC,* while collected infrequently during event with relatively small magnitude of *SSC*. The time between sampling changed from minutes to hours. The total number of samples varied from several to dozens.

Comment2: P7558-L15-16. You compute the variable *Di*, which is correct since this allows the comparison of runoff volumes in both basins regardless of their different area. The units of this variable is in mm (l/m2), however it is computed as *Q/A* (with *Q* being the mean discharge during the period i). I think this variable should be specified as *R/A*; with *R* being the mean annual Runoff for each period (in hm3 -or dm3 for the computation of Di in mm-). I assume that each "period" refers to the three periods (1980, 1990 and 2000). I think the same should be done for the suspended sediment yield (*SSY*). In this case it would be the Specific

Sediment Yield (*SSY=SY/A*). For clarity, instead of using SSY for the Suspended Sediment Yield, I would use *SY* (in tones/year) and *SSY* for the Specific Sediment Yield (in tones/year/km2).

Reply: We apologize to confuse you. We agree with you that *D* should be specified as *R/A*. However, in this study, *D*, *Q*, *SSC*, and *SSY* were discussed at different time scales (e.g. during event, daily, monthly, and yearly). The word "period" may have different meanings. The "period" refers to the sampling time during event but not "the three periods" when calculate *D*. Suspended Sediment Yield may confuse with Specific Sediment Yield, thus we avoid to use Specific sediment Yield.

Comment3: Figure 3. I would use colors in this Figure as it's confusing as it is. I would also consider using lines for indicating the temporal trend in SSY in both basins. Maybe just two lines with different colors (one for each basin) joining the annual values would be enough.

Reply: Thank you for your comment. We used colors in Figure 3 and used lines for indicating the temporal trend. We changed the unit of *SSY* follow your previous suggestion.

Comment4: P7591-L1. Add the values of *Q* variations that you are referring to in this part of the text. This would help the reader.

Reply: Thank you for your comment. We added variations of *Q* in the revised manuscript: "The annual *Dd* and *Dx* varied between 253 to 873 mm and 279 to 931 mm, respectively". (see P 9 L196)

Comment5: Figures 4 and 5. The captions are interchanged

Reply: We apologize for our carelessness. We revised the captions in the revision. (see P27)

Comment6: P7591-L9. You mention that a Mann-Kendall was applied to annual *Pi*, *Di* and *SSYi* data. However in Figure 5 the results of *Di* are not shown. Instead *Qi* trends are shown. Clarify this and use *Di* in the Figure.

Reply: Thank you for your comment. We apologize for our carelessness. The trends of *Q* is the same of the trends of *D*. We used *D* in revised manuscript.

Comment7: P7591-L12. How do you apply the Mann-Kendall test? Using annual data for the 30 year period? Hence you get one value of the test indicating the trend for this period. What are the values shown in Figure 5? A space is missing in "and_*Q* and *SSY*"

Reply: Thank you for your comment. M-K test was performed using annual data. We added the threshold value of the test. The Z values indicated in formula-(7). We clarified the values in the revised manuscript. We added the space in the revised manuscript.

Comment8: Tables 4 and 5. I would also include a line at the bottom of the table indicating the mean annual values of *Q* and *SSY* for each period. Also, specify in Table 5 what C1and C2 mean (as in Table 4).

Reply: We added lines at the bottom of the Table 4 and 5 to indicate the average annual values of *Q* and *SSY*. We also added note for C1 and C2 below Table 5.

Comment9. P7591-L25. I would not say the Table shows the "dynamics" of *SSC*, but only the monthly mean *SSC* values.

Reply: Thank you for your comment. We deleted "dynamics" in the revised manuscript.

Comment10: P7592-L3-5. Why is the "monthly SSC calculated by *SSY* and *Q*"? Why you do not use the actual SSC from the samples collected? Specify in the methods section how monthly values are computed.

Reply: Actual *SSC* acquired by sampling is an instantaneous value, thus, monthly *SSC* can't be calculated by actual *SSC*. We explained monthly SSC in the section "2.3 Data acquisition". (see P6.L146)

Comment11: Is there any explanation for the intra-annual variability of the results? Q and SSC decrease in some months while they increase in others

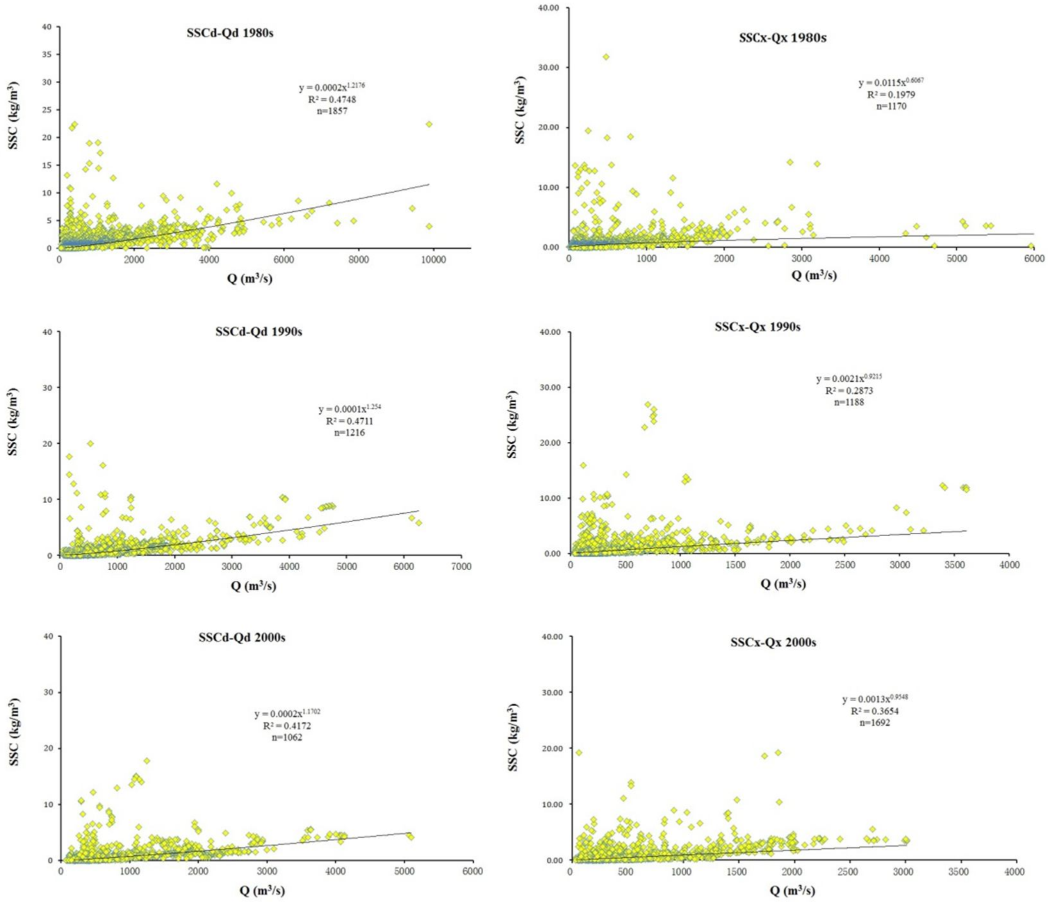
Reply: Thank you for your comment. The discharge and suspended sediment load showed opposite trend with rainfall through the M-K test. We concluded that the decreasing trend of *Q* mainly caused by land use change. However, intra-annual variability of *Q* and *SSC* could different with the annual trend. Monthly rainfall effected *Q* and *SSC*. Thus, *Q* and *SSC* decrease in some months while they increase in others.

Comment12: P7592-L7-8. The number of samples should be part of the methods section, not the results.

Reply: Thank you for your comment. We deleted this sentence and added it to the part of methods section. (see P6.L150)

Comment13: P7592-L8-9. The scatter in the *Q-SSC* relationship seems to be higher for low discharges (<1000 m^3/s), while for larger values of *Q* the scatter seems to be smaller.

Reply: Thank you for your comment. The Y axis is logarithmic in Figure 6. For larger values, the values of *Q* vary over many orders of magnitude. The numbers of larger values were much less than small values, thus, the scatter of larger and low values can't compared by i.e. R^2. We added a figure below using no logarithmic value. You can see the "real" relationship of *Q-SSC*. The large values look like more linear than small values but actually not.



Comment14: P7592-L11. Include here the values of the maximum *SSC* in both stations

Reply: Thank you for your comment. We added the values in the revised manuscript. (See P11.L248)

Comment15: P7592-L12. How do you evaluate the stability in the *Q-SSC* relationship.

Reply: Thank you for your comment. We used R^2 to evaluate the stability of the *Q-SSC* relationship and we indicated R^2 in Figure 6.

Comment16: I would merge sections 3.2 and 3.3 into a single one under the name of "*Q-SSC*" dynamics. Also, I would explain first the contents in section 3.3, which are quite descriptive of the values found during the study period, and then move to the contents in section 3.2.

Reply: Thank you for your comment. We merged sections 3.2 and 3.2 and used the name of "*Q-SSC* dynamics". We adjust the order of these two sections.

Comment17: P7592-L18. You mean Figure 7?

Reply: We apologize for our carelessness. It should be Figure 7.

Comment18: Figure 7. I would specify the years for each period in the x-axis as well. Original (1980); Cultivation (1990) and Reforestation (2000). Also use colors in the lines of the Figure, not only in the symbols. Do not use curves for joining the points, use straight lines.

Reply: Thank you for your comment. We have redrawn Figure 7 followed your suggestion. We use straight lines colors in the lines for the revision. According to your suggestion of comment 16, Figure 7 changed to Figure 6 in the revision.

Comment19: P7593-L3-6. Could you explain the classification of flows in detail? What do you mean by minimum 25% , middle 50% and maximum 25%? Do you refer to the values that are equaled or exceeded 25%, 50% and 75% of the time respectively? Why such thresholds?

Reply: We apologize to confuse you. We revised this sentence as: "*SSC* was sorted by ranking the paired *Q* values, which were classified using a threshold level approach (e.g., low flow (Q ≤25%), moderate flow (25<Q<75%), and high flow (Q≥75%))." The thresholds are subjective. However, during rainfall event, large runoff caused by peak flow or low runoff which can load sediment is relatively scarce. Most SSC data were acquired from moderate flow. Thus, we classified moderate flow to have more number of samples.

Comment20: P7593-L18-24. How to you perform the mean comparisons in the ANOVA test? You say you perform 6 one-way anova, but the table shows 18 values.. Did you perform a one-way anova or a two-way anova (using the cultivation period and the flow category as categorical variables?) or did you perform individual anovas for each flow category and period? The way you performed the anova tests is not clear, you specify this on the footnote in Table 6 but I think all the information should be on the text to help the reader. Also, I think it would be worth doing the same analysis for *Q* values. Last, I would include a table showing the anova results (statistic and p-value) instead on only adding a * in the table showing the mean *SSC* and *Q* values.

Reply: Thank you for your comment. Table 6 indicated both mean values and one-way ANOVA results, but not ANOVA of mean values. We apologize to confuse you. The ANOVA tests were performed using the all samples of *SSC*. Each flow category has three periods, thus 18 values indicated 6 tests. We added information to explain the ANOVA test in the revised manuscript. We modified Table 6 to show both statistic and p-values.

We compare the variances of *SSCs* of the same flow categories during different periods. Thus *Q* values have already been classified.

Comment21: P7594-L7. I don't see why the authors mention here the effects of impoundment in runoff and sediment yield when impoundment is not mentioned either in the results section. Is there any reservoir or dam in the studied basins that can affect the results? This statement is very general, and out of the context of the paper if this is not mentioned earlier in the previous sections.

Reply: Thank you for your comment. We apologize to confuse you. It was an expression mistake caused by language problem. We wanted to express forest can hold water. We deleted "impoundment" in the revised manuscript.

Comment22: P7594-L19. For the first time in the manuscript the term "water yield" is used here, do you mean the mean annual runoff volume (in hm^3/year) or what you specify as Discharge Depth (in mm). The use of different terms throughout the manuscript is confusing.

Reply: We apologize to confuse you. It should be mean annual runoff volume. (See P13.L317)

Comment23: P7594-L19-20. From the Study Basin section I understand that both basins are nested, and thus the Xinzhou is a nested basin within the Du basin (Zhushan station). Hence, I don't understand how the combined water yield of the catchment (the Du?) and the sub-catchment (the Xinzhou?) are nearly half of the total catchment output.. Do you mean that the water yield at the Xinzhou station is nearly half of the water yield in the Zhushan station? That half of the water yield is produced in the sub-basin? This paragraph is not clear. Could you explain this further?

Reply: Thank you for your comment. You are right. The mean annual runoff volume at Xinzhou station is nearly half of the water yield in Zhushan station, and half of the water yield is produced in the sub-basin. We reorganized this paragraph. (See P13. L318)

Comment24: The last paragraph of the discussion talking about the model is interesting; however, I don't think this is a discussion of the results found in the paper and an objective of the paper. This part of the discussion related to broader scale geomorphic processes, involving area and basin properties, which are not analysed in this manuscript. The manuscript aim is to analyse the trends in the *SSC-Q* relationship over a 30 year period and under different land covers. If the authors want to explain the importance of such model for their results, they should expand this section and explain further the relationship between the model and their results and why this is relevant for their case study.

Reply: Thank you for your comment. In this study, *SSCx* shows more variable than *SSCd*. We conclude sediment delivery ratio (SDR) is one of the main reasons. Our previous study found that the area scale dominates the SDR. We simplified these sentences and deleted the model in the revised manuscript. (See P13.L326)

Comment25: I don't think these are the main conclusions, this should be part of the discussion section.

Reply: We put parts of conclusions into discussion, and we added new conclusions.

Thank you for your time and instructive advice.

Point–by–point responses to the reviewer's comments/questions:

Dear reviewer #3:

General Comment: I found the paper of interest, well written and also with interesting findings. My comment is first for a technical question... I suggest that you will improve the figures as your findings are of high interest and you are telling us a nice story, but you need better figures to make your paper easy to read. A second comment is that your discussion needs to bring the results of other researchers to the discussion and show what they found in other parts of the world, and to show how similar is to what you found There is a clear reduction of the river discharge and you should tell this to the audience Also that the land use is the key factor...

Reply: Thank you very much for your time on our manuscript. We have redrawn Figure 3, 4, 5, 6, 7 and 8 in the revised manuscript. We have added more discussion and results of other studies. Such as: "Land use/cover has been widely documented to have dire environmental consequences through their adverse impacts on soil and water qualities (Zhang et al., 2015). Olang et al (2011) indicated that 40% and 51 of forest and agriculture land respectively revealed reduced runoff volumes by about 12%, while 86% land cover of agriculture increased runoff volumes by about 12 %. Buendia (2015) et al studied the effects of afforestation on runoff at a Pyrenean Basin (2807 km2), with forest of sub-basin increases ranging between 19% and 57%, forest cover can account for ~40% of the observed decrease in annual runoff. Liu et al (2014) demonstrated that afforestation leads to increased runoff in dry seasons in Yarlung Zangbo River basin. Borrelli et al (2013) illustrated that a disturbed forest sector could produce about 74% more net erosion than a nine times larger, undisturbed forest sector."

The relevant references:

Buendia, C., Batalla, R. J., Sabater, S., Palau, A., and Marcé, R.: Runoff Trends Driven by Climate and Afforestation in a Pyrenean Basin, Land Degrad Dev, Article in Press. DOI: 10.1002/ldr.2384, 2015.

Borrelli, P., Marker, M., and Schutt, B.: Modelling Post-Tree-Harvesting Soil Erosion and Sediment Deposition Potential in the Turano River Basin (Italian Central Apennine), Land Degrad Dev, 26, 356-366, 10.1002/ldr.2214, 2015.

Cerda, A., and Doerr, S. H.: Soil wettability, runoff and erodibility of major dry-Mediterranean land use types on calcareous soils, Hydrol Process, 21, 2325-2336, 10.1002/hyp.6755, 2007.

Liu, Z., Yao, Z., Huang, H., Wu, S., and Liu, G.: Land Use and Climate Changes and Their Impacts on Runoff in the Yarlung Zangbo River Basin, China, Land Degrad Dev, 25, 203-215, 10.1002/ldr.1159, 2014.

Olang, L. O., Kundu, P. M., Ouma, G., and Furst, J.: Impacts of Land Cover Change Scenarios on Storm Runoff Generation: A Basis for Management of the Nyando Basin, Kenya, Land Degrad Dev, 25, 267-277, 10.1002/ldr.2140, 2014.

Zhang, F., Tiyip, T., Feng, Z. D., Kung, H. T., Johnson, V. C., Ding, J. L., Tashpolat, N., Sawut, M., and Gui, D. W.: Spatio-Temporal Patterns of Land Use/Cover Changes over the Past 20 Years in the Middle Reaches of the Tarim River, Xinjiang, China, Land Degrad Dev, 26, 284-299, 10.1002/ldr.2206, 2015.

Effects of cultivation and reforestation on suspended sediment concentrations: a case study in a mountainous catchment in China

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Abstract

Understanding how sediment concentrations vary with land use/cover is critical for evaluating the current and future impacts of human activities on river systems. This paper presents suspended sediment concentration (*SSC*) dynamics and the relationship between *SSC* and discharge (*Q*) in the 8973-km^2 Du catchment and its sub-catchment (4635 km^2). In the Du catchment and its sub-catchment, 4235 and 3980 paired *Q*-*SSC* samples, respectively, were collected over 30 years. Under the influence of the "Household Contract Responsibility System" and Grain-for-Green projects in China, three periods were designated, the original period (1980s), cultivation period (1990s), and reforestation period (2000s). The results of a Mann-Kendall test showed that rainfall slightly increased during the study years; however, the annual discharge and sediment load significantly decreased. The annual suspended sediment yield of the Du catchment varied between 4 1.3×10^8 and 332 1.0×10^{10} kg s^{-1}, and that of the sub-catchment varied between 2 6.3×10^7 and 135 4.3×10^9 kg s^{-1}. The *SSCs* in the catchment and sub-catchment fluctuated between 1 and 22400 g m^{-3} and between 1 and 31800 g m^{-3}, respectively. The mean *SSC* of the Du catchment was relatively stable during the three periods (±83 g m^{-3}). ANOVA indicated that the *SSC* did not significantly change under cultivation for low and moderate flows, but was significantly different under high flow during reforestation of the Du catchment. The *SSC* in the sub-catchment was more variable, and the mean-*SSC* in the sub-catchment varied from 1058±2217 g m^{-3} in the 1980s to 1256±2496 g m^{-3} in the 1990s and 891 ±1558 g m^{-3} in the 2000s. Reforestation significantly decreased the *SSC*s during low and moderate flows, whereas cultivation increased the *SSCs* during high flow. The sediment rating curves showed a stable relationship between the *SSC* and *Q* in the Du catchment during the three periods. However, the *SSC*-*Q* of the sub-catchment exhibited scattered relationships during the original and cultivation periods and a more linear relationship during the reforestation period.

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1 Introduction

Suspended sediment is conventionally regarded as sediment that is transported by a fluid and is fine enough to remain suspended in turbulent eddies (Parsons et al., 2015). Suspended sediment plays important roles in the hydraulics, hydrology, and ecology of rivers (Luo et al., 2013). Land use/cover is thought to affect hydrology and suspended sediment yield (*SSY*) (Van Rompaey et al., 2002; Casali et al., 2010). Although many studies have assumed that forest cover is an effective method for controlling sediment yield throughout the world (e.g., Mount et al., 2005; Hopmans and Bren, 2007; Garzía-Ruiz et al., 2008; Stickler et al., 2009; Verbist et al., 2010；Lü et al., 2015; Wei et al., 2015), other studies have disagreed (e.g., Mizugaki et al., 2008; Ide et al., 2009). Additionally, many studies have implicated farmland as a major contributor of sediments (Gafur et al., 2003; Shi et al., 2004; Izaurralde et al., 2007; Cerdan et al., 2010). However, whether changes in land use/cover alter soil loss by changing the runoff volume or by changing the suspended sediment concentration (*SSC*) has received little attention. The relationships between *SSC* and discharge (*Q*) have been discussed using sediment rating curves (Walling, 1977), a fuzzy logic model (Kisi et al., 2006), artificial neural networks (Liu et al., 2012), and other multivariate regression methods (Francke et al., 2008). SSCs are highly variable and can vary over many orders of magnitude during storm events (Naden and cooper, 1999; Cooper, 2002; Fang et al., 2012). The mean annual/monthly *SSC* fails to capture the highly episodic nature of sediment transport because >90% of the sediment load can be transported in <10% of time (Collins et al., 2011). Morehead et al. (2003) indicated that the suspended sediment load carried by rivers varies spatially and temporally and that sediment rating curve parameters can exhibit time-dependent trends. Warrick et al. (2013) concluded that the discharge and sediment relationships from six coastal rivers varied substantially with time in response to land use. In most studies, *SSYs* were calculated using *SSCs* and *Q*. However, little work has focused on the effects of land use/cover change on *SSCs*.

China contains 22% of the world’s population but only 7% of the world's croplands (Liu and Diamond, 2005). In China, erosion by water affects an area of 3.6×10^6 km^2, or approximately 37% of the country’s land area (Ni et al., 2008). Thus, soil erosion has become an important topic for local and national policy makers. In the 1980s, a policy called the “Household Contract Responsibility System” was implemented in China’s rural areas. Consequently, more land was reclaimed for farming. In the late 1999s, the Grain-for-Green project was introduced to increase forest and grassland cover. To combat soil erosion on sloped croplands, farmland with slopes >25° was restored. The farmers who agreed to stop cultivating these lands received subsidies to cover their losses (Gao et al., 2012). Before this project, subtropical zones with adequate rainfall were often over-exploited due to economic and demographic pressures. Cultivation of steeply sloping lands in subtropical areas can result in serious soil erosion during intense rainfall (Fang et al., 2012). In this study, a mountainous catchment and its sub-catchment were investigated and analyzed in detail. This catchment is located in the Danjiangkou Reservoir Area, which is a source area in the Middle Route Project under the South-to-North Water Transfer Scheme (the largest water transfer project in the world). The study catchment has experienced cultivation and reforestation periods. The first part of this study focuses on how cultivation and reforestation affect Q, SSC, and SSY at different time scales. Then, we discuss the dual roles of cultivation and reforestation that affect the relationship between SSC and Q. Finally, the SSC dynamics in the catchment and sub-catchment were determined under land use/cover changes.

2 Study area and methods

2.1 Study area

This study was conducted in the Du catchment (31°30′-32°37′ N, 109°11′-110°25′ E), which is located in Hubei Province, China, and covers an area of 8973 km^2 (Figure 1). Elevations within the watershed range from 245 to 3002 m. The sub-catchment

(Xinzhou catchment) is located in the northwest region of the Du catchment and covers an area of 4635 km^2. The topography in the Du catchment is undulating and is characterized by mountain ranges, steep slopes and a subtropical climate with a mean temperature of 15°C. The mean annual precipitation in this region is approximately 1000 mm, with 80% of the precipitation occurring between May and September. The major soil types include yellow–brown soils, Chao soils, and purple soils (National Soil Survey Office, 1992), which correspond to Alfisols, Entisols, and Inceptisols, respectively, according to USDA Soil Taxonomy (Soil Survey Staff, 1999). The major crops in this region are corn (*Zea mays L.*) and wheat (*Triticum aestivum L.*). There were 1002 villages with total population of 1.9×106 based on the fifth population census of China in 2000.

Insert: Figure 1

2.2 Land use/cover change

The land cover was digitized as part of a previous research project. Reconnaissance field surveys were conducted in 2007. A watershed topographic map was used in combination with 1999 ETM photographs and Landsat imagery from 1987 and 2007. The land use/cover units were delineated on the photographs and verified in the field. We assigned the periods of the 1980s, 1990s, and 2000s to original, cultivation, and reforestation periods, respectively. The areas of the various types of land use/cover are presented in Tables 1 and 2. In 1987, forestland, farmland, and shrubland covered areas of 6316 km^2 (70.4%), 919 km^2 (10.2%) and 929 km^2 (10.4%), respectively. The other land use/cover types covered small areas and included barren land (0.4%), grassland (7.3%), urban land (0.9%), and water bodies (0.4%) (Table 1). During the 2000s, some steep lands with slopes of more than 25° were converted to forestland. The area of forestland increased to 75.2% in 2007, whereas the area of farmland decreased to 6.1% (Figure 2). The sub-catchment experienced a similar change in farmland, which increased from 11.5% in 1987 to 14.7% in 1999 and decreased to 6.7% in 2007. However, the change in forestland in the sub-catchment was different from that in the Du catchment, in which forestland increased from 66.3% in 1987 to 67.9% in 1999 and 74.0% in 2007 (Table 2).

Insert: Figure 2

Insert: Table 1

Insert: Table 2

2.3 Data acquisition

All of the hydrological data were obtained from the Hubei Provincial Water Resources Bureau. Two gauge stations (Zhushan and Xinzhou) and seven weather stations (nearly evenly distributed) are located in the study catchment. The yearly average rainfall measured at three weather stations in Xinzhou was very similar to the mean rainfall measured at the seven weather stations. Therefore, we used the average annual values of rainfall obtained from the seven stations for the Zhushan and Xinzhou stations. A continuously recording water-level stage recorder and a silt sampler (metal type) were used to record discharge and sediment (complemented by manual samples), respectively. The water stage was measured and transformed into discharge by using the calibrated rating curve obtained through periodic flow measurements. *SSCs* were determined using the gravimetric method, in which water samples were vacuum-filtered through a 0.45-μm filter and the residue was oven–dried at 105°C for 24 h. The weight of each dried residue and the initial sample volume were used to obtain the *SSC* (g m^{-3}). Next, the *SSY* was calculated from the *SSC* and *Q*. During a month, the total *SSY* was the sum *SSY* of each event. Monthly *SSC* was calculated by monthly *SSY* and *Q*. During rainfall events, the sampling measurement frequency was increased several times each day. Paired *SSC-Q* data were obtained during rainfall-runoff events. Because bed load measurements were not performed in this area, this study does not consider bed load sediment transport. From 1980 to 2009, 4235 paired *SSC-Q* samples were collected at the Zhushan station and 3980 samples were collected at the Xinzhou station. This study uses several variables,

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and their meanings and abbreviations are shown in Table 3. To distinguish between the variables of the two gauges, we used ~~*Qz*~~*Qd*, ~~*Dz*~~*Dd*, ~~*SSYz*~~*SSYd*, and ~~*SSCz*~~*SSCd* for the Zhushan station (Du catchment) and *Qx*, *Dx*, *SSYx*, and *SSCx* for the Xinzhou station (sub-catchment).

Insert: Table 3

The variables for D, SSY_i and SSY are calculated as follows:

$$D = Q/A \quad (1)$$

$$SSY_i = SSC_i \times Q_i \quad (2)$$

$$SSY = \int_1^n SSY_i \quad (3)$$

where A is the area of the catchment and SSY_i, SSC_i and Q_i are the suspended sediment yield, suspended sediment concentration, and discharge during period i, respectively.

2.4 Statistical analyses

The Mann-Kendall test, which was proposed by Mann (1945) and Kendall (1975), was used to identify trends in P, Q and SSY during the 30-year study period. The S statistic was calculated as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_j - x_i\right) \quad (4)$$

where n is the number of data points, x_i and x_j are the respective data values in the time series i and j (j>1), and $\operatorname{sgn}(x_j - x_i)$ is the sign function (Gao et al., 2012), which is determined as follows:

$$\operatorname{sgn}\left(x_j - x_i\right) = \begin{cases} +1, \ if \ x_j - x_i > 0 \\ 0, \ if \ x_j - x_i = 0 \\ -1, \ if \ x_j - x_i < 0 \end{cases} \quad (5)$$

The variance is computed as

$$\mathrm{VAR}(\mathrm{S})=\frac{1}{18}\left[\mathrm{n}(n-1)(2n+5)-\sum_{i=1}^{q}t_i(t_i-1)(2t_i+5)\right] \quad (6)$$

where n is the number of data points, q is the number of tied groups and t_i is the number of data values in the ith group. The standard test statistic, Z, is computed as follows:

$$Z=\begin{cases}\frac{S-1}{\sqrt{VAR(S)}} & if\ S>0\\ 0 & if\ S=0\\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S<0\end{cases} \quad (7)$$

A positive value of Z indicates an upward trend, and a negative value of Z indicates a downward trend. We use the threshold of ±1.96 for significant difference (Gao et al., 2012). The Mann-Kendall statistical test has frequently been used to quantify the significance of trends in hydro-meteorological time series (Gocic and Trajkovic, 2013).

To discuss relationships between *SSC* and *Q*, hydrologists often use sediment rating curves. The most common approach is to fit a power curve to the normal data (Khanchoul et al., 2010) as follows:

$$SSC=\alpha Q^{\beta} \quad (8)$$

Here, α and β are constants in the non-linear regression equation. The non-linear model assumes that the dependent variable (*SSC*) has a constant variance (scatter), which typically does not occur because the scatter around the regression generally increases with increasing *Q* (Harrington and Harrington, 2013). ~~Descriptive statistics were obtained using Excel 2010 and the SPSS17.0 statistical software package.~~ The Mann-Kendall test was performed in MATLAB 7.0.

3 Results

3.1 Stream flow and sediment yield during different periods

Figure 3 shows the annual *P*, *D* and *SSY* for the hydrological years of 1980-2009 from the Zhushan and Xinzhou gauges. The annual *P* fluctuated between 665 and 1219 mm~~, . and t~~The annual ~~*Q*~~ *Dd* and *Dx* varied between 253 to 873 mm and ~~from the two gauges showed similar variations~~279 to 931 mm, respectively. The annual *SSY* varied between 1.3×10^8 and 1.0×10^{10} ~~4 and 332~~ kg yr^{-1} ~~s^{-1}~~ from the Zhushan gauge and between 6.3×10^7 and 4.3×10^9 ~~2 and 135~~ kg yr^{-1} ~~s^{-1}~~ from the Xinzhou gauge. To identify the relationships between the annual *P*, ~~*Dz*~~*Dd*, *Dx*, ~~*SSYz*~~*SSYd*, and *SSYx*, we generated a Pearson's correlation matrix, as shown in Figure 4. The analysis showed significant correlations between all of the variables (n=30, p<0.0001). During the low-flow years (e.g., 1997 or 2001), ~~*SSYz*~~*SSYd* was similar to *SSYx*. However, during the high-flow years (e.g., 1983 or 2005), ~~*SSYz*~~*SSYd* was several times greater than *SSYx*.

Insert: Figures 3 and 4

The Mann-Kendall test was applied to the annual *P*, *D* and *SSY* data for 1980-2009. The test shows a decreasing but not significant trend for *P*, a significant (5% level) decreasing trend for ~~*Qz*~~*Qd*, and highly significant decreasing trends for *Qx*, *SSYx* and ~~*SSYz*~~*SSYd* (1% level) (Figure 5). After 2000, *P* shows an increasing trend and *Q* and *SSY* show decreasing trends.

Insert: Figure 5

To better understand the dynamics of *Q* and *SSC*, Tables 4 and 5 compare the observed average monthly *Q* and *SSC* among the three periods monitored at the Zhushan and Xinzhou gauges.

Insert: Tables 4 and 5

During 1980s-1990s, the annual ~~*Qz*~~*Qd* showed a decreasing trend (Table 4), with

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only 3 of 12 months showing a slightly increasing trend. The rate of decrease varied from -3.3% to -53.0%. In addition, *Qx* exhibited a decreasing trend that was similar to that of ~~*Qz*~~*Qd* during the same period. During 1990s-2000s, ~~*Qz*~~*Qd* greatly increased from 1% to 34% during 9 of 12 months. Meanwhile, *Qx* increased over eight months and fluctuated between 10% and 42%. During 1990s-2000s, ~~*Qz*~~*Qd* and *Qx* both exhibited a more obvious increasing trend during the winter than during the flow seasons.

Table 5 shows ~~the dynamics of~~ the monthly mean *SSC* from the two gauges. ~~*SSCz*~~*SSCd* decreased (-1% to -66%) during the flow seasons (May to September), except in August, when it slightly increased (2%) during 1980s-1990s. The decrease of ~~*SSCz*~~*SSCd* did not coincide with that of ~~*Qz*~~*Qd*. During 1990s-2000s, the decrease in ~~*SSCz*~~*SSCd* was more obvious than that in 1980s-1990s. Eight of ten months experienced a decreasing change, and the change over seven months was >-40%. In addition, the *SSCx* decreased over six months and increased during the other four months during 1980s-1990s. During 1990s-2000s, the *SSCx* decreased over seven months, and four out of five months showed a decreasing trend during the flow season. However, the monthly *SSC* is calculated by *SSY* and *Q* and is not the actual *SSC*. To better understand *SSC* dynamics, paired *SSC-Q* data collected by monitoring should be discussed.

3.2 ~~SSC-Q~~ SSC-Q dynamics~~Relationship~~

Figure 6 shows the statistical characteristics of the *SSC* and *Q* during the three periods. The mean-*SSCd* was relatively stable during the three periods (±83 g m^{-3}), and the mean-*SSCx* varied from 1058 g m^{-3} in the 1980s to 1256 g m^{-3} in the 1990s and then decreased to 891 g m^{-3} in the 2000s. In the 1980s, the max *SSCd* and max *SSCx* were 22400 and 31800 g m^{-3}, respectively. Next, the max *SSCd* shape decreased to 20000 g m^{-3} during the 1990s and to 17800 g m^{-3} during the 2000s. Meanwhile, the max *SSCx* decreased to 26900 and 19200 g m^{-3} during the 1990s and 2000s, respectively. The max *Qx* was more variable than the max *Qd* and was 12400 g m^{-3} in

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the 1980s, 3610 g m^{-3} in the 1990s and 3010 g m^{-3} in the 2000s. However, the rate of change of the mean *Qx* was similar to that of the mean *Qd*.

Insert: Figure 6

~~From 1980 to 2009, 4235 paired *SSC-Q* samples were collected at the Zhushan station and 3980 samples were collected at the Xinzhou station.~~ Figure ~~6~~7 shows that the *SSCs* varied by several orders of magnitude for a given discharge at both gauges. ~~*SSCz*~~*SSCd* and *SSCx* fluctuated between 1 and 22400 g m^{-3} and between 1 and 31800 g m^{-3}, respectively. The maximum *SSCx* (31800 g m^{-3}) was larger than the maximum ~~*SSCz*~~*SSCd* (21400 g m^{-3}). In Figure ~~6~~7, ~~*SSCz*~~*SSCd*-~~*Qz*~~*Qd* maintained a stable relationship during the three periods (~~1980-1989~~1980s, ~~1990-1999~~1990s, and 2000~~-2009~~s). However, *SSCx*-*Qx* showed a scattered relationship from ~~1980-1989~~1980s and ~~1990-1999~~1990s and showed a more liner relationship from 2000~~-2009~~s. During the three periods, the max ~~*Qz*~~*Qd* decreased from 9880 to 6140 and 5070 m^{-3} s^{-1}, respectively. Meanwhile, the max *Qx* was reduced from 5960 to 3580 and 2990 m^{-3} s^{-1}, respectively.

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Insert: Figure ~~6~~7

~~3.3 Paired SSC-Q dynamics~~

~~Figure 6 shows the statistical characteristics of the *SSC* and *Q* during the three periods. The mean *SSCz* was relatively stable during the three periods (±83 g m^{-3}), and the mean *SSCx* varied from 1058 g m^{-3} in the 1980s to 1256 g m^{-3} in the 1990s and then decreased to 891 g m^{-3} in the 2000s. In the 1980s, the max *SSCz* and max *SSCx* were 22400 and 31800 g m^{-3}, respectively. Next, the max *SSCz* shape decreased to 20000 g m^{-3} during the 1990s and to 17800 g m^{-3} during the 2000s. Meanwhile, the max *SSCx* decreased to 26900 and 19200 g m^{-3} during the 1990s and 2000s, respectively. The max *Qx* was more variable than the max *Qz* and was 12400 g m^{-3} in the 1980s, 3610 g m^{-3} in the 1990s and 3010 g m^{-3} in the 2000s. However, the rate of change of the mean *Qx* was similar to that of the mean *Qz*.~~

~~Insert: Figure 7~~

The relationship between *SSC* and *Q* is complicated. To better understand the dynamics of *SSC*, *SSC* was sorted by ranking the paired *Q* values, which were classified using a threshold level approach (e.g., low flow (*~~minimum~~* *Q*≤25%), moderate flow (~~middle 50%~~25<*Q*<75%), and high flow (*~~maximum~~* *Q*≥~~25~~75%~~)~~). The *SSC* dynamics were compared under different flow regimes. For the sub-catchment, the thresholds were 188 and 674 m^3 s^{-1} for the minimum 25% and maximum 25%, respectively. For *~~Qz~~Qd*, the thresholds of the minimum and maximum 25% were 332 and 1100 m^3 s^{-1}, respectively. Figure 8 presents box plots for *~~SSCz~~SSCd* and *~~SSCz~~SSCx* during the three periods for the three flow grades. The box plots indicate the maximum, 75%, 50%, 25%, and minimum values for each *SSC* (outliers are excluded). For the sub-catchment, *SSCx* increased between the original period and the cultivation period for moderate and high flow, but not for low flow. Then, *SSCx* decreased during the reforestation period for all flows. At the Zhushan station, *~~SSCz~~SSCd* was larger during the cultivation period for both moderate and high flows. During the reforestation period, the *~~SSCz~~SSCd* during low flow was higher than during the other periods.

Insert: Figure 8

Six ANOVA tests were performed using *SSC* as the dependent variable and using the different periods (land use) as independent variables. ANOVA was only conducted for the same flow during different periods. One-way ANOVA (Table 6) revealed that *SSCx* showed significant differences among the different periods for all three types of flows (p<0.001). However, a significant difference in *~~SSCz~~SSCd* was only observed among high flows (p<0.001). No statistically significant differences were observed among the *~~SSCz~~SSCd* values during the different periods for low or moderate flows.

Insert: Table 6

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4 Discussion

Land use/cover has been widely documented to have dire environmental consequences through their adverse impacts on soil and water qualities (Zhang et al., 2015). Olang et al (2011) indicated that 40% and 51 of forest and agriculture land respectively revealed reduced runoff volumes by about 12%, while 86% land cover of agriculture increased runoff volumes by about 12 %. Buendia (2015) et al studied the effects of afforestation on runoff at a Pyrenean Basin (2807 km^2), the results show with forest of sub-basins increase ranging between 19% and 57% account for ~40% of the observed decrease in annual runoff. Liu et al (2014) demonstrated that afforestation leads to increased runoff in dry seasons in Yarlung Zangbo River basin. In this study, l~~L~~and use/cover changes significantly affect *Q* and *SSY* (Tables 4 and 5). During the cultivation period, an increase in farmland resulted in an obvious decreasing trend in *Q* in the Du catchment and its sub-catchment.~~–~~ The sediment concentration in the direct runoff from a slope consists of a combination of the sediment stored on the slope and that generated by flow erosion during the current rainfall event (Aksoy and Kavvas 2005; Rankinen et al., 2010). Large storms generate sufficient surface runoff to deliver sediment from the uplands to the stream. In forest catchments over flow typically occurs only in a small fraction of the catchment, it is most likely to occur very close to the stream (Underwood et al., 2015). Reforestation many increased the return period of peak flow and peak sediment yield (Keesstra, 2007). Borrelli et al (2013) illustrated that a disturbed forest sector could produce about 74% more net erosion than a nine times larger, undisturbed forest sector. ~~However, h~~High *SSCs* are not detected in the absence of a high flow velocity to carry the suspended sediment to the outlet of a catchment. *SSCs* are determined by onsite sediment production and the connectivity of sediment sources to the ~~river~~channel. ~~.~~ Sediment delivered to the channel can deposited (Keesstra et al., 2009). When runoff is ~~impounded~~decreased, its erodibility is reduced (Bakker et al., 2008; Van Rompaey et al., 2002). Reduced stream flow can reduce the sediment transport capacity and

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increase the probability for further sediment deposition in the river (Zhu et al., 2015). Human-induced modifications of land use/cover in river basins may cause strong geomorphic responses by disturbing sediment supply, transport and deposition processes (Liebault et al., 2005).

Hydrological studies rely on the analysis of processes at different spatial scales (García-Ruiz et al., 2008). Sediment yield and watershed areas have been elucidated in many studies (e.g., Renschler and Harbor, 2002; de Vente and Poesen, 2005). The mean-*SSC* was stable during the study years in the Du catchment, and the mean-*SSC* varied in the sub-catchment. The increase in *Qx* was larger than the increase in *Q=Qd*. The monitored sub-catchment covered approximately half of the entire catchment. Likewise, the combined mean annual discharge volumewater yield of the sub-catchment and sub-catchment was nearly half of the total catchment output (i.e., a deficit of approximately 50% at the outlet). However, the *SSC* dynamics were more variable. Due to sediment delivery problems, sediment is generated on catchment slopes and is either stored on the surface or removed (Rankinen et al, 2010). Only a fraction of the gross soil erosion within a catchment will reach the outlet and be represented in the sediment yield. In addition, stream flow erodes the sediment directly from the surface or causes channel erosion, which both removes the stored surface layer of detached sediment. Previously, our studies involving 107 sub-watersheds of the Du catchment

Our previous study in Du catchment showed that the area demonstrated that the sediment delivery model can be expressed as follows (Shi et al., 2014):

$$\mathrm{SDR} = 0.46 + 4.74(\ln AREA)^{-1} - 0.49(HI) - 0.13\ln(CONTAG) + 0.12(SHDI), \left(R^2 = 0.76\right) \quad (9)$$

where *HI, CONTAG and SHDI* are all variables of the land pattern (hypsometric integral, contagion, and Shannon's diversity, respectively). In this system, the area scale dominates the *SDR*sediment delivery ratio (Shi et al., 2014,). the The sediment stored in the gullies is flushed to the river when a certain threshold is exceeded, and

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the deposition of sediment in channels is flushed at higher discharges. The max *SSCx* is greater than the max *SSCd* (31800 vs. 22400 g m^{-3}). One possible explanation is ~~During a flood,~~ the sediment stock is depleted during a flood, ~~.~~ ~~T~~this process ~~may~~ not occur simultaneously within the entire river basin and results in gradually decreasing *SSCs* downstream (Doomen et al., 2008). Cultivation or reforestation alter the slope surfaces but do not remove gullies and channels. ~~However, t~~The *SSC*s in Zhushan were only significantly different during high flow and the reforestation period when the forest cover greatly increased. ~~For low and moderate flow, the changes in *SSY* primarily resulted from runoff, while the SSC showed little change. For the sub-catchment, the changes in the *SSC* were more sensitive to land use/cover changesThus, the max *SSCx* is greater than the max *SSCz* (31800 vs. 22400 g m^{-3}).~~

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5 Conclusions

This study investigated *Q* and SSC dynamics for 30 years u~~Under~~ nder cultivation and reforestation~~,~~. The results of a Mann-Kendall test showed that rainfall slightly increased during the study years; however, the annual discharge and sediment load significantly decreased. ~~the~~ The sediment flux is extremely spatially and temporally variable. The relationship between *SSC* and *Q* is complicated. ~~However, the *SSCs* in Zhushan were only significantly different during high flow and the reforestation period when the forest cover greatly increased. For low and moderate flow, the changes in *SSY* primarily resulted from runoff, while the *SSC* showed little change. For the sub-catchment, the changes in the *SSC* were more sensitive to land use/cover changes. Reforestation caused significant differences in the *SSC* for both low and moderate flows.~~ Reforestation caused significant differences in the *SSC* for both low and moderate flows. For low and moderate flow, the changes in *SSY* primarily resulted from runoff, while the SSC showed little change. For the sub-catchment, the changes in the *SSC* were more sensitive to land use/cover changes. Meanwhile, cultivation resulted in significant differences in the *SSC* for high flow.

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Meanwhile, cultivation resulted in significant differences in the *SSC* for high flow. Overall, our results provide useful information regarding *SSC* dynamics relative to land use/cover changes in mountainous catchments in a subtropical climate, which have largely been undocumented in the literature.

Acknowledgements

Financial support for this research was provided by the National Natural Science Foundation of China (41525003 and 41301294), the West Light Foundation of the Chinese Academy of Sciences, and the Fundamental Research Funds for the Central Universities (2014YB053).

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Table 1 Land use/cover type and change ratio during 1978-2007 in the Du catchment

Land	Land use/cover (km^2) and ratio			Land use/cover change (km^2) and change ratio		
use/cover	1987	1999	2007	1999-1987	2007-1999	2007-1987
Water	35 (0.4%)	26 (0.3%)	31 (0.4%)	-9 (-0.1%)	5 (0.1%)	-4 (-0.0%)
Urban land	81 (0.9%)	88 (1.0%)	115 (1.3%)	8 (0.1%)	26 (0.3%)	34 (0.4%)
Barren land	37 (0.4%)	38 (0.4%)	62 (0.7%)	1 (0.0%)	24 (0.3%)	26 (0.3%)
Forest	6316 (70.4%)	6232 (69.5%)	6841 (75.2%)	-84 (-0.9%)	609 (6.8%)	525 (5.9%)
Shrub	929 (10.4%)	846 (9.4%)	851 (9.9%)	-83 (-0.9%)	5 (0.1%)	-78 (-0.9%)
Grass	657 (7.3%)	525 (5.8%)	551 (6.4%)	-132 (-1.5%)	26 (0.3%)	-106 (-1.2%)
Farmland	919 (10.2%)	1218 (13.6%)	522 (6.1%)	299 (3.3%)	-695 (-7.7%)	-397 (-4.4%)

Table 2 Land use/cover and change ratio during 1978-2007 in the Xinzhou catchment

Land	Land use/cover (km^2) and ratio			Land use/cover change (km^2)		
use/cover	1987	1999	2007	1999-1987	2007-1999	2007-1987
Water	16 (0.3%)	15 (0.3%)	14 (0.3%)	-1 (0.0%)	-1 (0.0%)	-2 (0.0%)
Urban land	52 (1. 1%)	57 (1.2%)	51 (1.1%)	5 (0.1%)	-6 (-0.1%)	-1 (0.0%)
Barren land	20 (0.4%)	22 (0.5%)	41 (0.9%)	2 (0.0%)	19 (0.4%)	21(0.5%)
Forest	3072 (66.3%)	3148 (67.9%)	3432 (74.0%)	76 (1.6%)	284 (6.1%)	360 (7.8%)
Shrub	537 (11.6%)	422 (9.1%)	479 (10.3%)	-115 (-2.5%)	57 (1.2%)	-58 (-1.3%)
Grass	404 (8.7%)	290 (6.3%)	307 (6.6%)	-114 (-2.5%)	17 (0.4%)	-97 (-2.1%)
Farmland	534 (11.5%)	679 (14.7%)	312 (6.7%)	145 (3.1%)	-367 (-7.9%)	-222 (-4.8%)

Table 3 Variables and associated abbreviations used in the statistical analysis

Abbreviations	Variables	Units
P	Rainfall	mm
Q	Stream flow	$m^3 s^{-1}$
D	Discharge depth	mm
SSY	Suspended sediment yield	kg ~~s^{-1}~~ or g s^{-1}
SSC	Suspended sediment concentration	kg m^{-3} or g m^{-3}

Table 4 Monthly mean stream flow from the Xinzhou and Zhushan gauges

	~~*Q*=~~*Qd* (m^3 s^{-1})			Change (100%)		*Qx* (m^3 s^{-1})			Change (100%)	
	1980s	1990s	2000s	C1	C 2	1980s	1990s	2000s	C1	C 2
Jan	35	33	41	-5.7%	24.2%	17	13	19	-23.5%	46.2%
Feb	37	46	49	24.3%	6.5%	18	19	21	5.6%	10.5%
Mar	85	96	74	12.9%	-22.9%	42	46	31	9.5%	-32.6%
Apr	186	146	160	-21.5%	9.6%	92	72	61	-21.7%	-15.3%
May	185	200	203	8.1%	1.5%	89	97	89	9.0%	-8.2%
Jun	274	224	192	-18.2%	-14.3%	132	115	111	-12.9%	-3.5%
Jul	412	223	262	-45.9%	17.5%	207	119	173	-42.5%	45.4%
Aug	269	260	257	-3.3%	-1.2%	129	136	156	5.4%	14.7%
Sep	338	159	202	-53.0%	27.0%	173	76	109	-56.1%	43.4%
Oct	255	136	155	-46.7%	14.0%	123	67	103	-45.5%	53.7%
Dec	121	94	95	-22.3%	1.1%	57	42	47	-26.3%	11.9%
Nov	49	41	62	-16.3%	51.2%	23	18	30	-21.7%	66.7%
Average	187	138	146	-26.2%	5.8%	92	68	79	-26.1%	16.2%

Note: C1 is the change for 1990-1980; C2 is the change for 2000-1990

Table 5 Monthly mean suspended sediment concentration from the Xinzhou and Zhushan gauges

	~~*SSCx*~~*SSCd* (g m^{-3})			Change (100%)		*SSCx* (g m^{-3})			Change (100%)	
	1980s	1990s	2000s	C1	C2	1980s	1990s	2000s	C1	C2
Jan	0	0	0	-	-	0	0	0	-	-
Feb	10	1	2	-90%	100%	3	0	0	-100%	-
Mar	7	15	1	114%	-93%	3	12	1	300%	-92%
Apr	224	147	56	-34%	-62%	118	81	28	-31%	-65%
May	427	256	139	-40%	-46%	298	128	127	-57%	-1%
Jun	629	623	321	-1%	-48%	471	718	430	52%	-40%
Jul	1222	755	686	-38%	-9%	929	895	603	-4%	-33%
Aug	942	963	364	2%	-62%	736	961	411	31%	-57%
Sep	674	229	239	-66%	4%	409	115	186	-72%	62%
Oct	268	146	46	-46%	-68%	185	84	84	-55%	0%
Dec	26	86	1	231%	-99%	18	54	1	200%	-98%
Nov	0	0	0	-	-	0	0	0	-	-
Average	369	268	155	-27.4%	-42.1%	264	254	156	-3.8%	-38.6%

Note: C1 is the change for 1990s-1980s; C2 is the change for 2000s-1990s.

Suspended sediment primarily loads during the flow season. Rainfall is rare in the winter (Dec, Nov and Jan), and the stream flow is dominated by a base flow; thus, in most years, there is no suspended sediment load.

Table 6 Mean *SSC* values and one-way ANOVA of *SSCs* during the different periods

		Original	Cultivation	Reforestation	p value
Mean ~~*SSCz*~~*SSCd* (g m^{-3})	Low flow	0.49	0.50	0.44	0.285
	Moderate flow	0.83	0.86	0.97	0.080
	High flow	2.42	2.43	2.02*	0.002
Mean *SSCx* (g m^{-3})	Low flow	0.68	0.66	0.36*	0.000
	Moderate flow	0.87	0.97	0.64*	0.000
	High flow	1.80	2.83*	1.80	0.000

Note: ANOVA was only conducted for the same flow during different periods; * means significant difference at α=0.05~~, $p<0.001$.~~

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Figure captions:

Figure 1 Location of study area

Figure 2 Land use changes during the three periods

Figure 3 Annual P, D and SSY for the hydrological years of 1980-2009 from the Zhushan and Xinzhou gauges

Figure 4 Bivariate scatter-plot matrix of selected variables Results of the Mann-Kendall test

Figure 5 Bivariate scatter-plot matrix of selected variablesResults of the Mann-Kendall test

Figure 6 SSC-Q relationships during the three periods for the two gaugesDescriptive statistics of Q and SSC

Figure 7 SSC-Q relationships during the three periods for the two gauges Descriptive statistics of Q and SSC

Figure 8 Box plots of SSC

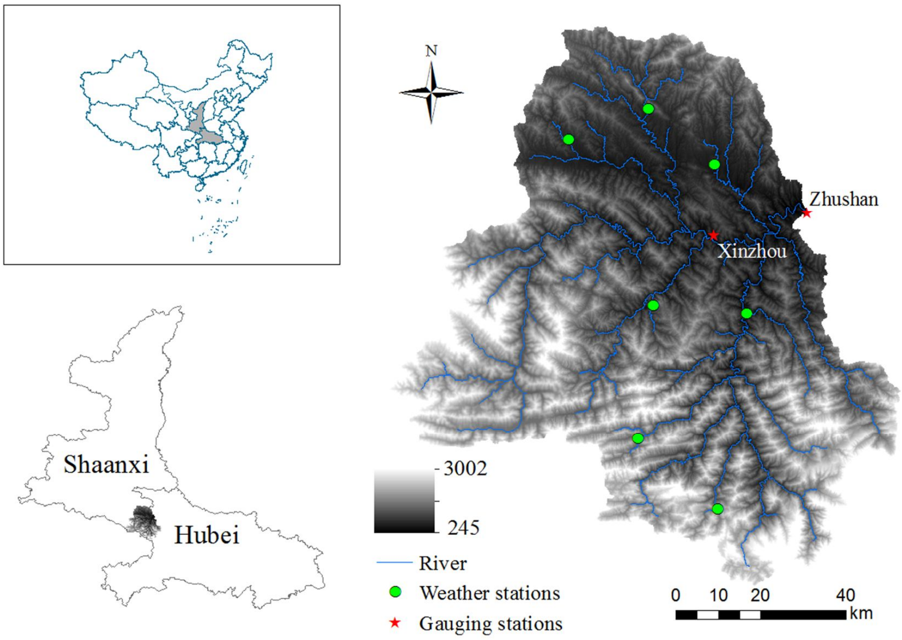
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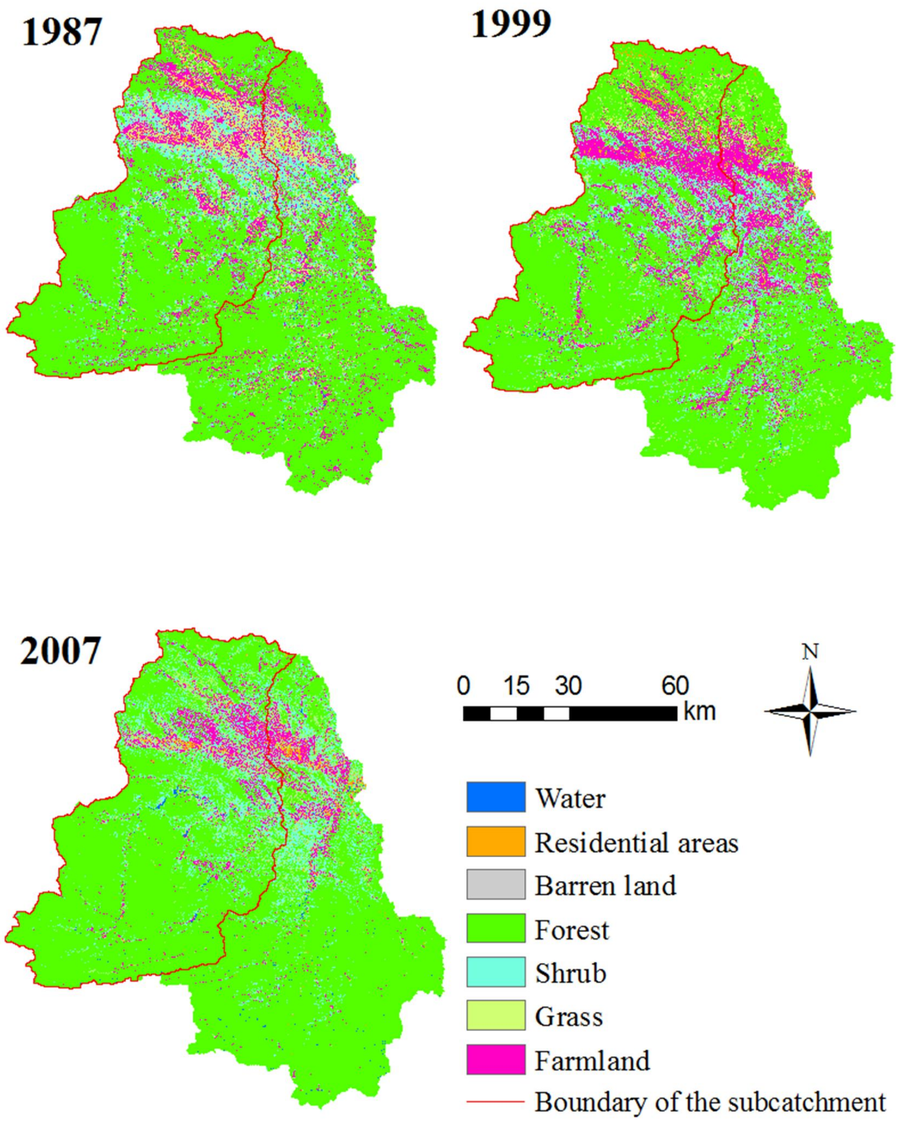
Figure 1



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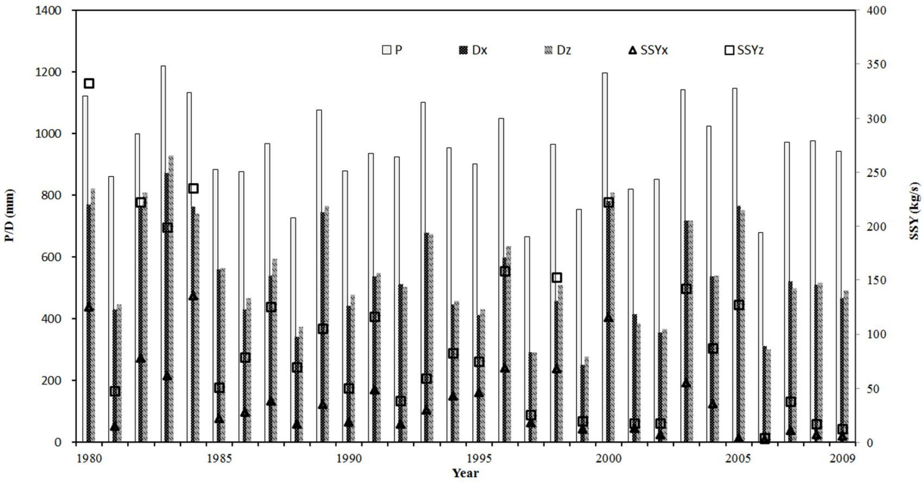

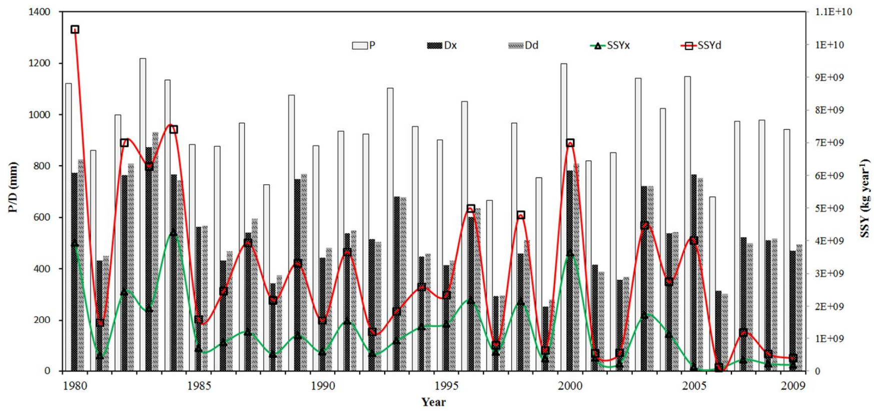

Figure 3

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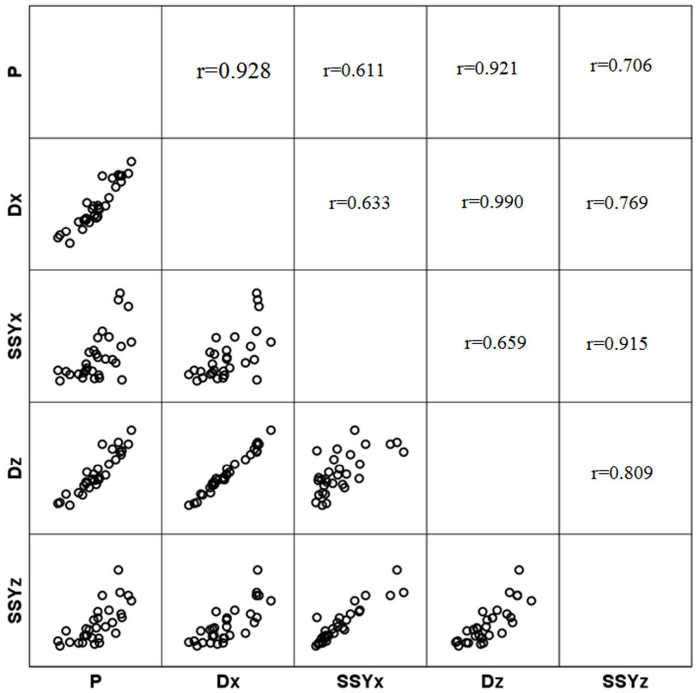

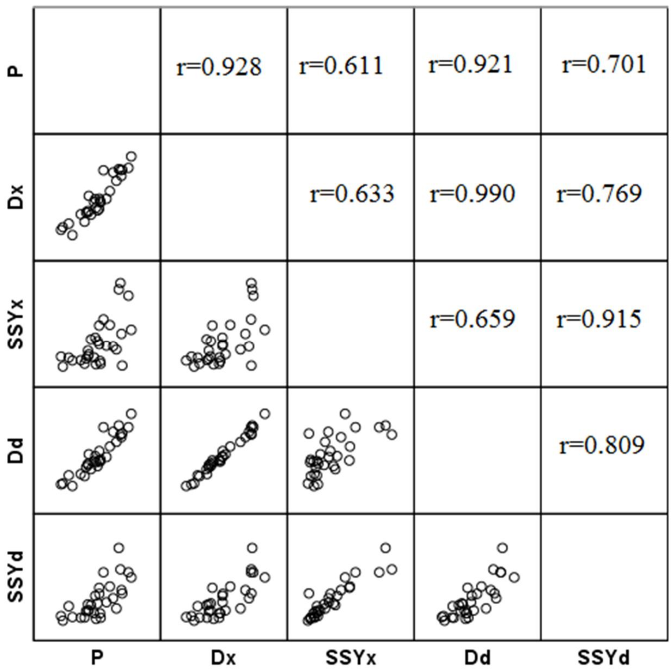

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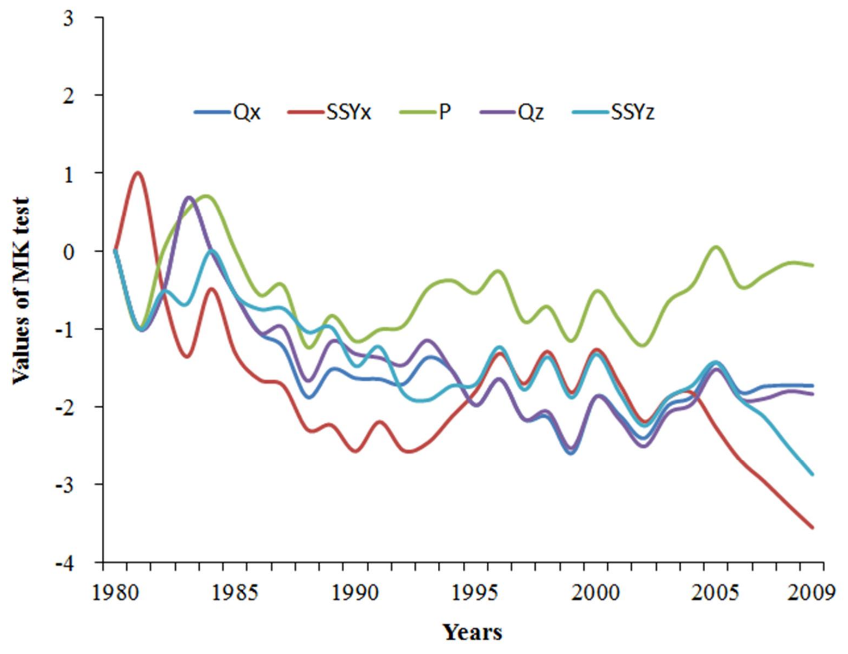

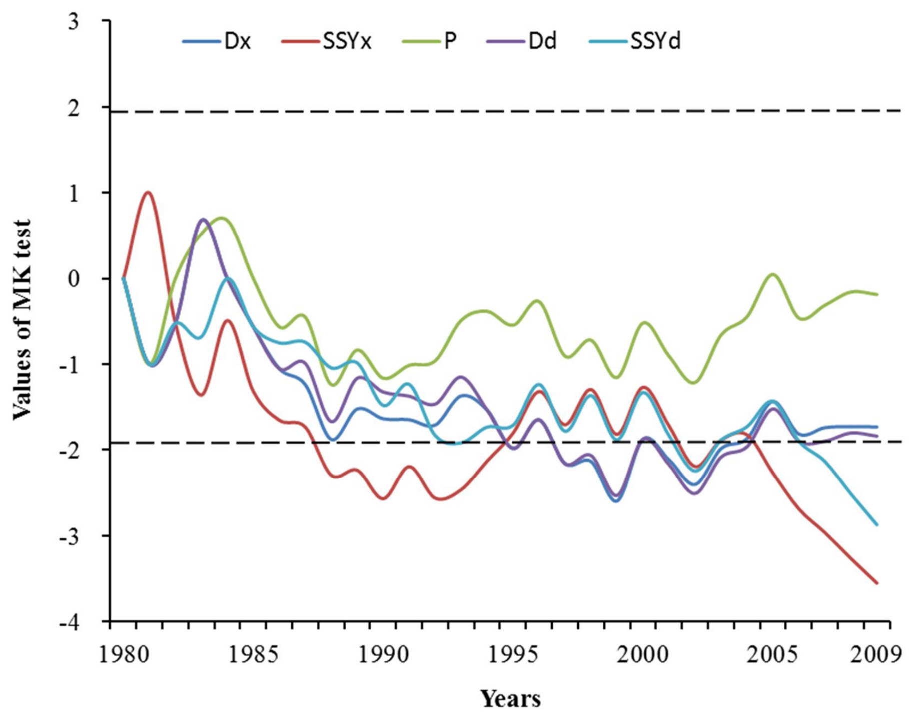

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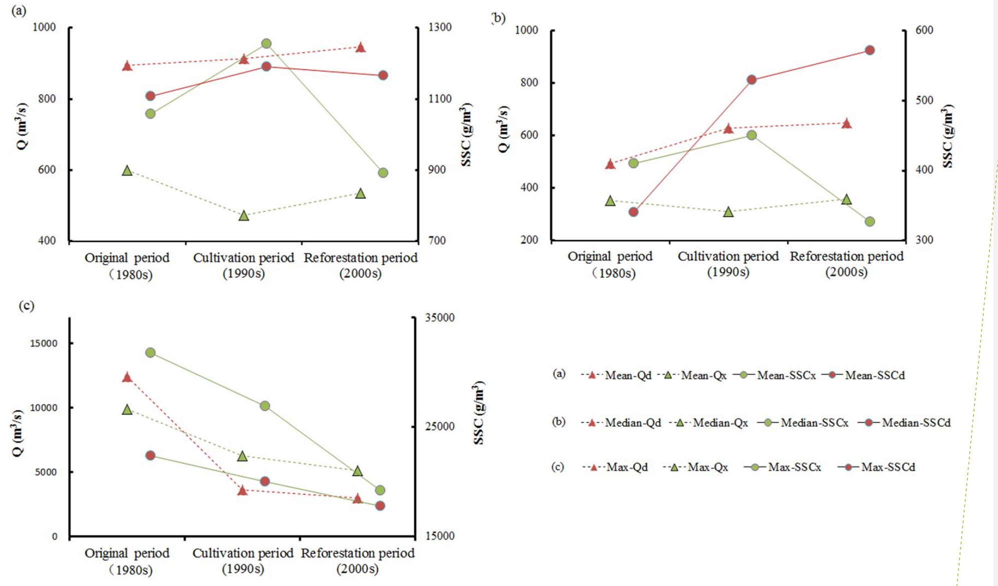

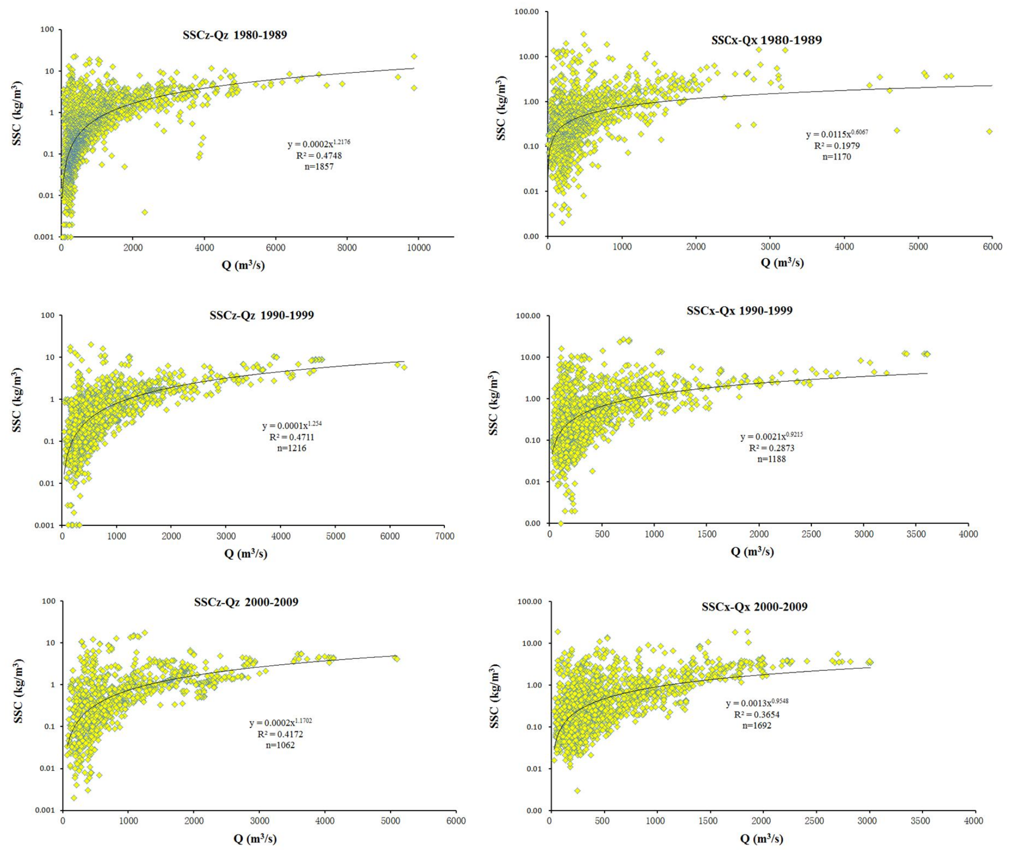

Figure 6

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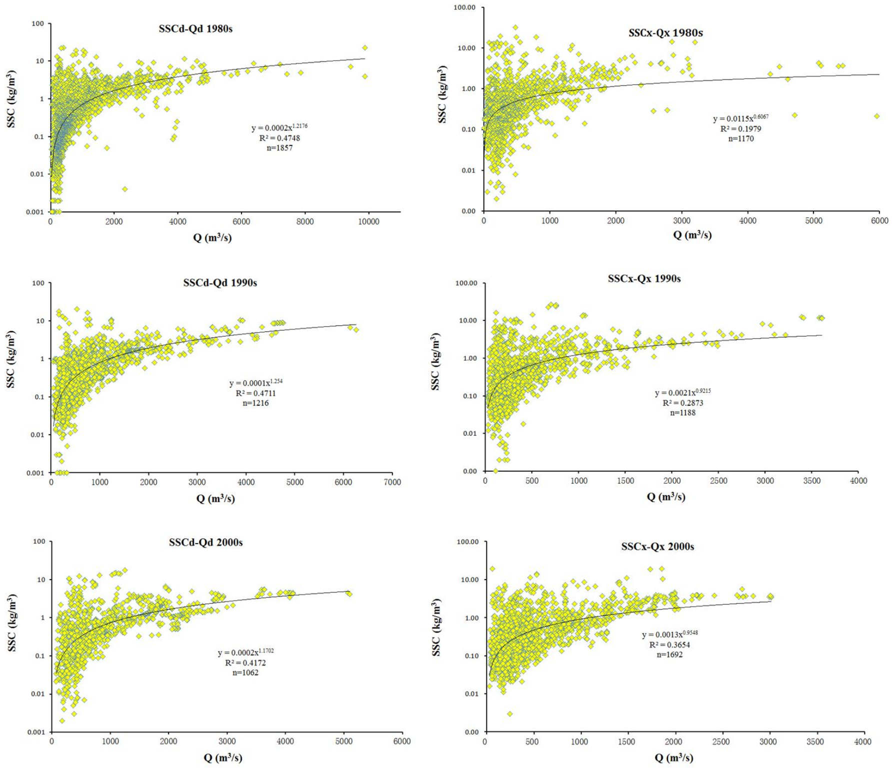

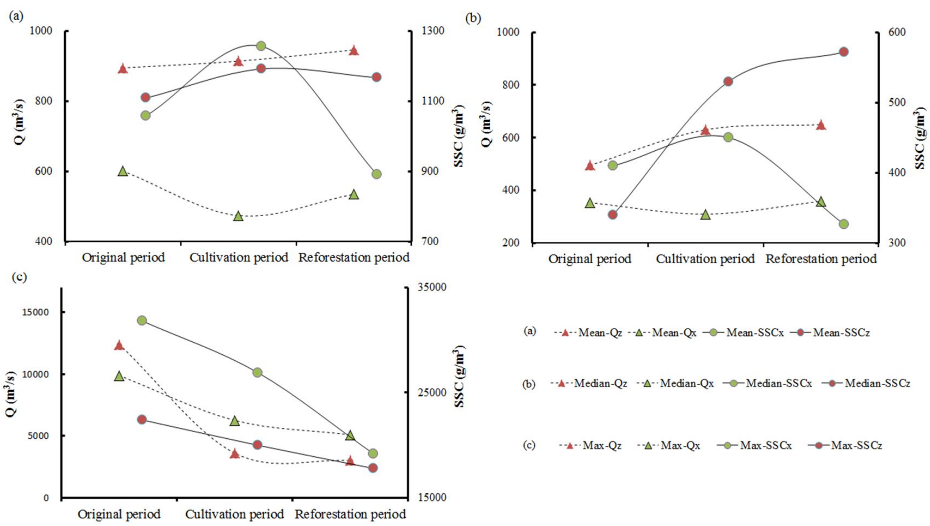

Figure 7

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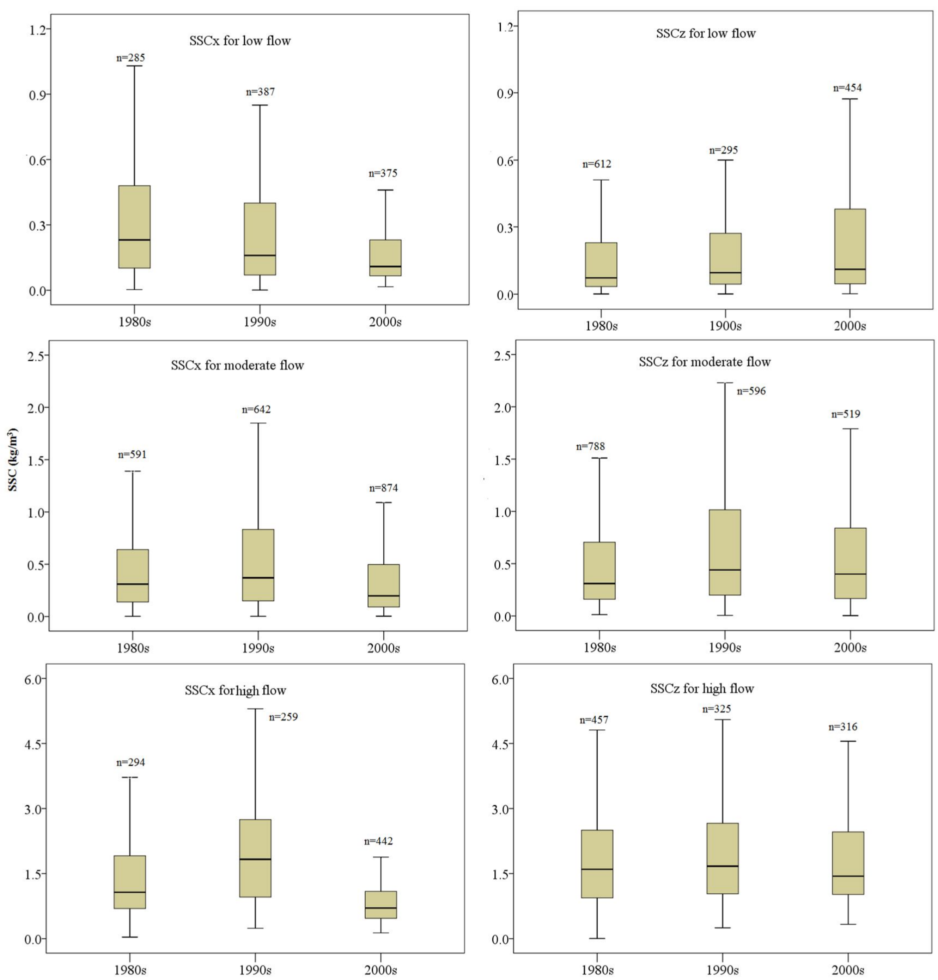

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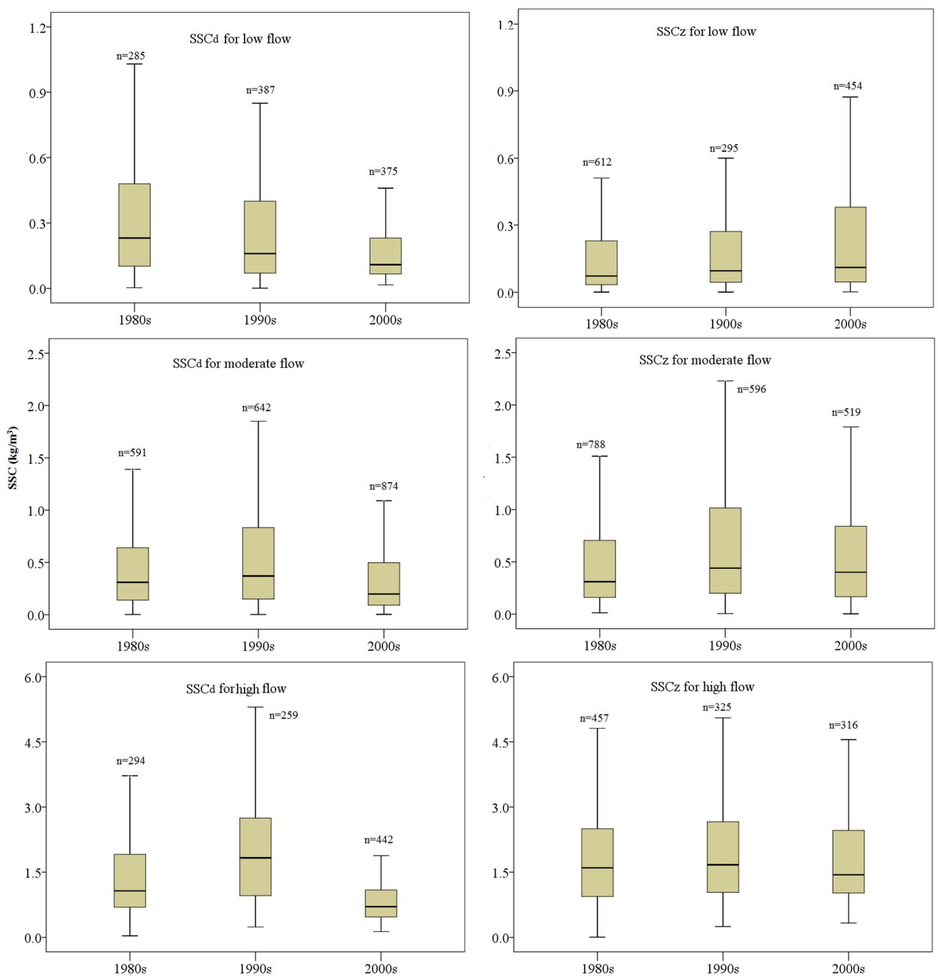

Figure 8

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