Dear Editor and Referees

Thank you for letter and for the referees' comments concerning our manuscript entitled "Dissolved Organic Carbon Driven by Rainfall Events from a Semi-arid Catchment during Concentrated Rainfall Season in the Loess Plateau, China" (ID: HESS201908). Those comments are all valuable and very helpful for improving this manuscript, as well as the important guiding significance to our study. We have made substantially revised our manuscript after reading the comments provided by the three referees, particularly in data interpretation and discussion part. We have carefully revised to the comments. Revised portion are marked in red in this response letter. The point-by-point corrections in the manuscript according to the referee's comments are as following:

Response to HESS-2019-8-RC1

Comment 1. Please illustrate the influences of DOC on the aquatic environments and climate change before enumerating the concentration ranges of DOC in different regions.

Response: Thanks for your suggestions. Line 33-36 describe the potential influence of DOC.

Line 33-36: For instance, high DOC concentrations can lead to water pollution and eutrophication, and thus have dramatic consequences on aquatic ecosystem services (Evans et al., 2005; Hu et al., 2016). In addition to ecological impacts, DOC in runoff also play an important role in social well-beings. High DOC concentrations will aggravate the complexation and adsorption of pesticides and heavy metals in hydrological process.

Comment 2. The previous paper about DOC export in the Loess Plateau should be presented in a more concise way and it is better to combine the lack of previous research and put forward your own hypothesis.

Response: Thanks for your suggestions. The lack of previous research and objective part has been rewritten and the details show in Line 69-79 of this manuscript:

Line 69-79: Less information is available on DOC export driven by rainfall event, which DOC flux is an important component in overall carbon balance for ecological restored catchment.

Therefore, the primary goal of this study is to investigate how variations of DOC concentration and flux response to a sequence of rainfall events from a restored catchment during concentrated rainfall season in the LPR. Specifically, the two objectives of this study were (1) to examine the dynamic changes in DOC concentration and flux and assess the difference in DOC export driven by various rainfall events, and (2) evaluate how rainfall, runoff, and antecedent factors affect DOC export from a catchment. To do so, we used high-frequency method to capture the temporal changes in DOC export and hydrological process driven by rainfall event within an ecological restored watershed in LPR. These results will provide evidence of DOC export response to rainfall events, especially driven by extreme events, which may be important for evaluating carbon balance and modeling DOC export through runoff at ecological restored catchment in LPR.

Comment 3. Please introduce the time/period of sampling or monitoring, how much rainfall events were monitored and how many samples were collected in the section of Field Monitoring and Sampling. The specific rainfall events mentioned in 3.2.2 and the reason for selecting these events should also be explained in 2.2.

Response: Thanks for your suggestions. Line 108-109 added the sampling information and Line 184-186 added the reason for selecting rainfall events.

Line 108-109: There were 278 samples collected for 22 hydrological processes induced by rainfall event over the monitoring period of June to September, 2016.

Line 184-186: Four rainfall events of total sampled events were chosen for detailed examine the relationship between DOC concentration (C_i) and flow rate in the hydrological process. These selected rainfall events represented 83% of the occurrence frequency of rainfall amount and the collected samples with high-frequency cover a complete of hydrological process during the monitoring period.

Comment 4. Please complete the name of the TOC analyser, like Vario TOC select or Vario TOC cube. I think it would be much better to describe what the 1% H_3PO_4 solution is used for.

Response: Thanks for your suggestions. These details show in Line 124-128 of this manuscript.

Line 122-126: DOC was recognized as the difference between total dissolved carbon (TDC) and dissolved inorganic carbon (DIC) for each sample (DOC=TDC-DIC). TDC and DIC were determined by Vario Select (Elementar, Germany), which included a high-temperature combustion furnace, a self-contained acidification module and a highly sensitive CO_2 detector. TDC was automatically measured by the combustion of a sample, whereas DIC was measured after acidified by 1% H_3PO_4 solution (phosphoric acid).

Comment 5. The meaning of DOC concentration and discharge should be consistent throughout the paper. DOC concentration has been defined as the flow-weighted mean DOC concentration. Ci and Qi were defined as the discharge and DOC in an individual runoff sample. However, the Y-axis in figure 5 corresponds to the discharge and DOC concentration of each sample. It is better to present flow-weighted mean DOC concentration in another way to distinguish it from the DOC in runoff samples and DOC in other studies.

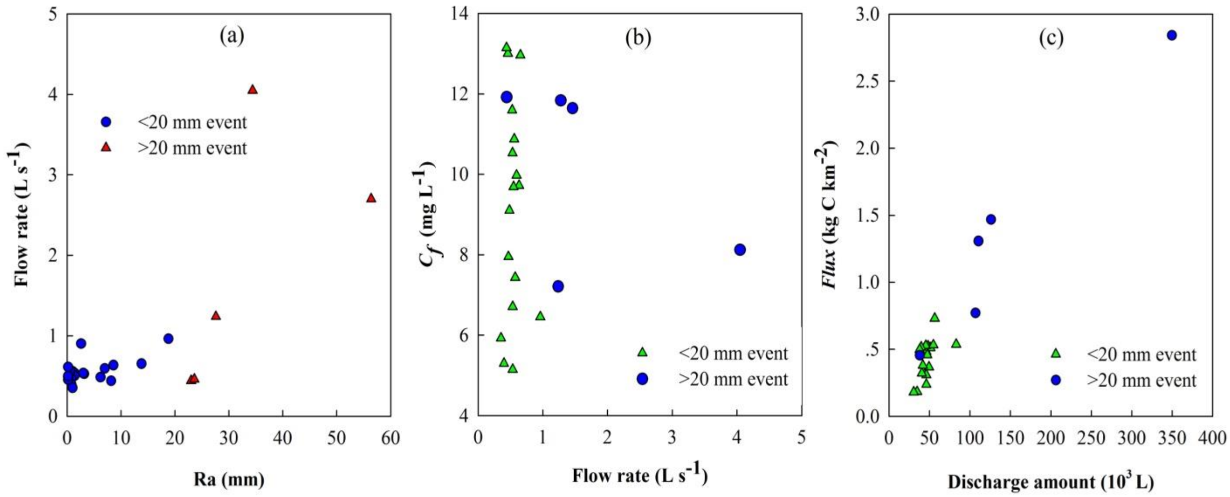
Response: Thanks for your suggestions. In order to differentiate event-based DOC concentration and instant DOC concentration, the details have been changed in text and figures.

Line 131-132: In the present study, the flow-weight mean concentration **(C_f)** was used to determine the average DOC concentration in a rainfall event. C_f was calculated by dividing the total DOC load by the total discharge in an event time.

Line 136-137: where, Q_i (L) is the discharge amount corresponding to sample i, which was calculated by flow rate and interval time; C_i (mg L^{-1}) is the DOC concentration in a runoff sample i;

***C_f* in Y axis of Figure 4-b:**

Figure 4



***Ci* in Y axis of Figure 5 and Figure 6**

Figure 5

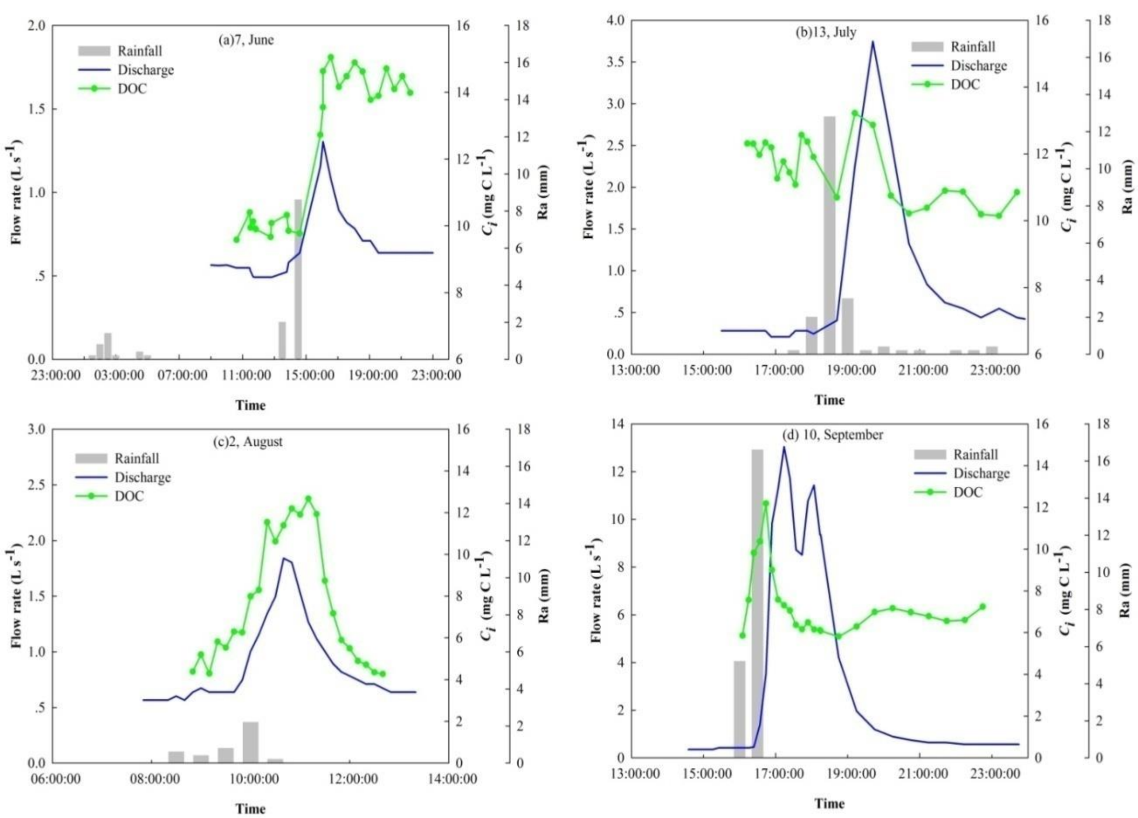
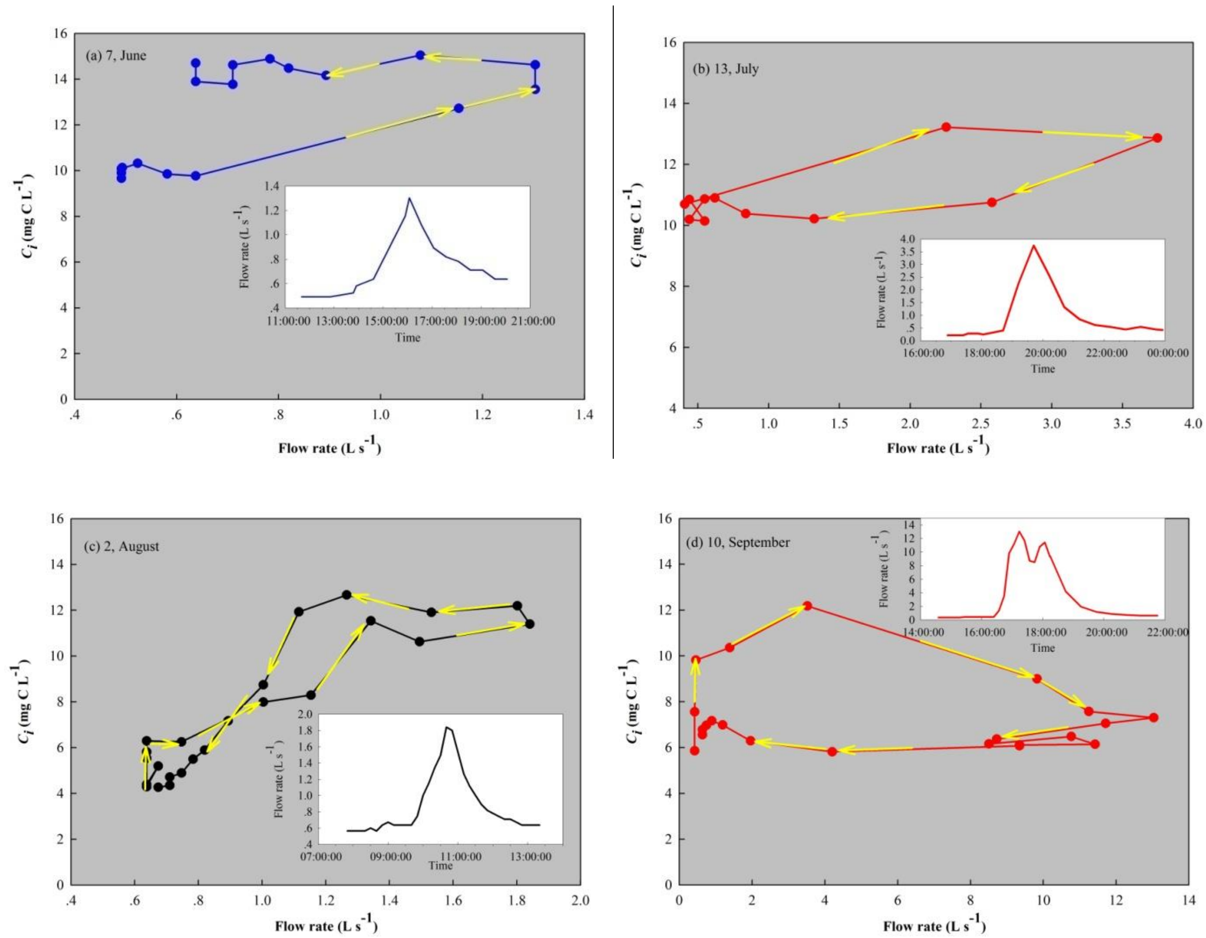


Figure 6



Comment 6. It would be better to use commas instead of semicolons. There should be a space between "7" and "and" (line 155-156). Do not use a colon to explain abbreviations (line 156).

Response: Thank you for your reminder. The details have changed in Line 143-147:

Line 143-147: These variables are Q (total discharge volume a rainfall), Ra (total rainfall amount in a rainfall event), R1, R7 and R14 (total rainfall amount in the 1, 7 and 14 days before the current rainfall event, respectively), SMC-7 and SMC-14 (soil moisture content in the 7 and 14 days before the current rainfall event), T_{air}-7 and T_{air}-14 (mean air temperature in the 7 and 14 days before the current rainfall event) and REI (interval days between the current and last rainfall event).

Comment 7. Please use the version information of SPSS instead of Statistics Package for Social Science.

Response: Thank you for your reminder. We have added the information in Line 149-151.

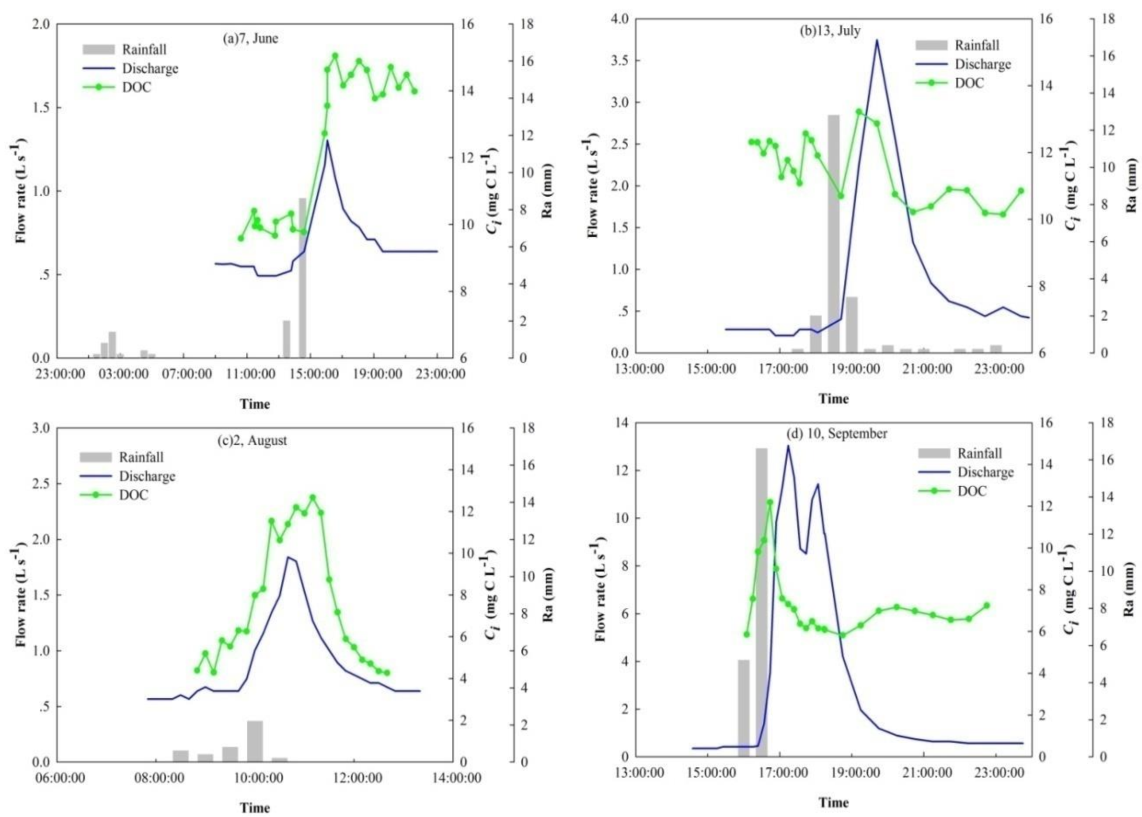
Line149-151: To analyze potential relationships among DOC concentration, flux, and selected variables, Pearson's test was performed using SPSS (Statistics Package for Social Science, Version 22).

Comment 8. I think the relationship between runoff and DOC concentration could be better explained by the DOC concentration of each runoff sample and its flow rate in the corresponding sampling period.

Response: Thank you for your reminder. The discharge in this manuscript is flow rate in a hydrological process. We have changed in the Line 176-179 and the Figure 5 showed the DOC concentration of each runoff sample and its flow rate in the corresponding sampling period.

Line 176-179: The relationship between flow rate and C_f for sampled rainfall events was shown in Figure 4-b. The C_f exhibited a poor relationship with flow rate, and the C_f was a more variable at low flow rate period compared to the high flow rate period, which is typically observed during consecutive rainfall events with high rainfall amount.

Figure 5



Comment 9. This part is the interpretation or analysis of the above results, and it should be included in the section of discussion with the citation.

Response: Thanks for your suggestions. This part has been rewritten and moved to discussion section Line 250-255.

Line250-255: The antecedent rainfall may increase connectivity in hydrology and DOC source contributed to runoff. Thus, the dilution effect diminished as flow rate decreased and the increased connectivity lead to a relatively higher DOC concentration during the falling limb (Hope et al., 1994; Ma et al., 2018; Williams et al., 2017). A clockwise hysteresis was observed in 13-July and 10-September. The rapid response of flow rate to rainfall can be attributed to the rainfall event with a shorter duration and larger rainfall amount. The higher discharge may bring a higher flushing capacity, thus an increased DOC concentration was observed during the rising limb (Blaen et al., 2017; Tunaley et al., 2017).

Comment 10. What is the difference between DOC export and DOC flux? DOC export and flux were mixed in several parts of the paper affecting readers' understanding of the study. Please explain the specific meaning of DOC flux/export.

Response: Thanks for your suggestions. In this study, *Flux* emphasize the amount of DOC loaded by a rainfall event and DOC export mean a transport process occurs in a hydrological process from a catchment. Line 136-137 has added the specific meaning of *Flux*.

Line 136-137: *Flux* (kg km^{-2}) is the quantity of DOC driven by a rainfall event for in the study region; and, *s* is the catchment area (km^2).

Comment 11. Substitute "uses" with "used". As shown in figure 2-b, the DOC concentration looked like the average DOC concentration daily or per rainfall event, rather than the results of each collected runoff samples. This figure did not show the high-frequency monitoring in your study.

Response: Thanks for your suggestions. Figure 2-b showed the event-driven DOC concentration during the monitoring period. However, the high-frequency monitoring mean the runoff samples collected in a hydrological process in this manuscript, details showed in method part in Line 102-104:

Line 102-104: High-frequency monitoring was carried out in a rainfall event based hydrological process, thus the ISCO was set to acquire samples every 10 min from the first 12 runoff samples and another 12 were sampled every 30 min.

The "uses" revised to "used" in Line 226-228:

Line 226-228: In this study, we used an in-situ auto- and high-frequency monitoring method to observe temporal changes in hydrological and DOC concentration for an event-based sampling period during the concentrated rainfall season (June-September, 2016) (Figure 2-b).

Comment 12. Is the result of the greater DOC flux with a large discharge obtained from your study? If not, it is better not to compare the result about DOC flux in previous studies with the result of DOC concentration in your study.

Response: Thanks for your suggestions. In line 230-245, these words describe the monthly DOC flux showed no linear relationship with discharge amount and discussed the potential reason. In line 272-276, these words discussed the event-driven DOC flux during the monitoring period. Details showed as following:

Line 230-245: Monthly DOC fluxes were not clearly correlated with discharge amount. The flow-weighted DOC concentrations decreased during the experimental period, which differed from the greater DOC flux with a large discharge (Chen et al., 2012; Cooper et al., 2007). Furthermore, the monthly DOC fluxes were negatively correlated with the discharge amount from June to August 2016. The DOC concentration was higher in June and decreased in August. This was reasonable because the accumulated soil organic carbon can be flushed by runoff in early rainfall period, and the DOC concentration may be diluted by increased runoff (Blaen et al., 2017; Chen et al., 2012). In addition, in combination with the increased discharge amount, the decreased concentration led to a decrease in monthly DOC flux from June to August. This could be explained by the relative changes in DOC concentrations being higher than changes in monthly discharge, indicating that the decreased concentration may outweigh the effect of increased discharge. However, the exception occurred in September, while increased DOC flux over the other three months was mainly due to a smaller increase in DOC concentration. These results were also probably associated with rainfall amount, land cover and runoff flow path (Laudon et al., 2004; Soulsby et al., 2003). For example, crops planted in the check-dam field were harvested, and the ratio of rainfall to runoff increased in September. The soil soluble organic carbon is more likely to leach through macropores from check-dam farmland into runoff, which further increased the DOC concentration in runoff. Thus, it led to a slight increase in DOC flux in September. Therefore, it could be inferred from these results that DOC flux may depend on runoff flushing capacity and flow path in a restored and check-dam catchment.

Line 261-272: For event-driven flux, the DOC flux is a function of total runoff discharge and DOC concentration (C_f). DOC flux showed a positive linear relationship with runoff discharges, which is not surprising and parallel with studies reported by Clark et al. (2007) and Ma et al. (2018). In addition, it should be noted that the DOC flux induced by larger rainfall amount was higher than flux driven by light rainfall, whereas the C_f showed no evident difference for the selected rainfall events. Thus, the greater DOC flux clearly showed that the DOC export was close linked to hydrologic process induced by various amount of rainfall event in LPR.

Comment 13. line 266-267, line 274-277, line 300-301; and line 308-310; The above sentences are the description of the figures or tables and it is best to move those to the result section.

Response: Thanks for your suggestions. These sentences have been moved to the results part and details showed as following:

Line 168-169: In addition, Figure 4-a showed the relationship between flow rate and rainfall amount during June to September.

Line 169-170: This indicated that event-driven flow rate varied with rainfall amount, and thus suggested that runoff discharges are highly sensitive to larger rainfall amount with greater than 20 mm in this area.

Line 179-182: Table 2 showed the correlation between C_f and a set of factors in all sampled rainfall events during the study period. On one hand, the C_f was positively correlated with rainfall amount (Ra) and R7. On the other hand, the C_f was extreme significantly and negatively correlated with SMC7 and SMC14.

Line 214-217: The relationship between event-based DOC flux and runoff discharge amount is shown in Figure 4-c. The DOC flux showed a positive linear relationship with the runoff discharge amount, especially for violent rainfall events. The DOC flux was more variable in lower runoff discharge conditions. In general, event-based DOC flux was significantly and positively correlated with Q, Ra, R1 and R, as showed in Table 2.

Comment 14. Why do you take the 20 mm rainfall amount as the break point to do the linear regression analysis respectively?

Response: Thanks for your suggestions. We have added a finding conducted by Yang and details show in the following:

Line 156-159: All the rainfall events in between June to September were grouped into four grades: <5 mm (Light rainfall), 5-10 mm (Moderate rainfall), 10-20 mm (Heavy rainfall), and >20 mm (Violent rainfall) according to rainfall amount classification (Yang et al., 2018).

Comment 15. line 288; The subtitle is too broad and general. Rainfall, one of the most important factors affecting DOC concentration, has been mentioned in 4.1, but not been fully discussed.

Response: Thanks for your suggestions. The subtitle has changed into "4.2 Potential Factors Influence on DOC Export". We have added some information in this discussion part and details show in the following:

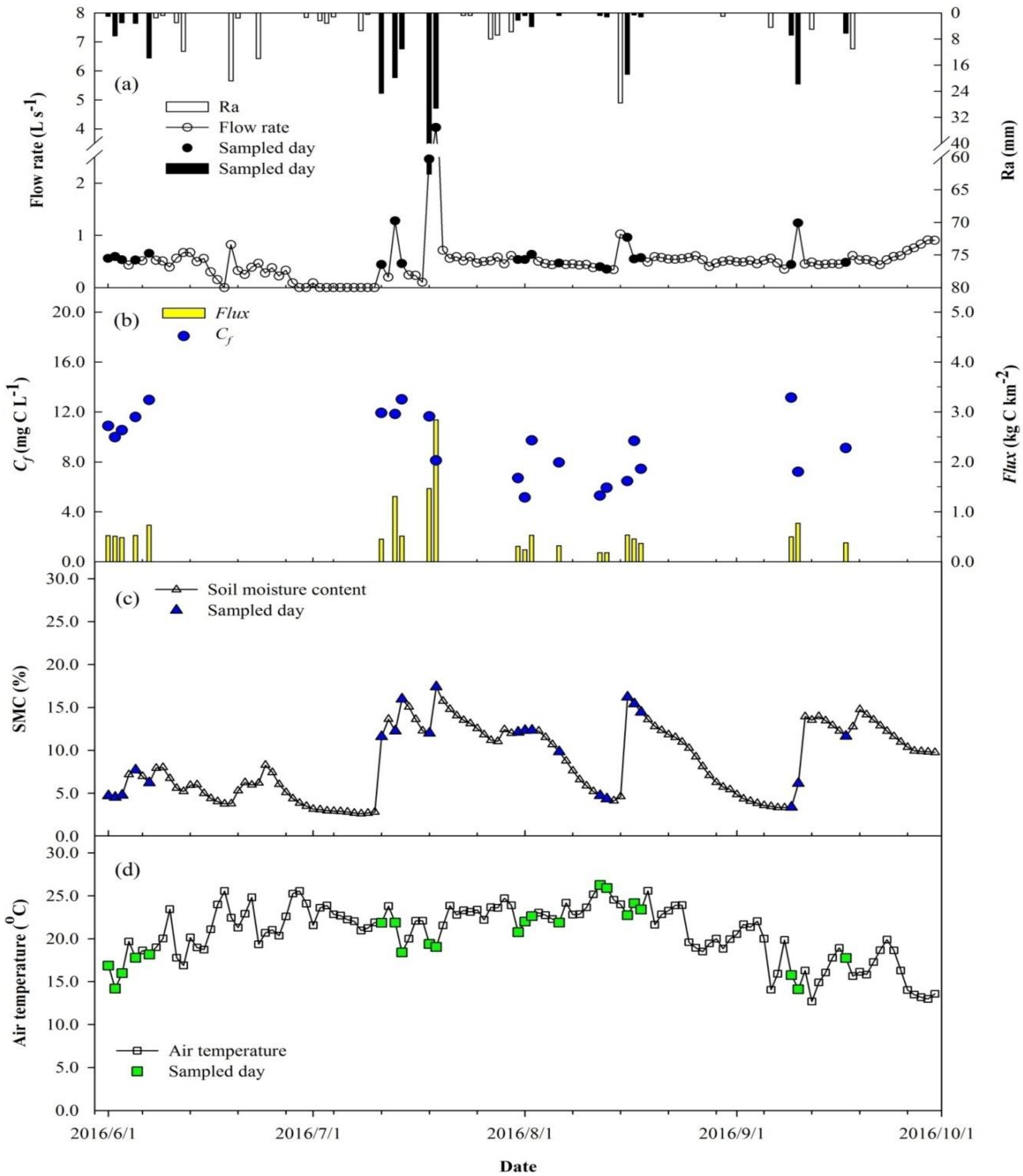
Line282-314: The infrequent and amount of violent rainfall events strongly influence the runoff discharges and soil moisture, which in turn impact on DOC during or later export from a catchment. In this study, temporal variations of rainfall, air temperature and soil moisture content were continuously monitored throughout the study period to provide detailed information describing the antecedent and current conditions. Positively correlation between Ra, R7 and C_f suggested that the combination of the current rainfall amount and the accumulated rainfall before a current rainfall event are important. R7 may reflect the antecedent hydrological condition and Ra represent the current rainfall input into the catchment, resulting in well hydrological connectivity, and more DOC source may contribute to runoff. Therefore, C_f can by strongly influenced by Ra and R7 due to the hydrological properties of the catchment. Apart from the hydrological changes, the antecedent soil moisture also played an important role in C_f and showed an extreme significantly and negatively correlated with SMC7 and SMC14 (Table 2). The soil moisture content was continuously dried and then effectively rewetted under a specific rainfall amount, as supported by the soil moisture variations shown in Figure 2-c. These results were also consistent with Yang et al. (2018), who found that the threshold of rainfall effectively recharged into soil was 20-26 mm for grassland and forestland in LPR. Therefore, the pattern of soil moisture dry-wet cycle may affect event-driven DOC concentration, and this highlights the importance of soil moisture condition in DOC export (Figure 7). The higher DOC concentrations from June to middle July coincided with light rainfall, and thus rainfall recharge into soil moisture. This is probably attributed to inactive microbial activity, caused by the relatively lower soil moisture (Jager et al., 2009). The DOC concentration decreased with increased soil moisture content, particularly in July-18 with a total rainfall amount of 56.4 mm. On one hand, violent rainfall events may induce a higher discharge, causing a dilution effects on DOC concentration. On the other hand, the rainfall water may effectively replenish soil moisture content, and thus stimulate a higher decomposition of soil carbon under wet and higher temperature condition. Then, the relative decreased DOC concentrations were observed in a drying soil moisture condition for the next rainfall events, which may attribute to an exhaustion of DOC (Laudon et al., 2004). These findings were similar to previous studies by Tunaley et al. (2017), who reported a strong influence of dry antecedent conditions on DOC export response to rainfall event.

For event-based flux, DOC flux was significantly and positively correlated with Q, Ra, R1 and R7. The Q and Ra reflect the direct effect of current rainfall and hydrological processes during a rainfall event, while R1 and R7 refer to the antecedent rainfall conditions and reflect indirect effects on DOC export. These results agreed with previous studies demonstrated by Blaen et al. (2017), who noted that antecedent conditions and rainfall were key drivers of DOC export during a rainfall event. Cooper et al. (2007) also concluded that DOC export is largely governed by interactions between hydrological and meteorological factors and carbon biogeochemical process. Overall, these results suggested that rainfall is a key factor influencing hydrological process, and thus DOC export from an ecological restored catchment in LPR. Apart from the increased soil carbon driven by increased vegetation (Wang et al., 2011b), the weaken hydrological process induced by increased vegetation may also cause a less terrestrial carbon export from a catchment. Therefore, our results highlight the need for research not only into the hydrological process and soil carbon cycle, but the integration of carbon export driven by a sequence of rainfall events across spatiotemporal scales to understand the carbon balance in a restored catchment in LPR.

Comment 16. Figure 2; Try to use shading or background fill to distinguish the values of sampling days instead of using different colored dots.

Response: Thanks for your suggestions. The Figure 2 has been revised as following:

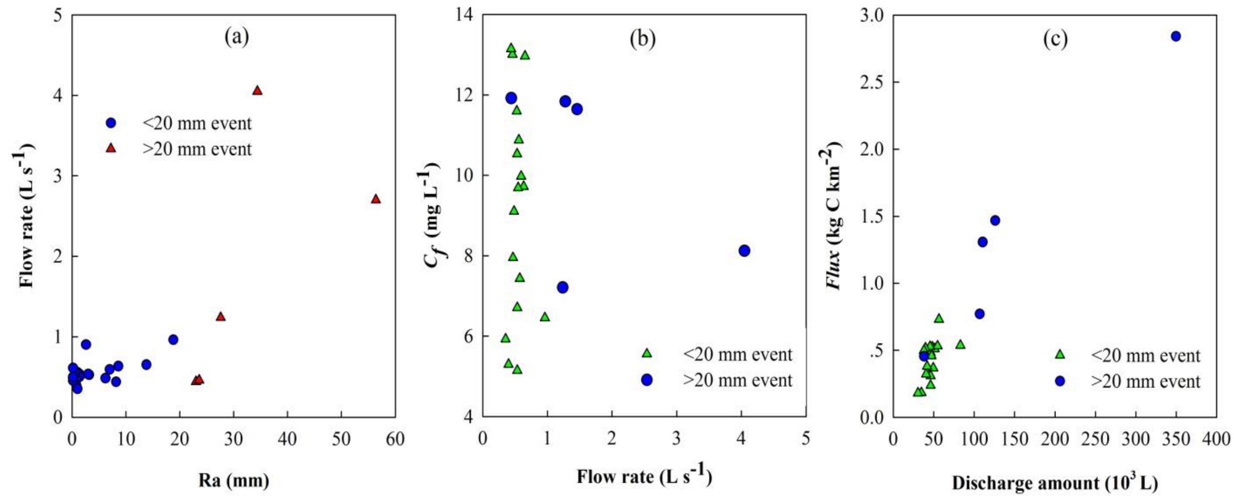
Figure 2



Comment 17. Figure 4; Is the regression curve in the right side of figure 4 fitted according to all sampled rainfall events or according to >20 mm rainfall events? Please indicate (a) and (b) in the figure 4.

Response: Thanks for your suggestions. For the Figure 4-c, we removed the relationship between DOC flux and discharge amount due to the flux was calculated by discharge amount. Thus, the Figure 4 has been changed and added (a), (b), (c), respectively. The details shown in Figure 4 as following:

Figure 4



Anonymous Referee #2

Comment 1. L43-50: these piled data didn't give a clear background on DOC export. They should be re-organized and present in term of different catchment characteristics.

Response: Thanks for your suggestions. These sentences of the introduction have been re-written in Line 40-59 as detail shown as following:

Line 40-57: DOC exported from catchments has attracted great attention in the last two decades due to global concerns about potential influences on the global carbon cycle and climate change (Laudon et al., 2004; Raymond et al., 2013). The transport of terrestrial DOC to runoff is strongly influenced by hydrological process, soil carbon cycle and climatological factors. Hydrological process driven by rainfall event plays an important role in controlling terrestrial DOC from soil pool to runoff. Previous studies have shown that the release of DOC concentrations ranged from 0.5 to 50 mg L^{-1} for global catchments (Mulholland, 2003). For instance, Clark et al. (2007) found that DOC concentration ranged between 5-35 mg L^{-1} with a highly variable in rainfall events from a peatland catchment, and a study by Blaen et al. (2017) showed that the DOC concentration ranged from 5.4 to 18.9 mg L^{-1}. Similar results were reported by Ran et al. (2018), who found that DOC concentration ranged from 1.4 to 9.5 mg L^{-1} in the Wuding River in the LPR. Such studies highlighted that the importance of hydrological process on DOC transport (Billett et al., 2006; Dawson et al., 2002; Inamdar et al., 2006). Different rainfall events may alter hydrological connectivity or the flow path, which in turn lead to a varied hydrological connectivity and DOC source contributing to runoff. Moreover, the intensity and frequency of rainfall event not only influenced the current hydrological and DOC loading processes, but also changed the soil moisture conditions. The latter point may be particularly important in soil biogeochemical cycle. For example, DOC concentration may increase due to accumulated soil organic carbon after a dry period (Jager et al., 2009). In addition, variations in the magnitude and frequency of precipitation are one of manifestations of climate change, and thus, changes in hydrological process induced by climate change are also impact on the transport of terrestrial DOC. Therefore, understanding the dynamic and magnitude of DOC export from catchment is an important component of prediction DOC flux under the circumstance of future climate change.

Comment 2. The knowledge gap is not well stated.

Response: Thanks for your suggestions. The knowledge gap and objective part has been reorganized as following:

Line 69-79: Less information is available on DOC export driven by rainfall event, which DOC flux is an important component in overall carbon balance for ecological restored catchment.

Therefore, the primary goal of this study is to investigate how variations of DOC concentration and flux response to a sequence of rainfall events from a restored catchment during concentrated rainfall season in the LPR. Specifically, the two objectives of this study were (1) to examine the dynamic changes in DOC concentration and flux and assess the difference in DOC export driven by various rainfall events, and (2) evaluate how rainfall, runoff, and antecedent factors affect DOC export from a catchment. To do so, we used high-frequency method to capture the temporal changes in DOC export and hydrological process driven by rainfall event within an ecological restored watershed in LPR. These results will provide evidence of DOC export response to rainfall events, especially driven by extreme events, which may be important for evaluating carbon balance and modeling DOC export through runoff at ecological restored catchment in LPR.

Comment 3. Be more specific about the experiment duration. How long/how many rainfall events have you been monitoring and sampling?

Response: Thanks for your suggestions. Line 108-109 added the sampling information.

Line 108-109: There were 278 samples collected for 22 hydrological processes induced by rainfall event over the monitoring period of June to September, 2016.

Comment 4. The author should either consider combining the result and discussion sections OR separating them clearly in the writing. There are multiple places that the results been re-stated in discussion or discussed the result right after without citation.

Response: Thanks for your suggestions. Some sentences in discussion part has been moved to the results part and details showed as following:

Line 168-169: In addition, Figure 4-a showed the relationship between flow rate and rainfall amount during June to September.

Line 169-170: This indicated that event-driven flow rate varied with rainfall amount, and thus suggested that runoff discharges are highly sensitive to larger rainfall amount with greater than 20 mm in this area.

Line 179-182: Table 2 showed the correlation between C_f and a set of factors in all sampled rainfall events during the study period. On one hand, the C_f was positively correlated with rainfall amount (Ra) and R7. On the other hand, the C_f was extreme significantly and negatively correlated with SMC7 and SMC14.

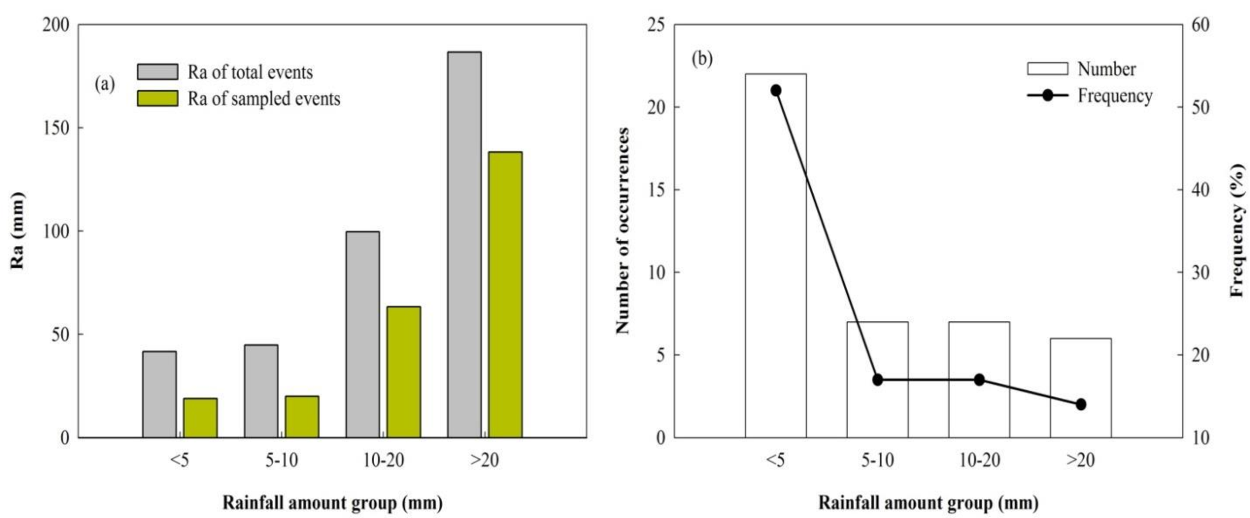
Line 214-217: The relationship between event-based DOC flux and runoff discharge amount is shown in Figure 4-c. The DOC flux showed a positive linear relationship with the runoff discharge amount, especially for violent rainfall events. The DOC flux was more variable in lower runoff discharge conditions. In general, event-based DOC flux was significantly and positively correlated with Q, Ra, R1 and R, as showed in Table 2.

Comment 5. I'm confused with the way you separate the rainfall events into 4 groups. In Figure 3 you stated in x-axis was rainfall intensity, but the unit was mm, not mm/h. Why do you define rainfall intensity based on accumulated rainfall depth? In the Yang et al. (2018) paper you referred, they denoted the rainfall replenishment in mm to effectively recharge the soil water.

Response: Thanks for your suggestions. Indeed, the rainfall events were grouped by rainfall amount and the Figure 3 has been changed. According to Yang's results, the threshold of rainfall amount mean rainwater can effectively recharge the soil water in LPR, which may affect soil moisture content. This is why we selected this classification. Thus, we choose the parameter of rainfall amount to analyze in this manuscript.

Line 156-158: All the rainfall events in between June to September were grouped into four grades: <5 mm (Light rainfall), 5-10 mm (Moderate rainfall), 10-20 mm (Heavy rainfall), and >20 mm (Violent rainfall) according to rainfall amount classification (Yang et al., 2018).

Figure 3:



Line 246-260: Despite the facts that the DOC export varied in different months, there were also differences in DOC concentration and flux response to a rainfall event. DOC concentrations exhibited different dynamic changes throughout an event-driven hydrological process. In our result, the anticlockwise hysteresis between DOC concentration and flow rate was observed at 6-June. The peak DOC concentration

was delayed compare to peak flow rate. These results may be attributed to a 5.2 mm rainfall was happen earlier than the maximum rainfall at 6-June (Figure 5-a). The antecedent rainfall may increase connectivity in hydrology and DOC source contributed to runoff. Thus, the dilution effect diminished as flow rate decreased and the increased connectivity lead to a relatively higher DOC concentration during the falling limb (Hope et al., 1994; Ma et al., 2018; Williams et al., 2017). A clockwise hysteresis was observed in 13-July and 10-September. The rapid response of flow rate to rainfall can be attributed to the rainfall event with a shorter duration and larger rainfall amount. The higher discharge may bring a higher flushing capacity, thus an increased DOC concentration was observed during the rising limb (Blaen et al., 2017; Tunaley et al., 2017). Moreover, the close link of DOC source to runoff may lead to a rapid increased in DOC concentration. A figure-of-eight hysteresis was observed in 2-August. due to the DOC concentration keep pace with flow rate during the rising and falling limb. Moreover, the event-driven DOC concentration at 2-August showed no distinct difference with other three higher rainfall amount events. These results suggested that a lower discharge induced by lower rainfall amount have a more complex and larger influence on DOC concentration from a catchment in LPR.

Comment 6. The major finding you stated was higher DOC export with low DOC concentration. I have several questions about this finding: In Figure 4, you stated DOC concentration depressed with increased discharge for greater intensity.

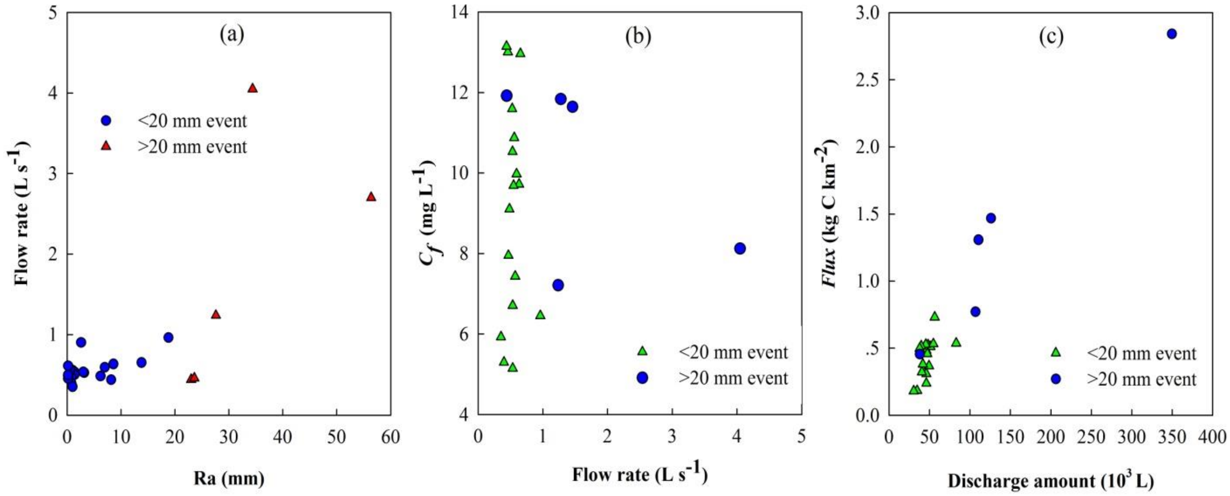
Response: Thanks for your suggestions. The conclusion has been rewritten as following:

Line 321-324: These results showed that higher DOC flux with low DOC concentration related to higher discharge and its dilution effects in a hydrological process driven by larger rainfall amount. The diluted DOC concentration induced by increased discharges contributed slightly to difference in DOC flux, due to total runoff discharge is a major variable for flux.

Comment 7. How are you sure since you only have 5 points with r2 value of 0.38. Is this correlation significant? In Figure 5, DOC do show positive relationship with discharge within individual event, how do you explain this contrary?

Response: Thanks for your suggestions. The regression has been removed. The results shown in Figure 5 has been reorganized in discussion part:

Figure 4



Comment 8. L32: insert a summary sentence before "For instance, high DOC. . .". The following statements come from nowhere and it's confusing.

Response: Thanks for your suggestions. The first paragraph in introduction has been reorganized and the details show in Line 28-39 of this manuscript:

Line 28-39: Dissolved organic carbon (DOC), often defined as the solute filtered through <0.45μm pore size, is regarded as one of the active constituents and provides a biologically available carbon source for organisms (Raymond and Saiers, 2010). The estimated DOC flux of terrestrial organic carbon through major worldwide rivers to ocean is from 0.45 to 0.78 Pg C y^{-1}(Drake et al., 2018; Hedge et al., 1997; Ran et al., 2018). The substantial magnitude of flux suggests that the DOC export on a global scale acts as one of the crucial processes of linking between terrestrial and aquatic ecosystem (Battin et al., 2008; Raymond et al., 2013; Raymond and Saiers, 2010). For instance, high DOC concentrations can lead to water pollution and eutrophication, and thus have dramatic consequences on aquatic ecosystem services (Evans et al., 2005; Hu et al., 2016). In addition to ecological impacts, DOC in runoff also play an important role in social well-beings. High DOC concentrations will aggravate the complexation and adsorption of pesticides and heavy metals in hydrological process. Therefore, the quality of domestic water could be damaged and it might potentially lead to adverse impacts on human health, such as increased risk of cancer, diabetes, or other diseases (Bennett et al., 2009; Ritson et al., 2014). Therefore, it is urgent to improve the associated knowledge on DOC export variability and develop a mechanistic understanding of DOC export from catchments.

Comment 9. give the time period for average annual temperature and precipitation. Is 535 mm only coming from rainfall or also including other type of precipitation?

Response: Thanks for your suggestions. We have added some information about the precipitation and details show in the following:

Line 86-88: The climate of this catchment is situated in a semi-arid continental monsoonal climate with an average annual temperature of 9.6℃ and average annual precipitation is 535 mm during the period from 1951 to 2012 (Li and Wang, 2015).

Comment 10. state specific land alteration in “represent an area with altered land use that has. . .”

Response: Thanks for your suggestions. These details show in Line 92-94 of this manuscript

Line 92-94: The proportion of sloping cropland has remarkably decreased from 16.9% in 1998 to 0.1% in 2006. The forestland increased from 15.2% in 1998 to 37.4% in 2006 since implemented the 'Grain-for-Green' and engineering measures (Wang et al., 2011b).

Comment 11. the part “In addition, the aim of hydrological. . .” should be stated before you introduce the meteorological station, and also should be condensed.

Response: Thanks for your suggestions. The sentence has been moved forward to Line 109-110.

Line 109-110: In addition, the aim of hydrological and meteorological factor monitoring was to characterize the temporal changes of catchment condition.

Comment 12. L133: “microbiologically biodegrade” to “microbially degrade”.

Response: Thanks for your suggestions. The “microbiologically biodegrade” has been changed to “microbially degrade” in Line 118-119.

Line 118-119: In the Yangjuangou catchment, researchers resided in the field observatory station and treated the samples immediately after a rainfall event to ensure that the DOC in the sampled water did not microbially degrade.

Comment 13. L138-L140: give CV of procedure accuracy.

Response: Thanks for your suggestions. We added the CV of procedure accuracy in Line 127-128:

Line 127-128: In order to control quality, each sample is determined through analysis of two replicate and the coefficient of variation of tested results was less than 10%.

Comment 14. L149-L156: this section should be in laboratory analysis or an independent section rather in data analysis.

Response: Thanks for your suggestions. The section has been reorganized.

Line 129-152:

2.4 Data Analysis

2.4.1 Event-driven DOC Concentration and Flux Calculation

2.4.2 Variables related to Event-driven DOC Transport

2.4.3 Statistical analysis

Comment 15. L166: “in June to September” to “in between June and September”.

Response: Thank you for your reminder.

Line 156-158: All the rainfall events in between June to September were grouped into four grades: <5 mm (Light rainfall), 5-10 mm (Moderate rainfall), 10-20 mm (Heavy rainfall), and >20 mm (Violent rainfall) according to rainfall amount classification (Yang et al., 2018).

Comment 16. L186: I suggest to open this paragraph with sentence "In general, runoff discharge tended to follow the pattern of rainfall amount in the study catchment."

Response: Thanks for your suggestions. we changed at the beginning of this paragraph in Line 163:

Line 163: In general, runoff discharge tended to follow the pattern of rainfall amount in the study catchment.

Comment 17. L189: where did the value "34.70 mg L^{-1}" come from? I didn't see this value in Figure 2 or Figure 5.

Response: Thank you for your reminder. The value has been changed in Line 175-176:

Line 175-176: For the event-driven DOC concentration, the flow-weight mean DOC concentration (C_f) ranged from 4.08 to 15.66 mg L^{-1} for all sampled rainfall events during June to September.

Comment 18. L191: "DOC concentration were less variable during June to September", less compare to what?

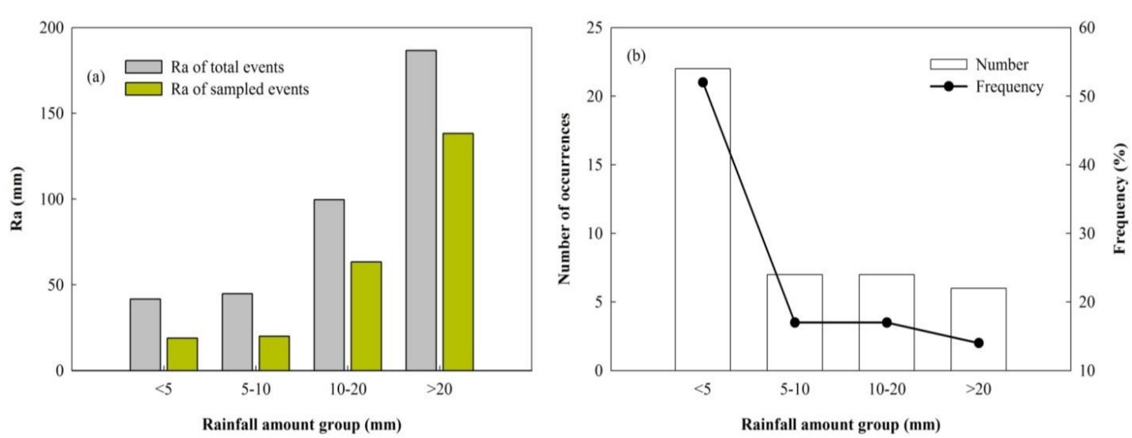
Response: Thanks for your suggestions. We revised this sentence in Line 185-186:

Line 174-175: There were less variations in the mean DOC concentration among monitoring months.

Comment 19. Figure 3: see previous comments about the grouping.

Response: Thanks for your suggestions. The rainfall events were grouped by rainfall amount and the Figure 3 has been changed.

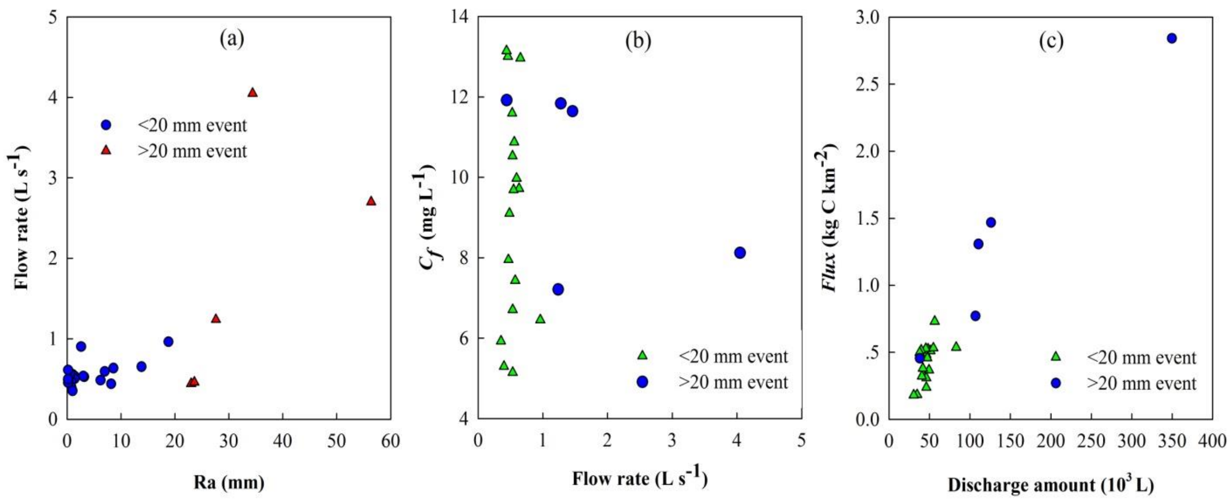
Figure 3



Comment 20. Figure 4: Is the second figure necessary? DOC flux is calculated based on discharge. Why present a variable that is highly dependent on the other variable?

Response: Thanks for your suggestions. hanks for your suggestions. For the Figure 4-c, we removed the relationship between DOC flux and discharge amount due to the flux was calculated by discharge amount. Thus, the regression has been removed and the details shown as following:

Figure 4

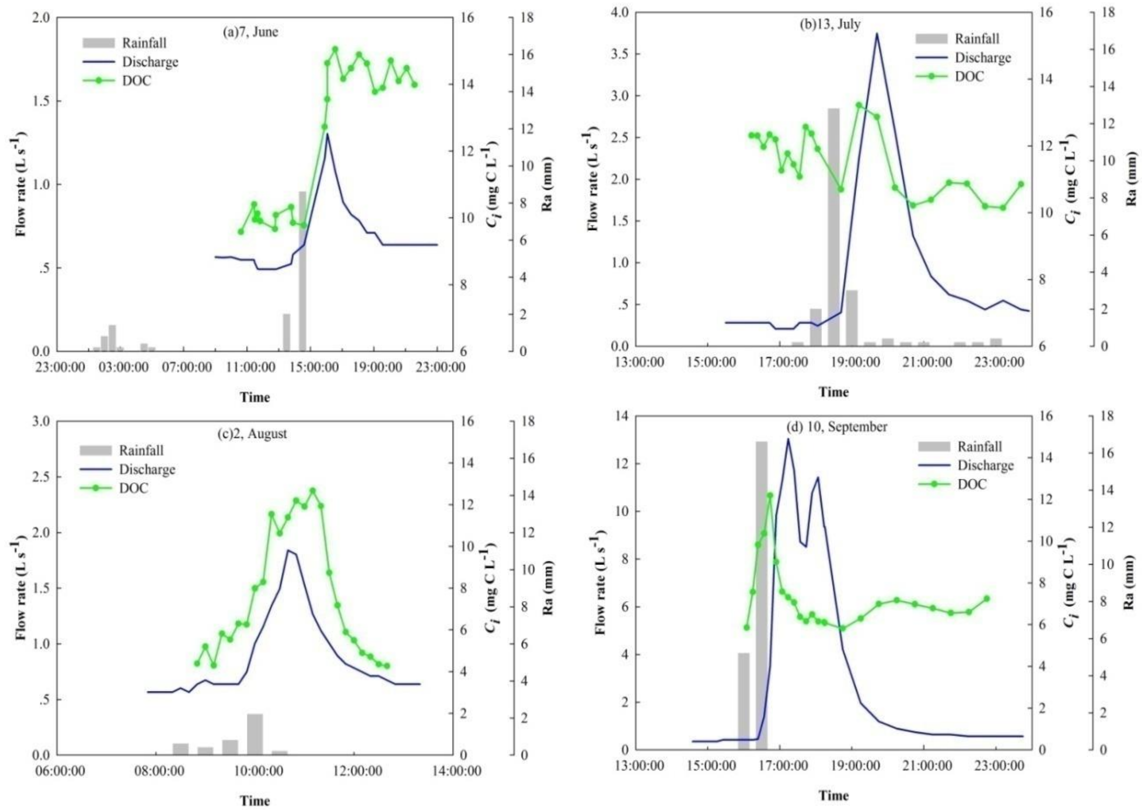


Comment 21. Figure 5: explain in result section why did you choose these four events? Do they show different rainfall intensity? Axis of DOC concentration could be in the same scale.

Response: Thanks for your suggestions. Line 184-186 has been added and explained why we choose these four events. The axis of DOC concentration in Figure 5 has been change to the same scale.

Line 184-186: Four rainfall events of total sampled events were chosen for detailed examine the relationship between DOC concentration (C_i) and flow rate in the hydrological process. These selected rainfall events represented 83% of the occurrence frequency of rainfall amount and the collected samples with high-frequency cover a complete of hydrological process during the monitoring period.

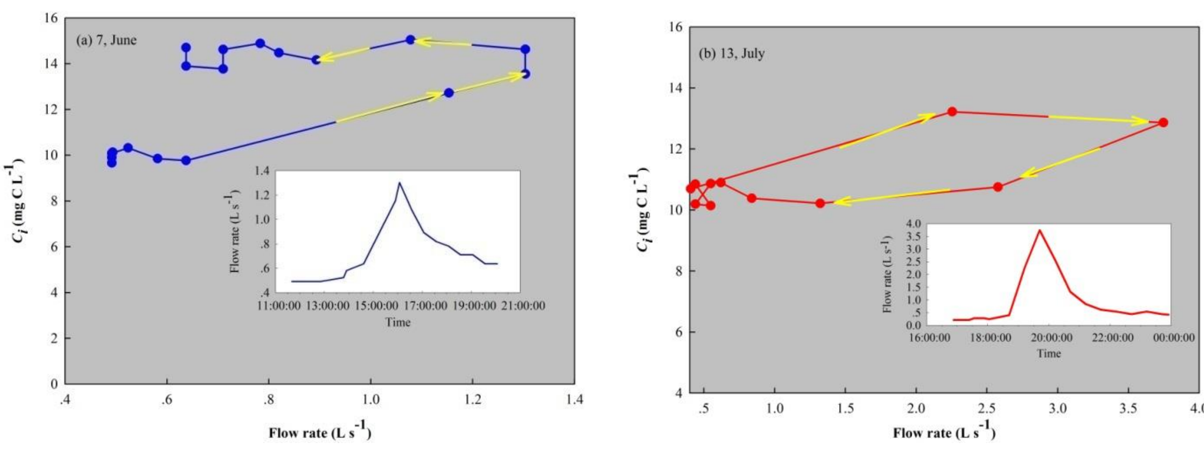
Figure 5

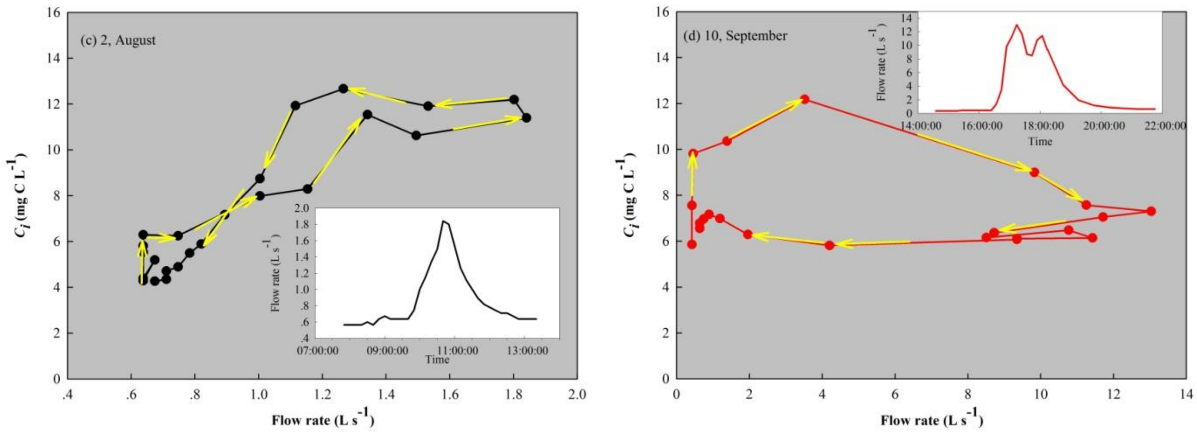


Comment 22. Figure 6: Axis of DOC concentration could be in the same scale.

Response: Thanks for your suggestions.

Figure 6





Response to HESS-2019-8-RC3

Comment 1. The authors declared that there were no reports to the LPR, but I do not think that is the reason they conducted such a study.

Response: Thanks for your suggestions. The Line 72-79 has been revised and explained why we conducted this study.

Line 72-79: Therefore, the primary goal of this study is to investigate how variations of DOC concentration and flux response to a sequence of rainfall events from a restored catchment during concentrated rainfall season in the LPR. Specifically, the two objectives of this study were (1) to examine the dynamic changes in DOC concentration and flux and assess the difference in DOC export driven by various rainfall events, and (2) evaluate how rainfall, runoff, and antecedent factors affect DOC export from a catchment. To do so, we used high-frequency method to capture the temporal changes in DOC export and hydrological process driven by rainfall event within an ecological restored watershed in LPR. These results will provide evidence of DOC export response to rainfall events, especially driven by extreme events, which may be important for evaluating carbon balance and modeling DOC export through runoff at ecological restored catchment in LPR.

Comment 2. They claimed that this study highlighted the interaction of rainfall and antecedent conditions for DOC exports in a catchment, but they did not say what interactions and what effects.

Response: Thanks for your suggestions. The Line 282-303 explained the antecedent condition for DOC exports.

Line 282-303: The infrequent and amount of violent rainfall events strongly influence the runoff discharges and soil moisture, which in turn impact on DOC during or later export from a catchment. In this study, temporal variations of rainfall, air temperature and soil moisture content were continuously monitored throughout the study period to provide detailed information describing the antecedent and current conditions. Positively correlation between Ra, R7 and C_f suggested that the combination of the current rainfall amount and the accumulated rainfall before a current rainfall event are important. R7 may reflect the antecedent hydrological condition and Ra represent the current rainfall input into the catchment, resulting in well hydrological connectivity, and more DOC source may contribute to runoff. Therefore, C_f can by strongly influenced by Ra and R7 due to the hydrological properties of the catchment. Apart from the hydrological changes, the antecedent soil moisture also played an important role in C_f and showed a extreme significantly and negatively correlated with SMC7 and SMC14 (Table 2). The soil moisture content was continuously dried and then effectively rewetted under a specific rainfall amount, as supported by the soil moisture variations shown in Figure 2-c. These results were also consistent with Yang et al. (2018), who found that the threshold of rainfall effectively recharged into soil was 20-26 mm for grassland and forestland in LPR. Therefore, the pattern of soil moisture dry-wet cycle may affect event-driven DOC concentration, and this highlights the importance of soil moisture condition in DOC export (Figure 7). The higher DOC concentrations from June to middle July coincided with light rainfall, and thus rainfall recharge into soil moisture. This is probably attributed to inactive microbial activity, caused by the relatively lower soil moisture (Jager et al., 2009). The DOC concentration decreased with increased soil moisture content, particularly in July-18 with a total rainfall amount of 56.4 mm. On one hand, violent rainfall events may induce a higher discharge, causing a dilution effects on DOC concentration. On the other hand, the rainfall water may effectively replenish soil moisture content, and thus stimulate a higher decomposition of soil carbon under wet and higher temperature condition. Then, the relative decreased DOC concentrations were observed in a drying soil moisture condition for the next rainfall events, which may attribute to an exhaustion of DOC (Laudon et al., 2004). These findings were similar to previous studies by Tunaley et al. (2017), who reported a strong influence of dry antecedent conditions on DOC export response to rainfall event.

Comment 3. The introduction is very difficult to follow, they presented a numerous report (for example, L40-L64), I think they need to summary these studies and then the potential readers can know why they design this study.

Response: Thanks for your suggestions. The introduction part has been rewritten and the details show in Line 25-79 of this manuscript:

Line 28-79: Dissolved organic carbon (DOC), often defined as the solute filtered through <0.45μm pore size, is regarded as one of the active constituents and provides a biologically available carbon source for organisms (Raymond and Saiers, 2010). The estimated DOC flux of terrestrial organic carbon through major worldwide rivers to ocean is from 0.45 to 0.78 Pg C y^{-1}(Drake et al., 2018; Hedge et al., 1997; Ran et al., 2018). The substantial magnitude of flux suggests that the DOC export on a global scale acts as one of the crucial processes of linking between terrestrial and aquatic ecosystem (Battin et al., 2008; Raymond et al., 2013; Raymond and Saiers, 2010). For instance, high DOC concentrations can lead to water pollution and eutrophication, and thus have dramatic consequences on aquatic ecosystem services (Evans et al., 2005; Hu et al., 2016). In addition to ecological impacts, DOC in runoff also play an important role in social well-beings. High DOC concentrations will aggravate the complexation and adsorption of pesticides and heavy metals in hydrological process. Therefore, the quality of domestic water could be damaged and it might potentially lead to adverse impacts on human health, such as increased risk of cancer, diabetes, or other diseases (Bennett et al., 2009; Ritson et al., 2014). Therefore, it is urgent to improve the associated knowledge on DOC export variability and develop a mechanistic understanding of DOC export from catchments.

DOC exported from catchments has attracted great attention in the last two decades due to global concerns about potential influences on the global carbon cycle and climate change (Laudon et al., 2004; Raymond et al., 2013). The transport of terrestrial DOC to runoff is strongly influenced by hydrological process, soil carbon cycle and climatological factors. Hydrological process driven by rainfall event plays an important role in controlling terrestrial DOC from soil pool to runoff. Previous studies have shown that the release of DOC concentrations ranged from 0.5 to 50 mg L^{-1} for global catchments (Mulholland, 2003). For instance, Clark et al. (2007) found that DOC concentration ranged between 5-35 mg L-1 with a highly variable in rainfall events from a peatland catchment, and a study by Blaen et al. (2017) showed that the DOC concentration ranged from 5.4 to 18.9 mg L-1. Similar results were reported by Ran et al. (2018), who found that DOC concentration ranged from 1.4 to 9.5 mg L-1 in the Wuding River in the LPR. Such studies highlighted that the importance of hydrological process on DOC transport (Billett et al., 2006; Dawson et al., 2002; Inamdar et al., 2006). Different rainfall events may alter hydrological connectivity or the flow path, which in turn lead to a varied hydrological connectivity and DOC source contributing to runoff. Moreover, the intensity and frequency of rainfall event not only influenced the current hydrological and DOC loading processes, but also changed the soil moisture conditions. The latter point may be particularly important in soil biogeochemical cycle. For example, DOC concentration may increase due to accumulated soil organic carbon after a dry period (Jager et al., 2009). In addition, variations in the magnitude and frequency of precipitation are one of manifestations of climate change, and thus, changes in hydrological process induced by climate change are also impact on the transport of terrestrial DOC. Therefore, understanding the dynamic and magnitude of DOC export from catchment is an important component of prediction DOC flux under the circumstance of future climate change.

The LPR, which has an area of 6.4×10^5 km^2, is situated in the middle reaches of the Yellow River, China, and approximately 90% of the river loading sediment is derived from this region (Tang, 2004). With regards to this fragile environment, the Chinese government has launched some ecological restoration projects since the beginning of this century, such as the 'Grain-for-Green' and 'Natural Forest Protection Project'. With the implementation of these projects, large areas of steep-sloping (higher than 20°) agricultural land was converted to forest, shrub, or grassland, and engineering measures were also applied to control erosion (Fu et al., 2017). For instance, check dams can retain sediment and also offer flat and fertile land behind the dam (Wang et al., 2011a). These measures have caused the Loess Plateau to experience a substantial change in land use, vegetation cover, soil properties, and catchment hydrology (Chen et al., 2007; Wang et al., 2011b; Wei et al., 2014). Consequently, the hydrological and carbon biogeochemical processes, which operate and interact with each other, were dramatically altered (Liang et al., 2015a; Liang et al., 2015b). These changes in hydrology and soil carbon cycle induced by land use and vegetation change may particularly important in the dynamics of DOC concentration and flux in an ecological restored catchment. Moreover, the majority of annual rainfall is concentrated between July and September in LPR. Less information is available on DOC export driven by rainfall event, which DOC flux is an important component in overall carbon balance for ecological restored catchment.

Therefore, the primary goal of this study is to investigate how variations of DOC concentration and flux response to a sequence of rainfall events from a restored catchment during concentrated rainfall season in the LPR. Specifically, the two objectives of this study were (1) to examine the dynamic changes in DOC concentration and flux and assess the difference in DOC export driven by various rainfall events, and (2) evaluate how rainfall, runoff, and antecedent factors affect DOC export from a catchment. To do so, we used high-frequency method to capture the temporal changes in DOC export and hydrological process driven by rainfall event within an ecological restored watershed in LPR. These results will provide evidence of DOC export response to rainfall events, especially driven by extreme events, which may be important for evaluating carbon balance and modeling DOC export through runoff at ecological restored catchment in LPR.

Comment 4. The three objectives of this study were not well described in the introduction section.

Response: Thanks for your suggestions. The objectives has been reorganized.

Line 73-76: Specifically, the two objectives of this study were (1) to examine the dynamic changes in DOC concentration and flux and assess the difference in DOC export driven by various rainfall events, and (2) evaluate how rainfall, runoff, and antecedent factors affect DOC export from a catchment. To do so, we used high-frequency method to capture the temporal changes in DOC export and hydrological process driven by rainfall event within an ecological restored watershed in LPR.

Comment 5. The result section is too long, making it difficult to read.

Response: Thanks for your suggestions. The result section has been reorganized in Line 152-222 as following:

Line 152-222: 3.1 Rainfall and Discharge in the Study Catchment

Rainfall is the main driving force of hydrological process in a catchment. Event-based rainfall amount varied from 62.6 mm (18 July) to 0.60 mm (17 August) from the June to September, 2016 (Figure 2-a). Over this period, the total rainfall amount was 372.1 mm, with approximately 70 % of the annual rainfall amount. All the rainfall events in between June to September were grouped into four grades: <5 mm (Light rainfall), 5-10 mm (Moderate rainfall), 10-20 mm (Heavy rainfall), and >20 mm (Violent rainfall) according to rainfall amount classification (Yang et al., 2018). Figure 3-a showed that the total rainfall amount was 41.1, 44.8, 99.6, and 186.6 mm for each grade, respectively. The occurrence frequency of rainfall in each grade was 52.4% (<5 mm), 17.1% (5-10 mm), 16.7% (10-20 mm), and 14.3% (>20 mm) (Figure 3-b). These results indicated that the light and moderate rainfall occurs frequently with a less total rainfall amount, whereas the majority of rainfall amount occurs with a less chance in violent rainfall.

In general, flow discharge tended to follow the pattern of rainfall amount in the study catchment. The mean flow rate at the outlet of the catchment was 0.46 L s^{-1}, but it was also more variable and ranged from 0 to 4.5 L s^{-1} during June to September, 2016. In particular, there was no runoff in the catchment, due to the higher temperature, evapotranspiration and lower rainfall amount in early July. The higher flow rate is caused by continuous heavy rainfall. For instance, the cumulative rainfall amount was 91.8 mm and the mean flow rate was 4.05 L s^{-1} from 18-19 July. Therefore, the flow rate increased rapidly with short duration and violent rainfall. In addition, Figure 4-a showed the relationship between flow rate and rainfall amount during June to September. This indicated that event-driven flow rate varied with rainfall amount, and thus suggested that runoff discharges are highly sensitive to larger rainfall amount with greater than 20 mm in this area.

3.2 DOC Concentrations in Runoff Discharges

3.2.1 Event-based DOC Concentrations during Concentrated Rainfall Season

In general, the monthly mean DOC concentration tended to decrease from 11.52 mg L^{-1} in June to 6.81 mg L^{-1} in August, and then slightly increased to 7.49 mg L^{-1} in September. There were less variations in the mean DOC concentration among monitoring months. For the event-driven DOC concentration, the flow-weight mean DOC concentration (C_f) ranged from 4.08 to 15.66 mg L^{-1} for all sampled rainfall events during June to September. The relationship between flow rate and C_f for sampled rainfall events was shown in Figure 4-b. The C_f exhibited a poor relationship with flow rate, and the C_f was a more variable at low flow rate period compared to the high flow rate period, which is typically observed during consecutive rainfall events with high rainfall amount. In addition, Table 2 showed the correlation between C_f and a set of factors in all sampled rainfall events during the study period. On one hand, the C_f was positively correlated with rainfall amount (Ra) and R7. On the other hand, the C_f was extreme significantly and negatively correlated with SMC7 and SMC14. These results showed that different rainfall and soil moisture condition may affect DOC concentration for a rainfall event.

3.2.2 Dynamic Changes of DOC Concentrations in a Rainfall Event

Four rainfall events of total sampled events were chosen for detailed examine the relationship between DOC concentration (C_i) and flow rate in the hydrological process. These selected rainfall events represented 83% of the occurrence frequency of rainfall amount and the collected samples with high-frequency cover a complete of hydrological process during the monitoring period. Figure 5 shows the dynamic changes in DOC concentration and flow rate via the hydrograph over a event-driven hydrological process. In general, C_i varied between the runoff discharge process induced by different rainfall amount. The C_i increased quickly in the rising limb of the hydrograph and the maximum concentration occurred behind the peak of the hydrograph on 7-June (Figure 5-a) and 2-August (Figure 5-c), a period with less rainfall and of a long duration. Then, the C_i then decreased from 1.35 to 0.41 mg L^{-1} at the falling limb on 2-August, while the C_i remained relatively high values at 1.41-1.50 mg L^{-1} in the falling limb on 7-June. In rainfall events on 13-July (Figure 5-b) and 10-September (Figure 5-d), the discharge hydrograph exhibited a higher fluctuation due to the high rainfall amount and short rainfall duration. The C_i was kept relatively stable despite the fact that it increased from 1.05 to 1.30 mg L^{-1} at the rising limb on 13-July. However, the C_i sharply increased from 0.61 to 1.24 mg L^{-1} and the maximum C_i was observed before the peak of the hydrograph. The C_i then declined and remained stable ranging from 0.61 to 0.75 mg L^{-1} at the falling limb on 10-September. Overall, the dynamic changes in C_i in the hydrograph show that the DOC export process varied with different rainfall and runoff condition.

3.3 Hysteresis of event-driven DOC Concentrations

The above results showed a nonlinear correlation with flow rate and DOC concentrations (C_i) over a rainfall event. Therefore, A hysteresis analysis was used to examine the dynamic changes of the C_i response to a hydrological process, which has been applied to investigate the temporal variation in solute concentration with flow rate (Blaen et al., 2017; Lloyd et al., 2016a; Lloyd et al., 2016b; Tunaley et al., 2017). Figure 7 shows that the C_i varied in the rising and falling hydrograph during four selected rainfall events. Three hysteresis patterns were observed, including clockwise (13-July and 10-September), anti-clockwise (7-June) and figure-of-eight (2-August). As shown in Figure 6-a, the C_i was higher during the falling limb than during the rising limb of the hydrograph, thus resulting in an anti-clockwise pattern. A figure-of-eight pattern and indicated that C_i generally varied in pace with runoff discharge on 2-August, 2016 (Figure 6-c). The difference of C_i between rising and falling limb at a given flow rate was small, as supported by the results shown in Figure 5-c. On 13-July (Figure 6-b) and 10-September (Figure 6-d), the C_i exhibited a clockwise pattern, which implied that the C_i was higher in the rising limb than in the falling limb. The relationships between concentration and flow rate highlighted that the DOC export behavior was different in a complete hydrological process driven by a single rainfall event.

3.4 DOC Fluxes from Catchment

A rainfall event-based monitoring method is helpful to better understand the hydrological, DOC concentration and flux process. The rainfall event-based DOC flux ranged from 0.08 to 2.81 kg km^{-2} with a mean DOC flux of 0.43 kg km^{-2} for all sampled rainfall events from June to September, 2016. The relationship between event-based DOC flux and runoff discharge amount is shown in Figure 4-c. The DOC flux showed a positive linear relationship with the runoff discharge amount, especially for violent rainfall events. The DOC flux was more variable in lower runoff discharge conditions. In general, event-based DOC flux was significantly and positively correlated with Q, Ra, R1 and R, as showed in Table 2. For the monthly DOC flux, the total DOC loading from the catchment ranged from 94.73 kg km^{-2} in August to 110.17 kg km^{-2} in September (Table 1). Although the total runoff discharge was lowest in June in these four months, the DOC monthly flux was 102.39 kg km^{-2} and had a higher flow-weighted DOC concentration (11.52 mg L^{-1}). However, the DOC flux was higher in September, with an increased runoff discharge and a lower flow-weighted DOC concentration. The larger runoff discharge amount may offset the effects of lower DOC concentration.

Comment 6. The authors need to redo the tables and figures. I do not understand Figure 2a. It is also difficult to understand Fig. 8. The authors also need to explain the abbreviations for R1, R2 in table 2 so the readers need not to find them in the text.

Response: Thanks for your suggestions. We redo the Table 1, 2 and Figure 2 a as following:

Table 1

Date	Ra(mm)	Flow rate ($L\ s^{-1}$)	C_f ($mg\ L^{-1}$)	*Flux* ($kg\ km^{-2}$)	Date	Ra(mm)	Flow rate ($L\ s^{-1}$)	C_f ($mg\ L^{-1}$)	*Flux* ($kg\ km^{-2}$)
1-Jun.	1.0	0.56	10.87	0.52	1-Aug.	0.8	0.54	5.14	0.24
2-Jun.	7.0	0.59	9.97	0.51	2-Aug.	4.2	0.63	9.72	0.53
3-Jun.	3.0	0.53	10.53	0.48	6-Aug.	0.8	0.47	7.95	0.32
5-Jun.	3.2	0.53	11.59	0.53	12-Aug.	0.8	0.40	5.30	0.18
7-Jun.	13.8	0.65	12.96	0.73	13-Aug.	1.2	0.35	5.93	0.18
Jun.	82.9	0.35	11.52	102.39	16-Aug.	18.8	0.96	6.46	0.54
11-Jul.	24.6	0.44	11.92	0.45	17-Aug.	0.6	0.55	9.69	0.46
13-Jul.	19.8	1.28	11.84	1.31	18-Aug.	1.2	0.57	7.44	0.37
14-Jul.	11.0	0.46	13.00	0.52	Aug.	53.8	0.53	6.81	94.73
18-Jul.	62.6	1.46	11.64	1.47	9-Sept.	6.8	0.44	13.14	0.50
19-Jul.	29.2	4.05	8.12	2.84	10-Sept.	21.8	1.24	7.21	0.77
31-Jul.	2.2	0.54	6.70	0.31	17-Sept.	6.2	0.48	9.10	0.38
Jul.	184.2	0.41	8.95	96.57	Sept.	51.2	0.57	7.49	110.17

Table 2

	Flux	Q	Ra	R1	R7	R14	REI	T_{air}-7	T_{air}-14	SMC-7	SMC-14
C_f	0.30	-0.01	0.30	-0.01	0.23	-0.05	-0.32^{*}	-0.25	-0.24	-0.44^{**}	-0.65^{**}
Flux		0.94^{**}	0.69^{**}	0.76^{**}	0.57^{**}	0.29	-0.14	-0.07	-0.04	0.06	-0.24
Q			0.60^{**}	0.85^{**}	0.53^{**}	0.33^{*}	-0.07	-0.02	0.01	0.19	-0.03
Ra				0.38^{*}	0.39^{*}	0.14	-0.06	0.02	0.07	-0.05	-0.30
R1					0.58^{**}	0.42^{**}	-0.27	0.11	0.10	0.12	-0.01
R7						0.69^{**}	-0.28	0.24	0.23	0.40^{**}	0.02
R14							-0.20	0.19	0.13	0.56^{**}	$.420^{**}$
REI								-0.02	0.03	0.26	0.25
T_{air}-7									0.96^{**}	0.09	0.20
T_{air}-14										0.09	0.17
SMC-7											0.79^{**}

Note: ** ($P<0.01$), * ($P<0.05$).

C_f: Flow-weighted mean concentration driven by a event, Flux: Event-driven DOC quantity,

Q: Total discharge volume, Ra: Total rainfall amount,

R1: Total rainfall amount in the 1 day before the current rainfall event,

R7: Total rainfall amount in the 7 days before the current rainfall event,

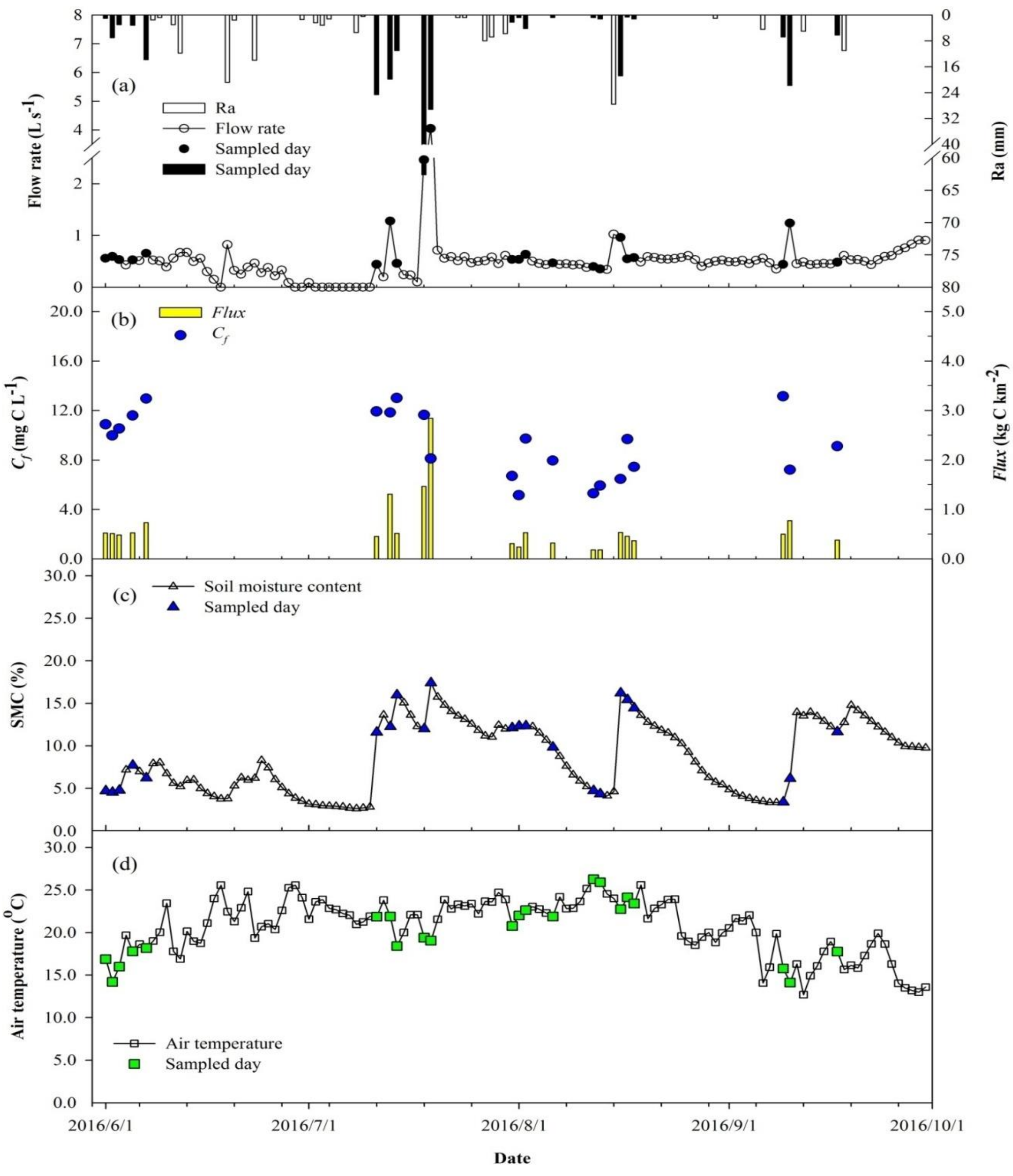
R14: Total rainfall amount in the 14 days before the current rainfall event,

SMC-7 and SMC-14: Soil moisture content in the 7 and 14 days before the current rainfall event,

T_{air}-7 and T_{air}-14: Mean air temperature in the 7and 14 days before the current rainfall event,

REI: Interval days between the current and last rainfall event.

Figure 2

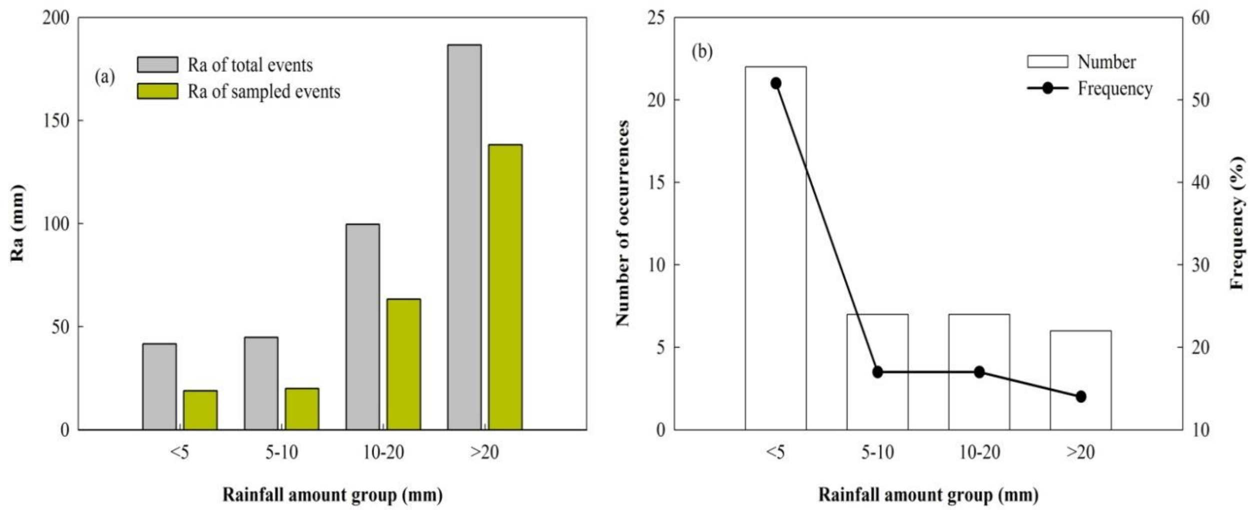


Comment 6. The authors should clarify the rainfall amount and rainfall intensity, which is important to class the rainfall events.

Response: Thanks for your suggestions. Indeed, the rainfall events were grouped by rainfall amount and the Figure 3 has been changed. According to Yang's results, the threshold of rainfall amount mean rainwater can effectively recharge the soil water in LPR, which may affect soil moisture content. This is why we selected this classification. Thus, we choose the parameter of rainfall amount to analyze in this manuscript.

Line 156-158: All the rainfall events in between June to September were grouped into four grades: <5 mm (Light rainfall), 5-10 mm (Moderate rainfall), 10-20 mm (Heavy rainfall), and >20 mm (Violent rainfall) according to rainfall amount classification (Yang et al., 2018).

Figure 3:

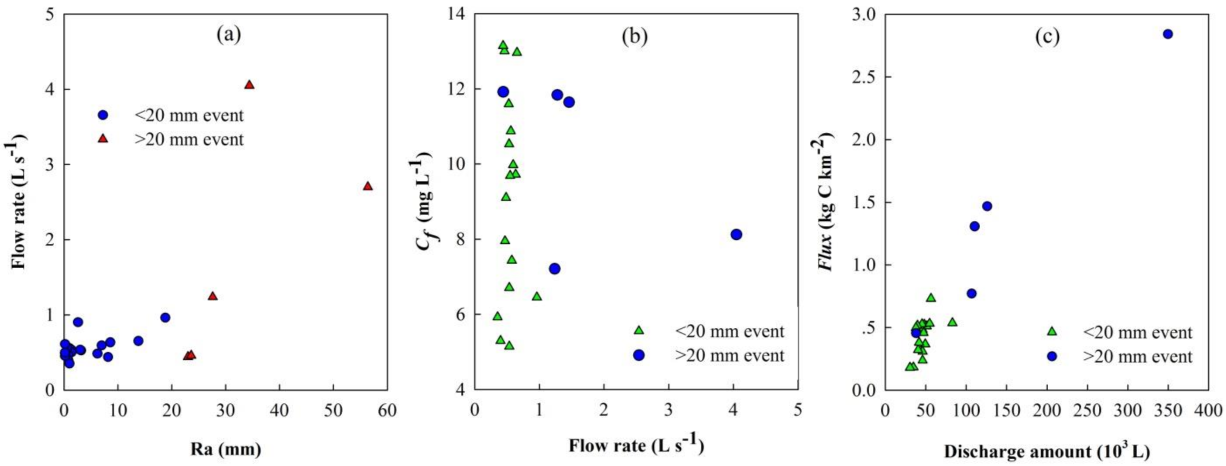


Comment 7. it is unclear about the time interval between these sampling times. If they want to conduct such analysis, they should check the original data to ensure the normal distribution.

Response: Thanks for your suggestions. details about sampling times showed in method part in Line 102-104. The regression was removed due to lack of data normal distribution and Figure 4 also has been changed accordingly.

Line 102-104: High-frequency monitoring was carried out in a rainfall event based hydrological process, thus the ISCO was set to acquire samples every 10 min from the first 12 runoff samples and another 12 were sampled every 30 min.

Figure 4



Comment 8. Conclusions. The findings of this study indicate that DOC concentrations were highly variable, particularly during low runoff discharge periods, granted, this belongs to the conclusion. The authors should think hard about the findings of this study and show that these findings are valuable.

Response: Thanks for your suggestions. The conclusion part has been rewritten and the details show in Line 327-342 of this manuscript.

Line 316-331: The DOC concentration and flux for individual rainfall events from a semi-arid catchment of the LPR was initially monitored during the concentrated rainfall season. DOC concentration showed a weak correlation with discharge, except in higher runoff discharge induced by extreme rainfall events. The findings of this study indicate that DOC concentrations were highly variable, particularly during low runoff discharge periods. Hysteresis analysis showed that the relationship between DOC concentration and runoff discharge for a rainfall event is nonlinear and varied with conditions in rainfall amount, discharge process. DOC flux increased with runoff discharge and showed a positive linear correlation with runoff discharge. These results showed that higher DOC flux with low DOC concentration related to higher discharge and its dilution effects in a hydrological process driven by larger rainfall amount. The diluted DOC concentration induced by increased discharges contributed slightly to difference in DOC flux, due to total runoff discharge is a major variable for flux. These results showed that the temporal variation magnitude of DOC is related to hydrological condition (Q and Ra) and antecedent condition (R1, R7 and SMC), and suggested that the event-driven DOC export is largely influenced by rainfall through direct effects on catchment hydrology and indirect effects on soil carbon cycles. Changes in catchment hydrology and soil carbon processes responded to climate change may play an important role in terrestrial carbon export, in particular for a restored catchment. Thus, further work should focus on carbon export response to various rainfall events at a larger spatiotemporal scale for better estimating future terrestrial carbon flux to aquatic ecosystem and evaluating carbon balance in ecological restored catchment in LPR. In addition, engineers and scientists can take advantage of the derived results to better develop advanced field monitoring work.

Other Changes:

We have revised the abstract part in Line 11-26. We also added discussion information in Line 261-271 and Line 304-314. The details show in the following part:

In Abstract **Line 11-26:** Dissolved organic carbon (DOC) transported by runoff has been identified as an important role of the global carbon cycle. Despite there being many studies on DOC concentration and flux, but little information is available in semi-arid catchments of the Loess Plateau Region (LPR). The primary goal of this study was to quantify DOC exported driven by a sequence of rainfall events during the concentrated rainfall season. In addition, factors that affect DOC export from a small headwater catchment will be investigated accordingly. Runoff discharge and DOC concentration were monitored at the outlet of the Yangjuangou catchment in Yanan, Shaanxi Province, China. The results showed that DOC concentration was highly variable, with event-based DOC concentrations ranging from 4.08 to 15.66 mg L^{-1}. Hysteresis analysis showed a nonlinear relationship between DOC concentration and flow rate in the hydrological process. The monthly DOC flux loading from the catchment was 94.73-110.17 kg km^{-2} from June to September, while the event-based DOC flux ranged from 0.18 to 2.84 kg km^{-2}. Variations of event-driven DOC concentration contributed slightly to a difference in DOC flux, whereas intra-events of rainfall amount and runoff discharge led to evident difference in DOC export. In conclusion, our case results highlighted the advantages of high-frequency monitoring for DOC export and indicated that event-driven DOC export is largely influenced by the interaction of catchment hydrology and antecedent condition within a catchment. Engineering and scientists can take advantage of the derived results to better develop advanced field monitoring work. In addition, more studies are needed to investigate the magnitude of terrestrial DOC export in response to projected climate change at larger spatiotemporal scale, which may have implication for the carbon balance and carbon cycle model from an ecological restored catchment in LPR.

Line 261 -271: For event-driven flux, the DOC flux is a function of total runoff discharge and DOC concentration (C_f). DOC flux showed a positive linear relationship with runoff discharges, which is not surprising and parallel with studies reported by Clark et al. (2007) and Ma et al. (2018). In addition, it should be noted that the DOC flux induced by larger rainfall amount was higher than flux driven by light rainfall, whereas the C_f showed no evident difference for the selected rainfall events. Thus, the greater DOC flux clearly showed that the DOC export was close linked to hydrologic process induced by various amount of rainfall event in LPR. For an ecological restored catchment in LPR, the soil carbon driven by increased vegetation was significantly increased and acted as a positive pathway to sequestration soil carbon on terrestrial ecosystem (Wang et al., 2011b). Meanwhile, the reduced hydrology responded to an increased vegetation may diminish soil carbon transported by hydrological process in a catchment. The event-driven DOC transport is an important component for evaluating carbon balance of the ecological restored catchment in LPR. Hence, further study should be long-term undertaking to investigate the hydrological response and its impact on terrestrial carbon loss from a catchment in LPR.

Line 304-314: DOC flux was significantly and positively correlated with Q, Ra, R1 and R7. The Q and Ra reflect the direct effect of current rainfall and hydrological processes during a rainfall event, while R1 and R7 refer to the antecedent rainfall conditions and reflect indirect effects on DOC export. These results agreed with previous studies demonstrated by Blaen et al. (2017), who noted that antecedent conditions and rainfall were key drivers of DOC export during a rainfall event. Cooper et al. (2007) also concluded that DOC export is largely governed by interactions between hydrological and meteorological factors and carbon biogeochemical process. Overall, these results suggested that rainfall is a key factor influencing hydrological process, and thus DOC export from an ecological restored catchment in LPR. Apart from the increased soil carbon driven by increased vegetation (Wang et al., 2011b), the weaken hydrological process induced by increased vegetation may also cause a less terrestrial carbon export from a catchment. Therefore, our results highlight the need for research not only into the hydrological process and soil carbon cycle, but the integration of carbon export driven by a sequence of rainfall events across spatiotemporal scales to understand the carbon balance in a restored catchment in LPR.

Dissolved Organic Carbon Driven by Rainfall Events from a Semi-arid Catchment during Concentrated Rainfall Season in the Loess Plateau, China

Linhua Wang[1], Haw Yen[2], Xinhui E[1,3], Liding Chen[1,3], Yafeng Wang[1,3,4*]

[1] State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Science, Chinese Academy of Sciences, Beijing 100085, China

[2] Blackland Research and Extension Center, Texas A&M AgriLife Research, Texas A&M University, Texas, 76502, USA

[3] College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China

[4] Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100101, China

** Corresponding author: Yafeng Wang: yfwang@rcees.ac.cn*

Abstract: Dissolved organic carbon (DOC) transported by runoff has been identified as an important role of the global carbon cycle. Despite there being many studies on DOC concentration and flux, but little information is available in semi-arid catchments of the Loess Plateau Region (LPR). The primary goal of this study was to quantify DOC exported ~~from~~driven by a sequence of runoff events during the concentrated rainfall season. In addition, factors that affect DOC export from a small headwater catchment will be investigated accordingly. Runoff discharge and DOC concentration were monitored at the outlet of the Yangjuangou catchment in Yanan, Shaanxi Province, China. The results showed that DOC concentration was highly variable ~~(1.91-34.70 mg L^{-1})~~, with event-based DOC concentrations ranging from 4.08 to 15.66 mg L^{-1}. Hysteresis analysis showed a nonlinear relationship between DOC concentration and flow rate in the hydrological process. The monthly DOC flux loading from the catchment was 94.73-110.17 kg km^{-2} from June to September, while the event-based DOC flux ranged from 0.08 to 2.81 kg km^{-2}. Variations of event-driven DOC concentration contributed slightly to a difference in DOC flux, whereas ~~I~~intra-events of rainfall amount and runoff discharge led to ~~event-based/monthly~~evident difference~~s~~ in DOC ~~concentration and flux.~~export.~~ Hysteresis analysis showed a nonlinear relationship between DOC concentration and discharge in the runoff process.~~ In conclusion, ~~O~~our case results highlighted the advantages of high-frequency monitoring for DOC export and indicated that DOC export and indicated that event-driven DOC export~~ from a catchment~~ is largely influenced by the interaction of ~~rainfall~~ catchment hydrology and antecedent condition~~s~~ within a catchment. ~~for a rainfall event.~~ Engineering and scientists can take advantage of the derived results to better develop advanced field monitoring work. In addition, more studies are needed to investigate the magnitude of terrestrial DOC export in response to projected climate change at larger spatiotemporal scale, which may have implication for the carbon balance and carbon cycle model from an ecological restored catchment in LPR.~~release of DOC runoff can take quantified during hydrological and biogeochemical processes within catchments in LPR.~~

1. Introduction

Dissolved organic carbon (DOC), often defined as the solute filtered through <0.45μm pore size, is regarded as one of the active constituents and provides a biologically available carbon source for organisms (Raymond and Saiers, 2010). The estimated DOC flux of terrestrial organic carbon through major worldwide rivers to ocean is from 0.45 to 0.78 Pg C yr^{-1} (Drake et al., 2018; Hedge et al., 1997; Ran et al., 2018). The substantial magnitude of flux suggest that the DOC export on a global scale acts as one of the crucial processes of linking between~~ Thus, the loading of DOC from catchments is widely recognized as a large flux from the soil carbon pool, and is a critical carbon biogeochemical process in~~ terrestrial and aquatic ecosystems (Battin et al., 2008; Raymond et al., 2013; Raymond and Saiers, 2010). ~~The annual DOC input from terrestrial to ocean environments is~~

~~approximately 0.25 Pg C, and the release as carbon dioxide from global surface water is estimated at 0.65-3.2 Pg C~~. For instance, high DOC concentrations can lead to water pollution and eutrophication, and thus have dramatic consequences on aquatic ecosystem services (Evans et al., 2005; Hu et al., 2016). In addition to ecological impacts, DOC in runoff also play an important role in social well-beings. ~~h~~High DOC concentrations will aggravate the complexation and adsorption of pesticides and heavy metals in hydrological processes. Therefore, the quality of domestic water could be damaged and it might potentially lead to adverse impacts on human health, such as increased risk of cancer, diabetes, or other diseases (Bennett et al., 2009; Ritson et al., 2014). ~~Consequently, the increasing magnitude of DOC via runoff on a global scale acts as one of the crucial nodes of linking between terrestrial and aquatic ecosystems, and plays an important role in social well-being.~~ Therefore, it is urgent to improve the associated knowledge on DOC export ~~concentration~~ variability and develop a mechanistic understanding of DOC export from catchments.

DOC exported from catchments has attracted great attention in the last two decades due to global concerns about potential influences on the ~~soil carbon pool, aquatic environments~~global carbon cycle and climate change (Laudon et al., 2004; Raymond et al., 2013). The transport of terrestrial DOC to runoff is strongly influenced by hydrological process, soil carbon cycle and climatological factors. Hydrological process driven by rainfall event plays an important role in controlling terrestrial DOC from soil pool to runoff. Previous studies have shown that the release of DOC concentrations ranged from 0.5 to 50 mg L^{-1} for global catchments (Mulholland, 2003). For instance, Clark et al. (2007) found that DOC concentration ranged from 5.4 to 18.9 mg L^{-1} with a ~~from a peatland catchment was~~ highly variable in ~~storm~~ rainfall events from a peatland catchment, ~~(approximately 5-35 mg L^{-1}),~~ and a study by Blaen et al. (2017) showed that the DOC concentration ranged from 5.4 to 18.9 mg L^{-1} ~~with a dynamic DOC source zone. Ma et al. (2018) examined the DOC concentrations in the Three Rivers Headwater Region of the Qinghai-Tibetan Plateau. The results showed that the mean DOC concentration was 3.95 mg L^{-1} and varied with land cover in the catchment~~. Similar results were reported by Ran et al. (2018), who found that DOC concentration ranged from 1.4 to 9.5 mg L^{-1} in the Wuding River in the Loess Plateau Region (LPR). ~~Previous studies have shown that the release of DOC concentrations from the global catchment ranged from 0.5 to 50 mg L^{-1} and were generally measured at monthly, weekly or daily intervals (Mulholland, 2003)~~. Such studies highlighted that the importance of hydrological process on DOC transport~~export was governed by hydrological and carbon biogeochemical processes, precipitation, soil type, and land use~~ (Billett et al., 2006; Dawson et al., 2002; Inamdar et al., 2006). Different rainfall events may alter hydrological connectivity or the flow path, which in turn lead to a varied hydrological connectivity and DOC source contributing to runoff. Moreover, the intensity and frequency of rainfall events not only influenced the current hydrological and DOC loading processes, but also changed the soil moisture conditions (Yang et al., 2018). The latter point may be particularly important in soil biogeochemical cycle. For example, DOC concentration may increase due to accumulated soil organic carbon after a dry period (Jager et al., 2009). ~~Precipitation can play an important role in DOC export from a catchment. During a rainfall event, increased discharge can caused a higher DOC concentration and flux by flushing accumulated soil organic matter and the relationship between discharge and DOC concentrations is nonlinear. Therefore, a hysteresis effect was found in the runoff process, which was helpful for characterizing the DOC export process in a rainfall event (Blaen et al., 2017; Lloyd et al., 2016a; Lloyd et al., 2016b; Tunaley et al., 2017). Different intensities of rainfall may alter hydrological connectivity or the flow path and lead to a varied DOC source contributing to runoff. Moreover, the intensity and frequency of rainfall events not only influenced the current hydrological and DOC loading processes, but also changed the soil moisture conditions.~~ In particular, ~~DOC concentration may increase due to accumulated soil organic carbon after a dry period (Jager et al., 2009).~~ In addition, variations in the magnitude and frequency of ~~rainfall~~ precipitation are one of manifestations of climate change, and thus, changes in hydrological process induced by climate change are also impact on the transport of terrestrial DOC. ~~.~~ Therefore, understanding the dynamic and magnitude of DOC export from catchment is an important component of prediction DOC flux under the circumstance of future climate change. ~~characterizing DOC export concentrations, fluxes and patterns from a catchment is critical for understanding DOC processes interacting with hydrological and carbon biogeochemical processes, and is beneficial for predicting DOC flux under future climate change circumstances. Compared to tropical and subtropical areas, comparatively few studies have investigated the dynamics and magnitude of DOC export from semi-arid catchments, particularly in the LPR.~~

The LPR, which has an area of 6.4×10^5 km^2, is situated in the middle reaches of the Yellow River, China, and approximately 90% of the river loading sediment is derived from this region (Tang, 2004). With regards to this fragile environment, the Chinese government has launched some ecological restoration projects since the beginning of this century, such as the 'Grain-for-Green' and 'Natural Forest Protection Project'. With the implementation of these projects, large areas of steep-sloping (higher than 20°) agricultural land was converted to forest, shrub, or grassland, and engineering measures were also applied to control erosion (Fu et al., 2017). For instance, check dams can retain sediment and also offer flat and fertile land behind the dam (Wang et al., 2011a). These measures have caused the Loess Plateau to experience a substantial change in land use, vegetation cover, soil properties, and geomorphology. Therefore, the associated hydrological process, ecosystem structure and functions may be alternated accordingly (Chen et al., 2007; Wang et al., 2011b; Wei et al., 2014). Consequently, the hydrological and carbon biogeochemical processes, which operate and interact with each other, were dramatically altered (Liang et al., 2015a; Liang et al., 2015b). These changes in hydrology and soil carbon cycle induced by land use and vegetation change may particularly important in the dynamics of DOC concentration and flux in an ecological restored catchment. Moreover, ~~Furthermore,~~ the majority of annual rainfall is concentrated between July and September in LPR. Less information is available on DOC export driven by rainfall event, which DOC flux is an important component in overall carbon balance for ecological restored catchment. ~~, accounting 60-70% of total annual precipitation (Shi and Shao, 2000). The dynamics of DOC concentration and flux response to rainfall events may differ from other sites in terms of vegetation and hydrological condition in a ecologically-restored catchment. Thus, attention should be paid to DOC export driven by rainfall events in a period of concentrated rainfall season, which DOC flux determine status in carbon sink or source for ecological restoration catchments. Until this point, no previous studies have attempted to investigate DOC concentration and the associated flux export over timescales consistent with event-based responses from a semi-arid catchment in the LPR.~~

Therefore, the primary goal of this study is to investigate how variations of DOC concentration and flux response to a sequence of rainfall events from a restored catchment during concentrated rainfall season in the LPR. Specifically, the two objectives of this study were (1) to examine the dynamic changes in DOC concentration and flux and assess the difference in DOC export driven by various rainfall events, and (2) evaluate how rainfall, runoff, and antecedent factors affect DOC export from a catchment. To do so, we used high-frequency method to capture the temporal changes in DOC export and hydrological process driven by rainfall event within an ecological restored watershed in LPR. These results will provide evidence of DOC export response to rainfall events, especially driven by extreme events, which may be important for evaluating carbon balance and modeling DOC export through runoff at ecological restored catchment in LPR.

~~Previous studies that monitored DOC loading from catchments have generally used traditional sampling methods at daily, weekly or monthly frequencies to characterize temporal DOC variation in annual or seasonal fluxes. In addition, DOC concentration and flux from catchments are not regular parameters in monitoring networks, such as the Chinese Ecosystem Research Network (CERN). The common approach of sampling frequency is in monthly or weekly schedule at this field gauge station. However, it may result in dissolved organic carbon in runoff samples that is degraded by microbial activities (Kieber et al., 2002; Willey et al., 2000). It is also the reason that only few studies are available in exploring DOC concentration and flux in the research area of this study. Furthermore, no previous study has examined DOC export for a sequence of rainfall events from~~

~~a catchment in the LPR. Continuously monitoring DOC export and hydrological processes in small catchments using event-based sampling methods has been a helpful technique for adequately capturing the temporal variations and has also broadened a comprehensive insight into DOC export fluxes from catchments. The primary goal of this study is to investigate the variation of DOC concentration for rainfall events to understand the magnitude of DOC flux from an ecologically-restored catchment in the LPR. Three objectives are defined: (i) to examine dynamic changes in DOC concentration and flux during an event-based and monthly period during the concentrated rainfall season; (ii) to quantify the relationship between DOC concentration, flux with discharge derived from detailed monitoring data; and (iii) to assess the rainfall, runoff and antecedent factors influencing DOC export from a semi-arid catchment in the LPR.~~

2. Materials and Methods

2.1 Site Description

As shown in Figure 1, this study was conducted in the Yangjuangou catchment (N 36° 42', E 109° 31'), which is an Ecological Restoration and Soil and Water Conservation Monitoring Station situated in Yan'an, Shaanxi Province, China. The catchment is located in the secondary tributary of the Yan River Watershed and covers an area of 2.02 km^2, ranging in elevation from 1050 to 1295 m above the mean sea level. The topography is characterized by a typical loess hilly and gully topography with a gully density of 2.74 km km^{-2} (Wang et al., 2011b). The climate of this catchment is situated in a semi-arid continental monsoonal climate with an average annual temperature of 9.6℃ and the average annual precipitation is 535 mm during the period from 1951 to 2012 (Li and Wang, 2015). Furthermore, the precipitation ~~This catchment receives a 535 mm of average annual rainfall, which~~ is unevenly distributed throughout the year and 60-70% of annual rainfall concentrated from June to September. The soil is classified as a typical loess with a fine silt texture and is weakly resistant to detachment by raindrops or runoff. Two check-dams were built in the main gully in the 1960s and it are currently filled with sediment and used for agricultural land. Land use is dominated by forest with a mix of shrub, grassland, and arable land. The proportion of sloping cropland has remarkably decreased from 16.9% in 1998 to 0.1% in 2006. The forestland increased from 15.2% in 1998 to 37.4% in 2006 since implemented the 'Grain-for-Green' and engineering measures (Wang et al., 2011b). The major forest species are *Robinia pseudoacacia*, *Salix spp.* and *Populus spp.* The area with *Artemisa argyi*, *Stipa Bungeana trin*., *Bothriochloa ischaemum*, *Lespedezadavurica schindl.*, and *Artemisia sacrorum* are classified as grassland. The major orchards are *Prunus armeniaca L.*, *Malus pumila Mill.*,and *Juglans rejia L.* The major crops are *Setaria italica, Zea may L. Glycinemax (L) Merr. Panicum miliaceum L.* and *Solanum tuberosum* (Fu et al., 2014). The Yangjuangou catchment was chosen as a study site, which represented an ecological restored catchment.~~to represent an area with altered land use that has implemented the 'Green-for-Grain' and engineering measures.~~

2.2 Field Monitoring and Sampling

To measure the temporal dynamics of DOC, a monitoring station was deployed at the outlet of the Yangjuangou catchment to sample runoff water and monitor discharge. The station was equipped with an ISCO 6712 (Lincoln, NE, USA) peristaltic pump for collecting water samples during a runoff process induced by rainfall events. High-frequency monitoring was carried out in a rainfall event based hydrological process, thus the ISCO was set to acquire samples every 10 min from the first 12 runoff samples and another 12 were sampled every 30 min. The equipment was programmed to monitor runoff discharge by capturing the runoff flow rate (L s^{-1}) and the interval time (min). The auto-sampler collects a runoff sample with a volume of 200 ml. The auto-sampler ceased sampling work after 24 samples were collected. Then, the experimenter poured the runoff water into high-density polyethylene bottles that were prewashed with ultra-pure water. The auto-sampler continued to monitor the hydrological process and sample runoff for the next rainfall event. There were 278 samples collected for 22 hydrological processes induced by rainfall event over the monitoring period of June to September, 2016. In addition, the aim of hydrological and meteorological factor monitoring was to characterize the temporal changes of catchment condition. A meteorological station was installed in the center of the catchment, which was away from high trees. It was used to continuously monitor the rainfall characteristics, air temperature, and soil moisture throughout the study period. Rainfall amount (Ra, mm) and air temperature were measured every 30 min. The volumetric soil moisture content at 20 cm depth of forestland was measured every 30 min, which accounts for a large proportion of land use. Because these factors drive the hydrological and carbon biogeochemical processes in the catchment, these monitoring works may offer another perspective for understanding the runoff and DOC export process within an individual or continuous temporal variation between rainfall events.~~In addition, the aim of hydrological and meteorological factor monitoring was to characterize the temporal changes and represent the catchment conditions~~ (Blaen et al., 2017). ~~Because these factors drive the hydrological and carbon biogeochemical processes in the catchment, these monitoring works may offer another perspective for understanding the runoff and DOC export process within an individual or continuous temporal variation between rainfall events.~~

2.3 Laboratory Analysis

In the Yangjuangou catchment, researchers resided in the field observatory station and treated the samples immediately after a rainfall event to ensure that the DOC in the sampled water did not microbially~~ologically~~ ~~bio~~degrade (Kieber et al., 2002; Willey et al., 2000). Therefore, 200 ml of the collected runoff water sample was immediately filtered through a 0.45μm membrane into high-density polyethylene bottles and stored in a cooler (4℃) at the field station. Then, the samples were transported to the State Key Laboratory of Urban and Regional Ecology in Beijing for the following analysis. DOC was recognized as the difference between total dissolved carbon (TDC) and dissolved inorganic carbon (DIC) for each sample (DOC=TDC-DIC). TDC and DIC were determined by Vario Select (Elementar, Germany), which included a high-temperature combustion furnace, a self-contained acidification module and a highly sensitive CO_2 detector. TDC was automatically measured by the combustion of a sample, whereas DIC was measured after acidified by 1% H_3PO_4 solution (phosphoric acid). Then, validation was conducted by analyzing various concentrations of a standard solution to achieve accurate result. In order to control quality, each sample is determined through analysis of two replicate and the coefficient of variation of tested results was less than 10%.

~~The DOC concentrations were determined by Vario (Elementar, Germany), which included a high-temperature combustion furnace, a self-contained acidification module and a highly sensitive CO_2 detector. Prior to measurement, the instrument should dosed 125 ml of 1% H_3PO_4 solution (phosphoric acid) in the acidification module, and validation was then conducted by analyzing various concentrations of a standard solution to achieve accurate results. Ultra-pure water was also tested every 50 samples as a blank to ensure the quality of the results.~~

2.4 Data Analysis

2.4.1 Event-driven DOC Concentration and Flux Calculation

In the present study, the flow-weight mean concentration (C_f) was used to determine the average DOC concentration in a rainfall event. C_f was calculated by dividing the total DOC load by the total discharge in an event time. The equations of the flow-weighted mean concentration and flux were defined as the following:

$$C_f = \frac{\sum_{i=1}^{n} C_i \times Q_i}{\sum_{i=1}^{n} Q_i} \qquad (1)$$

$$Flux = \frac{10^{-6}\times C_f\times \sum_{i=1}^{n} Q_i}{S} \qquad (2)$$

~~the DOC concentration in a runoff event was the flow-weighted mean concentration. The calculation of the flow-weighted mean concentration and flux were defined in the following equations:~~

$$\cancel{DOC = \frac{\sum_{i=1}^{n} Ci\times Qi}{\sum_{i=1}^{n} Qi} \qquad (1)}$$

$$\cancel{Flux = \frac{DOC\times \sum_{i=1}^{n} Qi}{s} \qquad (2)}$$

where, *Qi* (~~mm~~L) is the discharge amount corresponding to ~~each~~ sample *i*, which was calculated by flow rate and interval time; *Ci* (mg L^{-1}) is the DOC concentration in ~~an individual~~ a runoff sample *i*; n is the number of runoff samples in a runoff event. ~~or in a month and~~ *Flux* (kg km^{-2}) is the loading ~~flux~~ quantity of DOC ~~in~~ driven by a rainfall event ~~or the monthly measurement~~ for ~~in~~ the study region; and, *s* is the catchment area (km^2).

2.4.2 Variables related to Event-driven DOC Transport

To better understand DOC concentrations and fluxes from a catchment, specific hydrological and meteorological variables were selected. For instance, rainfall and soil moisture content may be related to hydrological connectivity in a runoff event, while soil moisture and temperature conditions impact on soil organic carbon content through biological processes (Blaen et al., 2017; Cooper et al., 2007; Soulsby et al., 2003). These variables are Q (total discharge volume a rainfall~~);~~), ~~RA~~ Ra (total rainfall amount in a rainfall event~~);~~), R1, R7 and R14 (total rainfall amount in the 1, 7 and 14 days before the current rainfall event, respectively~~);~~)a SMC-7 and SMC-14 (soil moisture content in the 7 and 14 days before the current rainfall event~~);~~), T_{air}-7 and T_{air}-14 (mean air temperature in the 7and 14 days before the current rainfall event) and REI~~:~~ (interval days between the current and last rainfall event).

2.4.3 Statistical analysis

To analyze potential relationships among DOC concentration, flux, and selected variables, Pearson's test was performed using SPSS (Statistics Package for Social Science, Version 22). The corresponding figures were developed using Sigma Plot 10.0 (Systat, 2008).

3. Results

3.1 Rainfall and Discharge in the Study Catchment

Rainfall is the main driving force of hydrological process in a catchment. ~~It is also an important factor affecting the carbon biogeochemical process, which results in substantial temporal changes in the concentration and flux of DOC export from a catchment. Figure 2-a shows the e~~Event-based rainfall amount varied from 56.4 mm (18 July) to 0.60 mm (17 August) ~~and daily runoff discharge~~ from the June to September, 2016 (Figure 2-a). ~~An event-based rainfall amount measured at the rainfall gauge varied from 56.4 mm (18 July) to 0.60 mm (17 August). The monthly rainfall amounts were 91.2, 192.0, 44.6, and 66.6 mm from June to September in this study catchment (Table 1). Over this period, the total rainfall amount was 394.4 mm, with approximately 74 % of the annual rainfall amount.~~ All the rainfall events in June to September were grouped into four grades: <5 mm (Light rainfall), 5-10 mm (Moderate rainfall), 10-20 mm (Heavy rainfall), and >20 mm (Violent rainfall) according to rainfall amount ~~Yang et al. (2018)~~ classification (Yang et al., 2018). Figure 3-a showed that the total rainfall amount was ~~39.6~~41.1, ~~59.4~~44.8, ~~104.6~~99.6, and ~~187.2~~186.6 mm for each grade, respectively. The occurrence frequency of rainfall in each grade was 5~~4.9~~2.5 % (<5 mm), 17.1 % (5-10 mm), 1~~5~~6.7 % (10-20 mm), and 1~~1~~4.3~~.8~~ % (>20 mm) (Figure 3-b). These results indicated that the light and moderate rainfall occurs frequently with a less total rainfall amount, whereas the majority of rainfall amount occurs with a less chance in violent rainfall. ~~Figure 3-a showed that the total rainfall amount was 39.6, 59.4, 104.6, and 187.2 mm for each grade, respectively. The occurrence frequency of rainfall in each grade was 54.9 % (<5 mm), 17.1 % (5-10 mm), 15.7 % (10-20 mm), and 11.8 % (>20 mm) (Figure 3-b). These results indicated that the light and moderate rainfall occurs frequently with a less total rainfall amount, whereas the majority of rainfall amount occurs with a less chance in violent rainfall. In addition, the total amount of sampled events were 19.4, 30, 32.6 and 165 mm for each grade, respectively (Figure 3-a). Consequently, the majority of rainfall occurred from June to September, which is the typical rainfall characteristic of the study area.~~

In general, flow discharge tended to follow the pattern of rainfall amount in the study catchment. The mean flow rate at the outlet of the catchment was 0.46 L s^{-1}, but it was also more variable and ranged from 0 to 4.5 L s^{-1} during June to September, 2016. In particular, there was no runoff in the catchment, due to the higher temperature, evapotranspiration and lower rainfall amount in early July. The higher flow rate is caused by continuous heavy rainfall. For instance, the cumulative rainfall amount was 91.8 mm and the mean flow rate was 4.05 L s^{-1} from 18-19 July. Therefore, the flow rate increased rapidly with short duration and violent rainfall. In addition, Figure 4-a showed the relationship between flow rate and rainfall amount during June to September. This indicated that event-driven flow rate varied with rainfall amount, and thus suggested that runoff discharges are highly sensitive to larger rainfall amount with greater than 20 mm in this area.

~~For runoff discharge, the mean daily discharge at the outlet of the catchment was 0.46 L s^{-1}, but it was also more variable and ranged from 0 to 4.5 L s^{-1}. The mean runoff discharges in June-September were 0.35, 0.41, 0.53 and 0.57 L s^{-1}, respectively (Table 1). In particular, there was no runoff in the catchment, due to the higher temperature, evapotranspiration and lower rainfall amount in early July. The higher runoff discharge is caused by continuous heavy rainfall. For instance, the cumulative rainfall amount was 91.8 mm and the mean daily discharge flow was 4.05 L s^{-1} from 18-19 July. Similarly, from 15-16 August and 9-10 September, the cumulative rainfall amounts were 45.8 and 28.6 mm. Therefore, the runoff discharge increased rapidly with short duration and violent rainfall. In addition, the evapotranspiration of vegetation decreased as the temperature decreased, and the crops were harvested in the dam field in the late September. The concentrated rainfall season was the source of effective replenishment of the soil water in the dam field. Therefore, runoff discharge still showed a trend of gradually increase slowly with less rainfall occurring during this period. The monthly runoff discharge to rainfall amount ratios were varied from 5.6 % (July) to 31.2 % (August). On average, the discharge to rainfall ratio was 17.2 % in the study period of June to September. In general, runoff discharge tended to follow the pattern of rainfall amount in the study catchment.~~

3.2 DOC Concentrations in Runoff Discharges

3.2.1 Event-based DOC Concentrations during Concentrated Rainfall Season

In general, the monthly mean DOC concentration tended to decrease from 11.52 mg L^{-1} in June to 6.81 mg L^{-1} in August, and then slightly increased to 7.49 mg L^{-1} in September. There were less variations in the mean DOC concentration among monitoring months. For the event-driven DOC concentration, the flow-weight mean DOC concentration (C_f) ranged from 4.08 to 15.66 mg L^{-1} for all sampled rainfall events during June to September. The relationship between flow rate and C_f for sampled rainfall events was shown in Figure 4-b. The C_f exhibited a poor relationship with flow rate, and the C_f was a more variable at low flow rate period compared to the high flow rate period, which is typically observed during consecutive rainfall events with high rainfall amount. In addition, Table 2 showed the correlation between C_f and a set of factors in all sampled rainfall events during the study period. On one hand, the C_f was positively correlated with rainfall amount (Ra) and R7. On the other hand, the C_f was extreme significantly and negatively correlated with SMC7 and SMC14. These results showed that different rainfall and soil moisture condition may affect DOC concentration for a rainfall event.

~~DOC concentrations in runoff discharge were often between 1.91 and 34.70 mg L^{-1}. However, the mean DOC concentration for an individual rainfall event ranged from 4.08 to 15.66 mg L^{-1}. Over the study period, patterns in monthly flow-weighted mean DOC concentration were less variable during June to September (Table 1). In general, the monthly mean DOC concentration tended to decrease from 11.52 mg L^{-1} in June to 6.81 mg L^{-1} in August and then slightly increased to 7.49 mg L^{-1} in September. Indeed, the mean DOC concentration was not substantially different during the study period. The relationship between daily discharge and event-based DOC concentration for sampled rainfall events is shown in Figure 4-a. DOC concentrations exhibited a poor relationship with daily discharge for the Yangjuangou catchment. In addition, the DOC concentration was a more variable and had low runoff discharge compared to the high runoff discharge period, which is typically observed during consecutive rainfall events with high rainfall amount. These results showed that different runoff discharge conditions may affect DOC concentration.~~

3.2.2 Dynamic Changes of DOC Concentrations in a Rainfall Event

Four rainfall events of total sampled events were chosen for detailed examine the relationship between DOC concentration (C_i) and flow rate in the hydrological process. These selected rainfall events represented 83% of the occurrence frequency of rainfall amount and the collected samples with high-frequency cover a complete of hydrological process during the monitoring period. ~~To examine the relationship between DOC concentration and runoff discharge in the hydrological process, four rainfall events in each month were selected.~~ Figure 5 shows the dynamic changes in DOC concentration and runoff via the hydrograph over a rainfall event. In general, C_i~~DOC concentrations~~ varied between the runoff discharge process induced by different rainfall amount.~~during the runoff discharge process.~~ The C_i~~DOC concentration~~ increased quickly in the rising limb of the hydrograph and the maximum concentration occurred behind the peak of the hydrograph on ~~7~~ 7-June (Figure 5-a) and ~~2~~ 2-August (Figure 5-c), a period with less rainfall and of a long duration. Then, the DOC concentration then decreased from 1.35 to 0.41 mg L^{-1} at the falling limb on ~~2~~ 2-August, while the DOC maintained relatively high values at 1.4-1.50 mg L^{-1} in the falling limb on 7 June. In rainfall events on ~~13~~ 13-July (Figure 5-b) and ~~10~~ 10-September (Figure 5-d), the discharge hydrograph exhibited a higher fluctuation due to the higher rainfall amount and short rainfall duration. The DOC concentration was kept relatively stable despite the facts that it increased from 1.05 to 1.30 mg L^{-1} at the rising limb on 13 July. However, the DOC concentration sharply increased from 0.61 to 1.24 mg L^{-1}and the maximum DOC concentration was observed before the peak of the hydrograph. The DOC concentrations then declined and remained stable ranging from 0.61 to 0.75 mg L^{-1} at the falling limb on 10 September. Overall, the dynamic changes in DOC concentrations in the hydrograph show that the DOC export process varied with different rainfall and runoff conditions.

3.3 Hysteresis of event-driven DOC Concentrations

The above results showed a nonlinear correlation with flow rate and DOC concentrations (C_i) over a rainfall event. Therefore, A hysteresis analysis was used to examine the dynamic changes of the C_i response to a hydrological process, which has been applied to investigate the temporal variation in solute concentration with flow rate (Blaen et al., 2017; Lloyd et al., 2016a; Lloyd et al., 2016b; Tunaley et al., 2017).

~~A hysteresis analysis was used to examine the dynamic changes of the DOC concentration response to a hydrological process, which has been applied to investigate the temporal variation in concentration export for a catchment.~~ Figure ~~6~~ 7 shows that the C_i~~DOC concentrations~~ varied in the rising and falling hydrograph during four selected rainfall events~~ (7 June, 13 July, 2 August and 10 September 2016)~~. Three hysteresis patterns were observed, including clockwise (~~13~~ 13-July and ~~10~~ 10-September), anti-clock wise (~~7~~ 7-June) and ~~figure~~ figure-~~of~~ of-eight (~~2~~ 2-August). As shown in Figure 6-a, the C_i~~DOC concentrations~~ was~~ere~~ higher during the falling limb than during the rising limb of the hydrograph, thus resulting in an anti-clock wise pattern. ~~The delayed maximum DOC concentration may be attributed to longer runoff flushing upstream, with increased hydrological connectivity induced by longer rainfall duration. Thus, it leads to a relatively higher DOC concentration during the falling period. Figure 6-c showed a~~A figure-of-eight pattern and indicated that C_i~~DOC concentration~~ generally varied in pace with runoff discharge on ~~2~~ 2-August, 2016 (Figure 6-2). The difference of C_i~~DOC concentration~~ between rising and falling limb at a given flow rate was small, as supported by the results shown in Figure 5-c. On ~~13~~ 13-July (Figure 6-b) and 10 September (Figure 6-d), the DOC exhibited a clockwise pattern, which implied that the DOC concentration was higher in the rising limb than in the falling limb. ~~The increased DOC was attributed to rapid flushing from soil organic carbon into stream water during the rising limb, and the DOC then declined due to the dilution effect. Moreover, previous studies reported that the close link between the DOC source and discharge flow may lead to a rapid increase in the DOC concentration.~~ The relationships between concentrations~~ in monthly~~ and ~~event-based processes~~flow rate highlighted that the DOC export behavior was different in a complete hydrological process or intra-events.

3.3 DOC Fluxes from Catchment

A rainfall event-based monitoring method is helpful to better understand the hydrological, DOC concentration and flux process. The rainfall event based on DOC flux ranged from 0.08 to 2.81 kg km^{-2} with a mean DOC flux of 0.43 kg km^{-2} for all sampled rainfall events from June to September 2016. The relationship between event-based DOC flux and runoff discharge amount is shown in Figure ~~3-b~~4-c. The DOC flux showed a positive ~~linear~~ relationship with the runoff discharge amount, especially for violent ~~for all sampled~~ rainfall events. ~~However, t~~The DOC flux was more variable in lower runoff discharge conditions. In general, event-based DOC flux was significantly and positively correlated with Q, Ra, R1 and R, as showed in Table 2. For the monthly DOC flux, the total DOC loading from the catchment ranged from 94.73 kg km^{-2} in August to 110.17 kg km^{-2} in September (Table 1). Although the total runoff discharge was lowest in June in these four months, the DOC monthly flux was 102.39 kg km^{-2} and had a higher flow-weighted DOC concentration (11.52 mg L^{-1}). However, the DOC flux was higher in September, with an increased runoff discharge and a lower flow-weighted DOC concentration. The larger runoff discharge amount may offset the effects of lower DOC concentrations. ~~These results showed that variation in DOC flux during sequential rainfall events induced hydrological processes in the concentrated rainfall season. Thus, it highlights the complexity of the DOC loading process, which may be influenced by rainfall, hydrological and carbon biogeochemical processes.~~

4. Discussion

4.1 Relationship between Rainfall and DOC Export

It has been known that hydrological and carbon processes are important aspects of the regional carbon cycle and for restoring ecosystem service. However, the event-driven DOC exported from a catchment in the LRP has rarely been studied. In this study, we ~~uses~~ used an in-situ auto- and high-frequency monitoring method to observe temporal changes in hydrological and DOC concentration dynamics for an event-based sampling period during the concentrated rainfall season (June-September) (Figure 2-b). For DOC export on a monthly scale, the DOC was calculated as the product of total discharge and flow-weighted mean concentration in a month; and thus, these two variables represented hydrological and carbon biogeochemical processes. Monthly

DOC fluxes were not clearly correlated with discharges. The flow-weighted DOC concentrations decreased during the experimental period, which differed from the greater DOC flux with a large discharge (Chen et al., 2012; Cooper et al., 2007). Furthermore, the monthly DOC fluxes were negatively correlated with the discharge amount from June to August 2016. The DOC concentration was higher in June and decreased in August. This was reasonable because the accumulated soil organic carbon can be flushed by runoff in early rainfall period, and the DOC concentration may be diluted by increased runoff (Blaen et al., 2017; Chen et al., 2012). In addition, in combination with the increased discharge amount, the decreased concentration led to a decrease in monthly DOC flux from June to August. This could be explained by the relative changes in DOC concentrations being higher than changes in monthly discharge, indicating that the decreased concentration may outweigh the effect of increased discharge. However, the exception occurred in September, while increased DOC flux over the other three months was mainly due to a smaller increase in DOC concentration. These results were also probably associated with rainfall amount, land cover and runoff flow path (Laudon et al., 2004; Soulsby et al., 2003). For example, crops planted in the check-dam field were harvested, and the ratio of rainfall to runoff increased in September. The soil soluble organic carbon is more likely to leach through macropores from check-dam farmland into runoff, which further increased the DOC concentration in runoff. Thus, it led to a slight increase in DOC flux in September. Therefore, it could be inferred from these results that DOC flux may depend on runoff flushing capacity and flow path in a restored and check-dam catchment.

Despite the fact that the DOC export varied in different months, there were also differences in DOC concentration and flux response to a rainfall event. DOC concentrations exhibited different dynamic changes throughout an event-driven hydrological process. In our result, the anticlockwise hysteresis between DOC concentration and flow rate was observed at 6-June. The peak DOC concentration was delayed compare to peak flow rate. These results may be attributed to a 5.2 mm rainfall was happen earlier than the maximum rainfall at 6-June (Figure 5-a). The antecedent rainfall may increase connectivity in hydrology and DOC source contributed to runoff. Thus, the dilution effect diminished as flow rate decreased and the increased connectivity lead to a relatively higher DOC concentration during the falling limb (Hope et al., 1994; Ma et al., 2018; Williams et al., 2017). A clockwise hysteresis was observed in 13-July and 10-September. The rapid response of flow rate to rainfall can be attributed to the rainfall event with a shorter duration and larger rainfall amount. The higher discharge may bring a higher flushing capacity, thus an increased DOC concentration was observed during the rising limb (Blaen et al., 2017; Tunaley et al., 2017). Moreover, the close link of DOC source to runoff may lead to a rapid increased in DOC concentration. A figure-of-eight hysteresis was observed in 2-August. due to the DOC concentration keep pace with flow rate during the rising and falling limb. Moreover, the event-driven DOC concentration at 2-August showed no distinct difference with other three higher rainfall amount events. These results suggested that a lower discharge induced by lower rainfall amount have a more complex and larger influence on DOC concentration from a catchment in LPR.

~~Despite the fact that the DOC fluxes varied in different months, there were also differences in DOC concentration and flux response to a rainfall event. Figure 7 showed the relationship between rainfall amount and mean daily discharge during June to September. This indicated that a rainfall event-driven discharge varied with rainfall amount, and thus need to be grouped by rainfall amount according to the rainfall grade. Linear regression analysis between discharge and rainfall amount with larger than 20 mm (k=0.07, R^2=0.62) showed a more rapidly changes than with rainfall amount less than 20 mm (k=0.02, R^2=0.59). Our results suggested that runoff discharges are highly sensitive to larger rainfall amount with greater than 20 mm in this area. In combined with soil moisture content changes during monitoring period, the infrequent and amount of violent rainfall events strongly influence the discharges, DOC during or later export from a catchment. Therefore, rainfall events caused considerable variations in event-based DOC concentration (Figure 4). There is a poor relationship between discharges and DOC concentrations for all sampled rainfall events and means that a necessary to grouped by rainfall amount correspondingly. Weak~~

~~and negative relationship were observed between DOC concentrations and runoff discharges induced by all rainfall events less than 20 mm (R^2=0.002, N=37). In contrast, DOC concentration generally decreased with discharge and showed a clear negative correlation for rainfall events higher than 20 mm (R^2=0.038, N=5). These findings are contrary to the studies that larger discharges resulted in higher DOC concentrations (Hope et al., 1994; Ma et al., 2018; Williams et al., 2017). Indeed, the large variations in DOC concentration were observed a general dilution effect induced by higher rainfall amount with larger runoff discharge, as reported by Clark et al. (2007) and Evans et al. (2006). Our results suggested that a lower discharge induced by lower rainfall amount have a more complex and larger influence on DOC concentration in semi-arid catchment of Loess Plateau.~~

For event-driven flux, the DOC flux is a function of total runoff discharge and DOC concentration (C_f). DOC flux showed a positive linear relationship with runoff discharges, which is not surprising and parallel with studies reported by Clark et al. (2007) and Ma et al. (2018). In addition, it should be noted that the DOC flux induced by larger rainfall amount was higher than flux driven by light rainfall, whereas the C_f showed no evident difference for the selected rainfall events. Thus, the greater DOC flux clearly showed that the DOC export was close linked to hydrologic process induced by various amount of rainfall event in LPR. For an ecological restored catchment in LPR, the soil carbon driven by increased vegetation was significantly increased and acted as a positive pathway to sequestration soil carbon on terrestrial ecosystem (Wang et al., 2011b). Meanwhile, the reduced hydrology responded to an increased vegetation may diminish soil carbon transported by hydrological process in a catchment. The event-driven DOC transport is an important component for evaluating carbon balance of the ecological restored catchment in LPR. Hence, further study should be long-term undertaking to investigate the hydrological response and its impact on terrestrial carbon loss from a catchment in LPR.

~~An event-based DOC flux is a function of total runoff discharge and DOC concentration. DOC flux showed a positive linear relationship with runoff discharges, which is not surprising and parallel with studies reported by Clark et al. (2007) and Ma et al. (2018). Although the DOC concentration decreased with the runoff discharge, the greater DOC flux clearly showed that the DOC export from a catchment was linked to hydrologic process induced by various amount of rainfall events. Therefore, these results showed that rainfall characteristics, hydrological conditions and soil carbon content are important for understanding DOC export from a catchment.~~

4.2 Factors Influence on DOC Export from a Catchment in Semi-arid Region

The mechanisms of DOC export from terrestrial ecosystems may be complicated and depend on many factors, such as soil organic carbon, vegetation, rainfall, hydrological condition and sampling period (Blaen et al., 2017; Cooper et al., 2007; Ma et al., 2018). Comparatively few previous studies have investigated how changes in hydrological factors and rainfall affect on DOC export. For instance, a current rainfall event leads to changes in a hydrological process, and it may also simultaneously change soil moisture content, which may influence the soil carbon biogeochemical process. For the next rainfall event, the antecedent conditions, such as hydrological conditions and the soil organic carbon content, may also influence the DOC concentration and flux. In general, antecedent conditions drive DOC export through exerting influences on availability of DOC and impacts on hydrologic connectivity (Brocca et al., 2010; McMillan et al., 2018). Therefore, DOC export from a catchment during rainfall events was the result of carbon biogeochemical processes, and the antecedent hydrological and rainfall characteristics. ~~In this study, temporal variations of rainfall, air temperature and soil moisture content were continuously monitored throughout the study period to provide detailed information describing the antecedent and current conditions.~~

The infrequent and amount of violent rainfall events strongly influence the runoff discharges and soil moisture, which in turn impact on DOC during or later export from a catchment. In this study, temporal variations of rainfall, air temperature and soil moisture content were continuously monitored throughout the study period to provide detailed information describing the antecedent and current conditions. Positively correlation between Ra, R7 and C_f ~~Table 2 showed the correlation between DOC concentration/flux and a set of factors in all sampled rainfall events during the study period. The event-based DOC concentrations were positively correlated with rainfall amount (RA) and R7. These results~~ suggest that the combination of the current rainfall amount and the accumulated rainfall before a current rainfall event are important. ~~The influence of~~ R7 may reflect the antecedent hydrological condition and Ra represent the current rainfall input into the catchment, resulting in well ~~that impacted runoff generation and~~hydrological connectivity and more DOC source may contribute to runoff. Therefore, C_f can by strongly influenced by Ra and R7 due to the hydrological properties of the catchment. Apart from the hydrological changes, the antecedent soil moisture also played an important role in C_f and showed ~~in a rainfall event rather than the direct influence on DOC concentration. However, event-based DOC concentrations were~~ an extreme significantly and negatively correlated with SMC7 and SMC14 (Table 2). ~~A previous study by Yang et al. (2018) in the LPR found that rainfall recharge into soil had a rainfall threshold value.~~ These results were also consistent with Yang et al. (2018), who found that the threshold of rainfall effectively recharged into soil was 20-26 mm for grassland and forestland in LPR. Therefore, the pattern of soil moisture dry-wet cycle may affect event-driven DOC concentration, and this highlights the importance of soil moisture condition in DOC export (Figure 7). ~~The soil moisture content was continuously dried and then effectively rewetted under a specific rainfall amount, as supported by the soil moisture variations shown in Figure 2-c. Given variation pattern of soil moisture content during studied period, the relationship between DOC concentration and the dry-wet cycle of soil moisture was shown in Figure 8.~~ The higher DOC concentrations from June to middle July coincided with light rainfall, and thus rainfall recharge into soil moisture. ~~low discharge~~. This is probably attributed to inactive microbial activity, caused by the relatively lower soil moisture (Jager et al., 2009). The DOC concentration decreased with increased soil moisture content, particularly in ~~July~~ July-18 with a total rainfall amount of 56.4 mm. On one hand, violent rainfall events may induce a higher discharge, causing a dilution effects on DOC concentration. On the other hand, the rainfall water may effectively replenish soil moisture content, and thus stimulate a higher decomposition of soil carbon under wet and higher temperature condition. Then, the relative decreased DOC concentrations were observed in a drying soil moisture condition for the next rainfall events, which may attribute to an exhaustion of DOC (Laudon et al., 2004). These findings were similar to previous studies by Tunaley et al. (2017), who reported a strong influence of dry antecedent conditions on DOC export response to rainfall event.

~~For event-based DOC fluxes,~~ DOC flux was significantly and positively correlated with Q, ~~RA~~Ra, R1 and R7. The Q and ~~RA~~ Ra reflect the direct effect of current rainfall and hydrological processes during a rainfall event, while R1 and R7 refer to the antecedent rainfall conditions and reflect indirect effects on DOC export. These results agreed with previous studies demonstrated by Blaen et al. (2017), who noted that antecedent conditions and rainfall were key drivers of DOC export during a rainfall event. Cooper et al. (2007) also concluded that DOC export is largely governed by interactions between hydrological and meteorological factors and carbon biogeochemical process. Overall, these results suggested that rainfall is a key factor influencing hydrological process, and thus DOC export from an ecological restored catchment in LPR. Apart from the increased soil carbon driven by increased vegetation (Wang et al., 2011b), the weaken hydrological process induced by increased vegetation may also cause a less terrestrial carbon export from a catchment. Therefore, our results highlight the need for research not only into the hydrological process and soil carbon cycle, but the integration of carbon export driven by a sequence of rainfall events across spatiotemporal scales to understand the carbon balance in a restored catchment in LPR.

~~Since the DOC export process is complicated, the influence of the selected factors, including current and antecedent conditions, is intuitive to some extent. Therefore, prediction of DOC concentration induced by rainfall is complicated to establish. Given that our results were based on rainfall event date and collected during a concentrated rainfall season in a small catchment, this~~

~~process requires further investigation regarding soil organic carbon changes under intra rainfall events and dry-rewetting conditions on DOC release from soil into runoff during different rainfall events in the LPR.~~

5. Conclusion

The DOC concentration and flux for individual rainfall events from a semi-arid catchment of the LPR was initially monitored during the concentrated rainfall season. DOC concentration showed a weak correlation with discharge, except in higher runoff discharge induced by extreme rainfall events. The findings of this study indicate that DOC concentrations were highly variable, particularly during low runoff discharge periods. Hysteresis analysis showed that the relationship between DOC concentration and runoff discharge for a rainfall event is nonlinear and varied with conditions in rainfall amount, discharge process. DOC flux increased with runoff discharge and showed a positive linear correlation with runoff discharges. These results showed that higher DOC ~~export~~ flux with low DOC concentration related to higher discharge and its dilution effects in a hydrological process driven by larger rainfall amount.~~, in turn caused by larger rainfall amount.~~ The diluted DOC concentration induced by increased discharges contributed slightly to difference in DOC flux, due to total runoff discharge is a major variable for flux. These results showed that the temporal variation magnitude of DOC is related to hydrological condition and antecedent condition, and suggested that the event-driven DOC export is largely influenced by rainfall through direct effects on catchment hydrology and indirect effects on soil carbon cycles. Changes in catchment hydrology and soil carbon processes responded to climate change may play an important role in terrestrial carbon export, in particular for a restored catchment. Thus, further work should focus on carbon export response to various rainfall events at a larger spatiotemporal scale for better estimating future terrestrial carbon to aquatic ecosystem and evaluating carbon balance in ecological restored catchment in LPR. In addition, engineers and scientists can take advantage of the derived results to better develop advanced field monitoring work.

~~The findings of this study indicate that DOC concentrations were highly variable, particularly during low runoff discharge periods. The detailed monitoring method used to capture multiple factors, including runoff discharge, rainfall, DOC concentration, soil moisture and temperature through the concentrated rainfall season, facilitates a better understanding of the dynamic DOC export process in a rainfall event. Hysteresis analysis showed that the relationship between DOC concentration and runoff discharge for a rainfall event is nonlinear and varied with conditions in rainfall amount, discharge process, and monitoring time. These results showed that the DOC response to rainfall is related to hydrological conditions (Q and RA) and antecedent conditions (R1, R7 and SMC). Therefore, our results preliminarily highlight that DOC export was influenced by the interaction of hydrological and carbon biogeochemical processes. Engineers and scientists can take advantage of the derived results to better develop advanced field monitoring work. In addition, release of DOC in runoff can the quantified during hydrological and biogeochemical processes within catchments in LPR.~~

Data availability: The dataset used for this manuscript can be provided by e-mail contact with the first or corresponding author.

Author contributions. Linhua Wang: analyzing data and organizing the manuscript; Haw Yen: discussing the relationship between DOC concentration/flux and runoff discharges induced by a sequence of rainfall events; Xinhui E: sampling and lab testing work; Liding Chen ang Yafeng Wang: discussing and guiding the field monitoring work.

Competing interests: The authors declare that they have no conflict of interest.

Acknowledgments

This work was financially supported by the National Nature Science Foundation of China (41671271, 41807176 and 41571130083). We wish to thank Shibo Chen and Weiliang Chen for their help during the field sampling work and laboratory analysis.

References

Battin, T.J., Kaplan, L.A., Findlay, S., Hopkinson, C.S., Marti, E., Packman, A.I., Newbold, J.D., Sabater, F.: Biophysical controls on organic carbon fluxes in fluvial networks. Nature Geoscience 1, 95-100, 2008.

Bennett, E.M., Peterson, G.D., Gordon, L.J.: Understanding relationships among multiple ecosystem services. Ecology Letters 12, 1394-1404, 2009.

Billett, M.F., Deacon, C.M., Palmer, S.M., Dawson, J.J.C., Hope, D.: Connecting organic carbon in stream water and soils in a peatland catchment. Journal of Geophysical Research: Biogeosciences 111, G02010, doi:10.1029/2005JG000065, 2006.

Blaen, P.J., Khamis, K., Lloyd, C., Comer-Warner, S., Ciocca, F., Thomas, R.M., MacKenzie, A.R., Krause, S.: High-frequency monitoring of catchment nutrient exports reveals highly variable storm event responses and dynamic source zone activation. Journal of Geophysical Research: Biogeosciences 122, 2265-2281, 2017.

Brocca, L., Melone, F., Moramarco, T., Wagner, W., Hasenauer, S.: ASCAT soil wetness index validation through in situ and modeled soil moisture data in central Italy. Remote Sensing of Environment 114(11): 2745-2755, 2010.

Chen, L., Huang, Z., Gong, J., Fu, B., Huang, Y.: The effect of land cover/vegetation on soil water dynamic in the hilly area of the loess plateau, China. Catena 70, 200-208, 2007.

Chen, N., Wu, J., Hong, H.: Effect of storm events on riverine nitrogen dynamics in a subtropical watershed, southeastern China. The Science of the Total Environment 431, 357-365, 2012.

Clark, J.M., Lane, S.N., Chapman, P.J., Adamson, J.K.: Export of dissolved organic carbon from an upland peatland during storm events: Implications for flux estimates. Journal of Hydrology 347, 438-447, 2007.

Cooper, R., Thoss, V., Watson, H.: Factors influencing the release of dissolved organic carbon and dissolved forms of nitrogen from a small upland headwater during autumn runoff events. Hydrological Processes 21, 622-633, 2007.

Dawson, J., Billett, M., Neal, C., Hill, S.: A comparison of particulate, dissolved and gaseous carbon in two contrasting upland streams in the UK. Journal of Hydrology 257:226-246, 2002.

Drake, T.W., Raymond, P.A., Spencer, R.G.M.: Terrestrial carbon inputs to inland waters: A current synthesis of estimates and uncertainty. Limnology and Oceanography Letters 3, 132-142, 2018.

~~Evans, C.D., Chapman, P.J., Clark, J.M., Monteith, D.T., Cresser, M.S.: Alternative explanations for rising dissolved organic carbon export from organic soils. Global Change Biology 12, 2044-2053, 2006.~~

Evans, C.D., Monteith, D.T., Cooper, D.M.: Long-term increases in surface water dissolved organic carbon: observations, possible causes and environmental impacts. Environmental Pollution 137, 55-71, 2005.

Fu, B., Wang, S., Liu, Y., Liu, J., Liang, W., Miao, C.: Hydrogeomorphic ecosystem responses to natural and anthropogenic changes in the Loess Plateau of China. Annual Review of Earth and Planetary Sciences 45:223-43, 2017.

Fu, B., Zhao, W., Zhao, Q., Liu, Y.: Changes of landscape pattern and soil erosion in Loess Plateau. Science Press. Beijing p:186-199 (in Chinese), 2014.

Hedge, J., Keil, R., Benner, R.: What happens to terrestrial organic matter in the ocean? Organic Geochemistry 27(5/6):195-212, 1997.

Hope, D., Billett, M., Cresser, M.: A review of the export of carbon in river water: Fluxes and processes. Environmental Pollution 84(3):301-324, 1994.

Hu, B., Wang, P., Zhang, N., Wang, C., Ao, Y.: Photoproduction of dissolved organic carbon and inorganic nutrients from resuspended lake sediments. Environmental Science and Pollution Research International 23, 22126-22135, 2016.

Inamdar, S.P., O'Leary, N., Mitchell, M.J., Riley, J.T.: The impact of storm events on solute exports from a glaciated forested watershed in western New York, USA. Hydrological Processes 20, 3423-3439, 2006.

Jager, D.F., Wilmking, M., Kukkonen, J.V.: The influence of summer seasonal extremes on dissolved organic carbon export from a boreal peatland catchment: evidence from one dry and one wet growing season. The Science of the Total Environment 407, 1373-1382, 2009.

Kieber, R., Peake, B., Willey, J., Avery, B.: Dissolved organic carbon and organic acids in coastal New Zealand rainwater. Atmospheric Environment 36, 3557-3563, 2002.

Laudon, H., Kohler, S., Buffam, I.: Seasonal TOC export from seven boreal catchments in northern Sweden. Aquatic Sciences - Research Across Boundaries 66, 223-230, 2004.

Li, B., Wang, L., Statistical analysis of precipitation in recent 60 years in Yan'an. Shaanxi Water Resources 1:126-129, 2015 (in Chinese with English abstract).

Liang, W., Bai, D., Jin, Z., You, Y., Li, J., Yang, Y.: A Study on the Streamflow Change and its Relationship with Climate Change and Ecological Restoration Measures in a Sediment Concentrated Region in the Loess Plateau, China. Water Resources Management 29, 4045-4060, 2015a.

Liang, W., Bai, D., Wang, F., Fu, B., Yan, J., Wang, S., Yang, Y., Long, D., Feng, M.: Quantifying the impacts of climate change and ecological restoration on streamflow changes based on a Budyko hydrological model in China's Loess Plateau. Water Resources Research 51, 6500-6519, 2015b.

Lloyd, C.E., Freer, J.E., Johnes, P.J., Collins, A.L.: Using hysteresis analysis of high-resolution water quality monitoring data, including uncertainty, to infer controls on nutrient and sediment transfer in catchments. The Science of the Total Environment 543, 388-404, 2016a.

Lloyd, C.E.M., Freer, J.E., Johnes, P.J., Collins, A.L.: Technical Note: Testing an improved index for analysing storm discharge–concentration hysteresis. Hydrology and Earth System Sciences 20, 625-632, 2016b.

Ma, X., Liu, G., Wu, X., Smoak, J.M., Ye, L., Xu, H., Zhao, L., Ding, Y.: Influence of land cover on riverine dissolved organic carbon concentrations and export in the Three Rivers Headwater Region of the Qinghai-Tibetan Plateau. The Science of the Total Environment 630, 314-322, 2018.

McMillan, S., Wilson, H., Tague, C., Hanes, D., Inamdar, S., Karwan, D., Loecke, T., Morrison, J., Murphy, S., Vidon, P.: Before the storm: antecedent conditions as regulators of hydrologic and biogeochemical response to extreme climate events. Biogeochemistry 141(3): 487-501, 2018.

Mulholland, P.: Large-Scale Patterns in Dissolved Organic Carbon Concentration, Flux, and Sources. in Aquatic Ecosystems Interactivity of Dissolved Organic Matter, edited by S. E. G. Findlay and R. L. Sinsabaugh pp. 139-159, 2003.

Ran, L., Tian, M., Fang, N., Wang, S., Lu, X., Yang, X., Cho, F.: Riverine carbon export in the arid to semiarid Wuding River catchment on the Chinese Loess Plateau. Biogeosciences 15, 3857-3871. 2018.

Raymond, P.A., Hartmann, J., Lauerwald, R., Sobek, S., McDonald, C., Hoover, M., Butman, D., Striegl, R., Mayorga, E., Humborg, C., Kortelainen, P., Durr, H., Meybeck, M., Ciais, P., Guth, P.: Global carbon dioxide emissions from inland waters. Nature 503, 355-359, 2013.

Raymond, P.A., Saiers, J.E.: Event controlled DOC export from forested watersheds. Biogeochemistry 100, 197-209, 2010.

Ritson, J.P., Graham, N.J., Templeton, M.R., Clark, J.M., Gough, R., Freeman, C.: The impact of climate change on the treatability of dissolved organic matter (DOM) in upland water supplies: a UK perspective. The Science of the Total Environment 473-474, 714-730, 2014.

Shi, H., Shao, M.: Soil and water loss from the Loess Plateau in China. Journal of Arid Environments 45, 9-20, 2010.

Soulsby, C., Rodgers, P., Smart, R., Dawson, J., Dunn, S.: A tracer-based assessment of hydrological pathways at different spatial scales in a mesoscale Scottish catchment. Hydrological Processes 17, 759-777, 2003.

Systat: Sigma Plot. Version 10.0, Systat Software Inc., San Jose, CA, 2008.

Tang, K.: Soil and water conservation in China. Chinese Science Press: Beijing, p15-20 (in Chinese), 2004.

Tunaley, C., Tetzlaff, D., Soulsby, C.: Scaling effects of riparian peatlands on stable isotopes in runoff and DOC mobilisation. Journal of Hydrology 549, 220-235, 2017.

Wang, Y., Fu, B., Chen, L., Lu, Y., Gao, Y.: Check dam in the Loess Plateau of China: engineering for environmental services and food security. Environmental Science & Technology 45, 10298-10299, 2011a.

Wang, Y., Fu, B., Lü, Y., Chen, L.: Effects of vegetation restoration on soil organic carbon sequestration at multiple scales in semi-arid Loess Plateau, China. Catena 85, 58-66, 2011b.

Wei, W., Jia, F., Yang, L., Chen, L., Zhang, H., Yu, Y.: Effects of surficial condition and rainfall intensity on runoff in a loess hilly area, China. Journal of Hydrology 513, 115-126, 2014.

Willey, J., Kieber, R., Eyman, M., Avery, G.B.: Rainwater dissolved organic carbon: concentrations and global flux. Global Biogeochemical Cycles 14(1):139-148, 2000.

Williams, M., King, K., Fausey, N.: Dissolved organic carbon loading from the field to watershed scale in tile-drained landscape. Agricultural Water Management 192:159-169, 2017.

Yang, L., Zhang, H., Chen, L.: Identification on threshold and efficiency of rainfall replenishment to soil water in semi-arid loess hilly areas. Science China Earth Sciences 61, 292-301, 2018.

Table 1 Characteristics of rainfall (Ra), ~~runoff discharge~~flow rate, DOC concentration~~–~~ (C_f) and *Flux* ~~and flux~~for event-based samples collected during the concentrated rainfall season (June-September, 2016).

Table 2 Summary of correlation coefficients between C_f , *Flux*~~DOC concentration/flux~~ and a set of factors.

Figure 1 Geographic location of the Yangjuangou catchment in the Loess Plateau Region, China and the red and yellow dot denote the weather station and runoff sampling site.

Figure 2 Temporal variations in Ra (rainfall amount) (a), flow rate (a), C_f (flow-weighted mean concentration) and *Flux* (b), SMC (soil moisture content) (c) and air temperature (d) during the concentrated rainfall season (June-September, 2016).~~Temporal variations in rainfall amount (a), runoff discharge (a), DOC concentration and flux (b), soil moisture content (c) and air temperature (d) during the concentrated rainfall season (June-September, 2016). The green dots and bars denote the sampled rainfall events.~~

Figure 3 Statistics characteristics of rainfall events from June to September, 2016: (a) ~~statistics~~ characteristics of total and sampled rainfall amount, (b) characteristics~~statistics~~ of rainfall grades and its occurrence frequency.

Figure 4 Relationships between Ra (rainfall amount) and flow rate (a), C_f (flow-weighted mean concentration) and flow rate (b), *Flux* and total discharge (c) for sampled rainfall events during the monitoring period (June-September, 2016).~~Relationships between runoff discharge and DOC concentration and flux for sampled rainfall events during the concentrated rainfall season (June-September, 2016).~~

Figure 5 Dynamic changes of DOC concentration in an individual runoff event: (a) ~~6~~ 6-June, 2016~~;~~, (b)~~13~~ 13-July, 2016~~;~~, (c) ~~2~~ 2-August, 2016~~;~~, (d) ~~10~~ 10-September, 2016.

Figure 6 Hysteresis loops for four selected runoff events from June to September: (a) ~~6~~ 6-June, 2016~~;~~, (b)~~13~~ 13-July, 2016~~;~~, (c) ~~2~~ 2-August, 2016~~;~~, (d) ~~10~~ 10-September, 2016.

~~Figure 7 The relationship between rainfall amount and discharges during monitoring period.~~

Figure ~~8~~ 7 The changes of event-driven C_f (flow-weighted mean concentration) response to dry-wet and wet-dry variations in soil moisture content.~~The relationship between DOC concentration and dry-wet variation of soil moisture concentrated during monitoring period.~~

Table 1

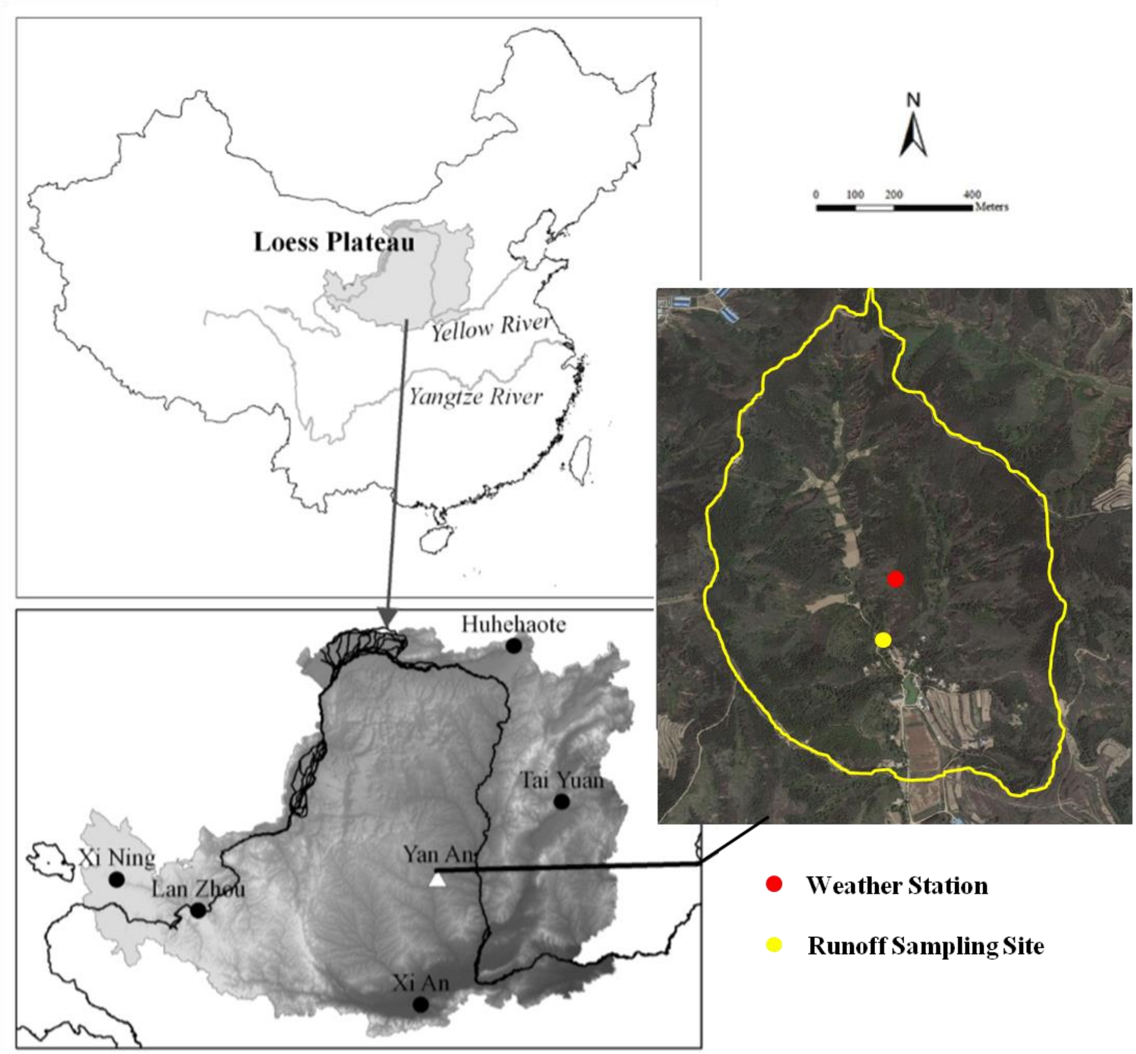
Date	Ra(mm)	Flow rate ($L\ s^{-1}$)	C_f ($mg\ L^{-1}$)	*Flux* ($kg\ km^{-2}$)	Date	Ra(mm)	Flow rate ($L\ s^{-1}$)	C_f ($mg\ L^{-1}$)	*Flux* ($kg\ km^{-2}$)
1-Jun.	1.0	0.56	10.87	0.52	1-Aug.	0.8	0.54	5.14	0.24
2-Jun.	7.0	0.59	9.97	0.51	2-Aug.	4.2	0.63	9.72	0.53
3-Jun.	3.0	0.53	10.53	0.48	6-Aug.	0.8	0.47	7.95	0.32
5-Jun.	3.2	0.53	11.59	0.53	12-Aug.	0.8	0.40	5.30	0.18
7-Jun.	13.8	0.65	12.96	0.73	13-Aug.	1.2	0.35	5.93	0.18
Jun.	82.9	0.35	11.52	102.39	16-Aug.	18.8	0.96	6.46	0.54
11-Jul.	24.6	0.44	11.92	0.45	17-Aug.	0.6	0.55	9.69	0.46
13-Jul.	19.8	1.28	11.84	1.31	18-Aug.	1.2	0.57	7.44	0.37
14-Jul.	11.0	0.46	13.00	0.52	Aug.	53.8	0.53	6.81	94.73
18-Jul.	62.6	1.46	11.64	1.47	9-Sept.	6.8	0.44	13.14	0.50
19-Jul.	29.2	4.05	8.12	2.84	10-Sept.	21.8	1.24	7.21	0.77
31-Jul.	2.2	0.54	6.70	0.31	17-Sept.	6.2	0.48	9.10	0.38
Jul.	184.2	0.41	8.95	96.57	Sept.	51.2	0.57	7.49	110.17

Table 2

	Flux	Q	RA	R1	R7	R14	REI	T_{air}-7	T_{air}-14	SMC-7	SMC-14
DOC	0.30	-0.01	0.30	-0.01	0.23	-0.05	-0.32*	-0.25	-0.24	-0.44**	-0.65**
Flux		0.94**	0.69**	0.76**	0.57**	0.29	-0.14	-0.07	-0.04	0.06	-0.24
Q			0.60**	0.85**	0.53**	0.33*	-0.07	-0.02	0.01	0.19	-0.03
RA				0.38*	0.39*	0.14	-0.06	0.02	0.07	-0.05	-0.30
R1					0.58**	0.42**	-0.27	0.11	0.10	0.12	-0.01
R7						0.69**	-0.28	0.24	0.23	0.40**	0.02
R14							-0.20	0.19	0.13	0.56**	.420**
REI								-0.02	0.03	0.26	0.25
T_{air}-7									0.96**	0.09	0.20
T_{air}-14										0.09	0.17
SMC-7											0.79**

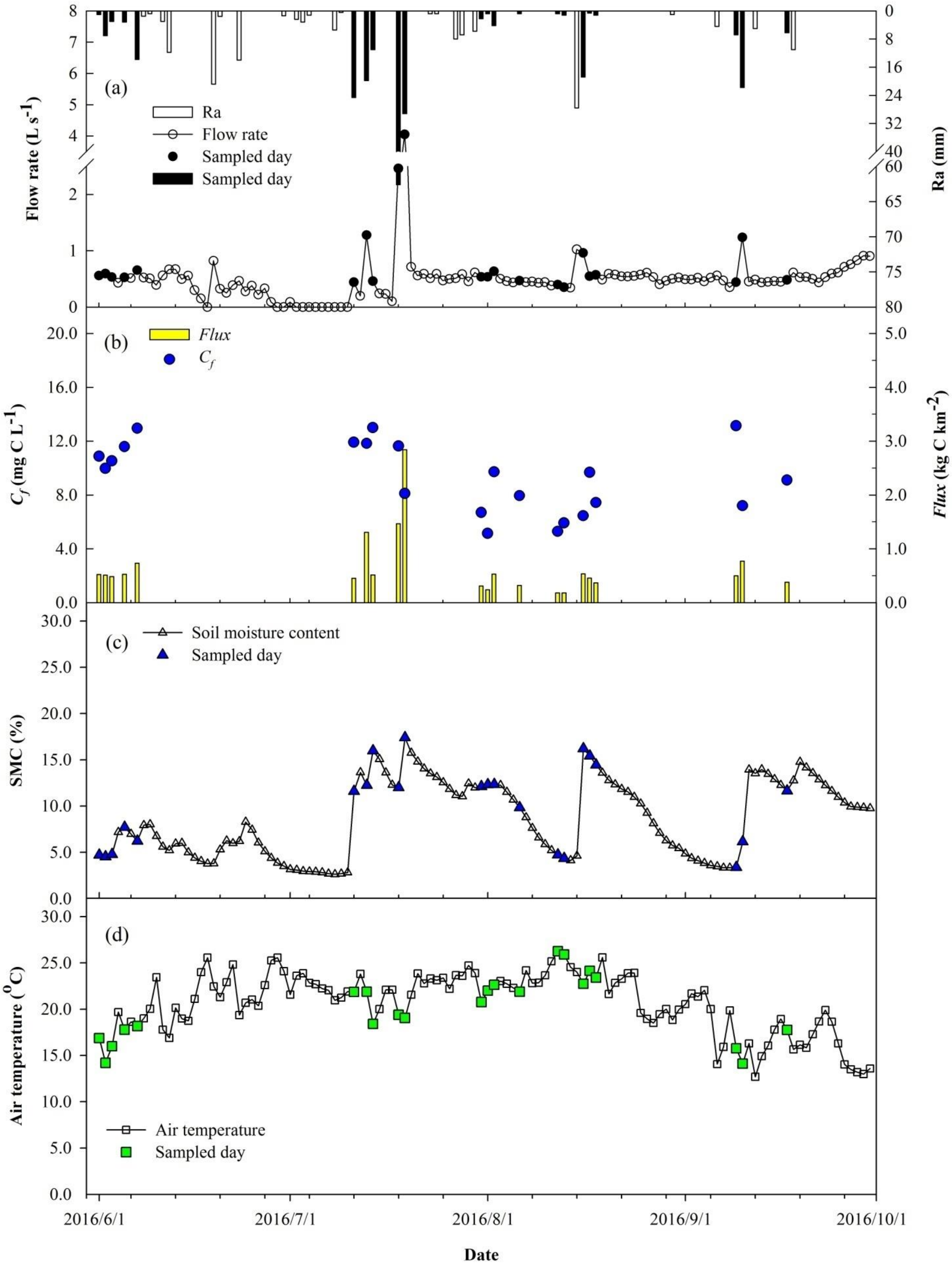
~~Note: ** (P<0.01), * (P<0.05).~~Note: ** (P<0.01), * (P<0.05).
C_f: Flow-weighted mean concentration driven by an event, *Flux*: Event-driven DOC quantity,
Q: Total discharge volume, Ra: Total rainfall amount,
R1: Total rainfall amount in the 1 day before the current rainfall event,
R7: Total rainfall amount in the 7 days before the current rainfall event,
R14: Total rainfall amount in the 14 days before the current rainfall event,
SMC-7 and SMC-14: Soil moisture content in the 7 and 14 days before the current rainfall event,
T_{air}-7 and T_{air}-14: Mean air temperature in the 7and 14 days before the current rainfall event,
REI: Interval days between the current and last rainfall event.

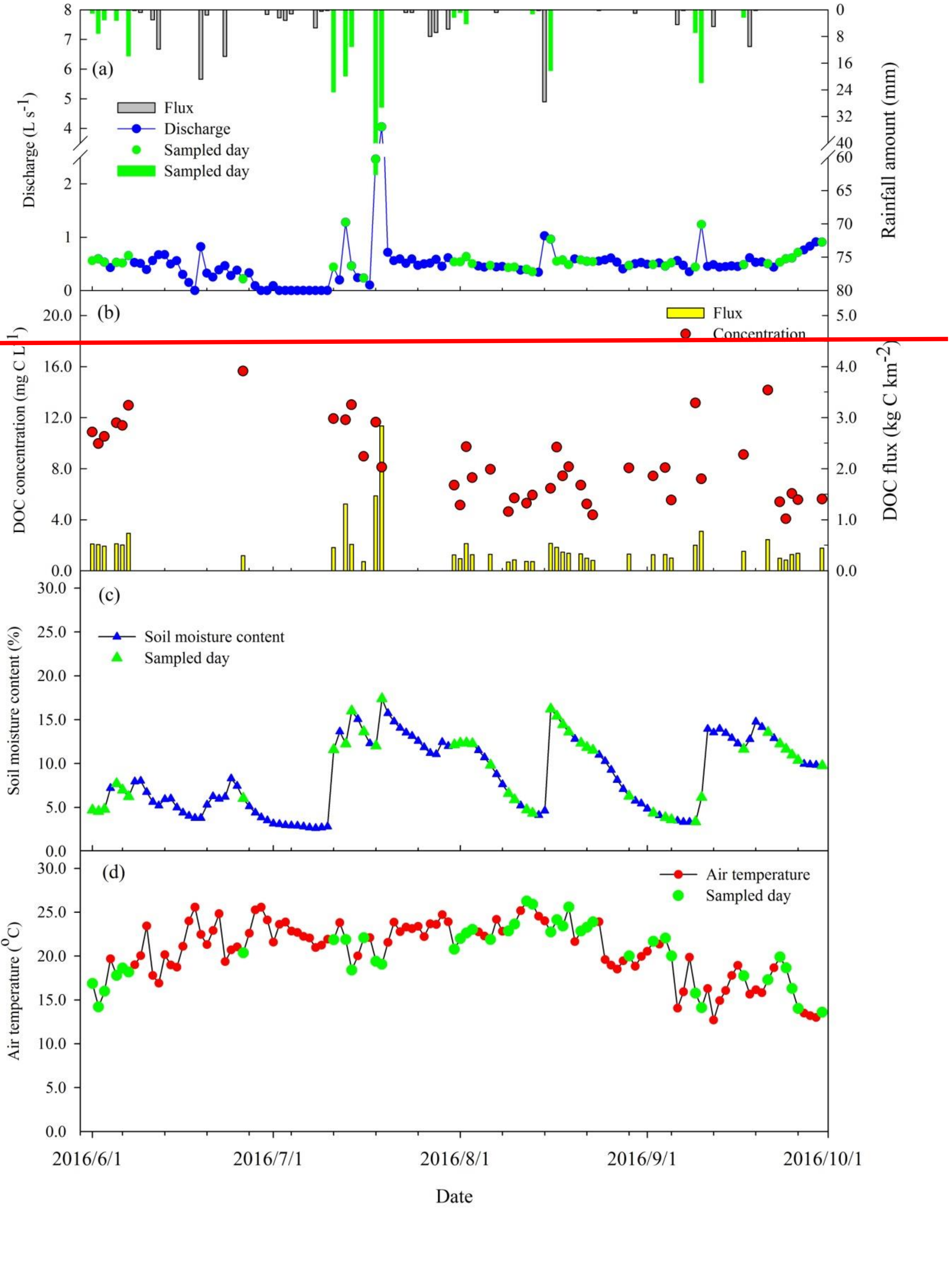
Figure 1



1525

1530 **Figure 2**

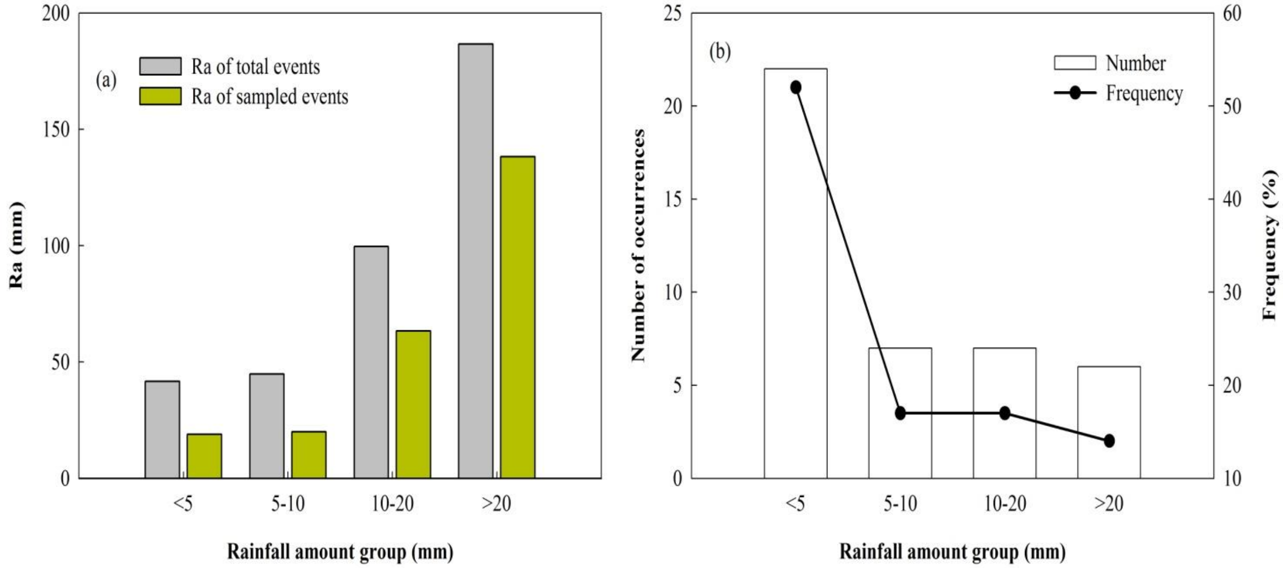




(a)
Flux
Discharge
Sampled day
Sampled day
Discharge (L s-1)
Rainfall amount (mm)
(b)
Flux
Concentration
DOC concentration (mg C L-1)
DOC flux (kg C km-2)
(c)
Soil moisture content
Sampled day
Soil moisture content (%)
(d)
Air temperature
Sampled day
Air temperature (oC)
2016/6/1
2016/7/1
2016/8/1
2016/9/1
2016/10/1
Date

1535

Figure 3


(a)
Ra of total events
Ra of sampled events
Ra (mm)
200
150
100
50
0
<5
5-10
10-20
>20
Rainfall amount group (mm)
(b)
Number
Frequency
Number of occurrences
Frequency (%)
25
20
15
10
5
0
60
50
40
30
20
10
<5
5-10
10-20
>20
Rainfall amount group (mm)

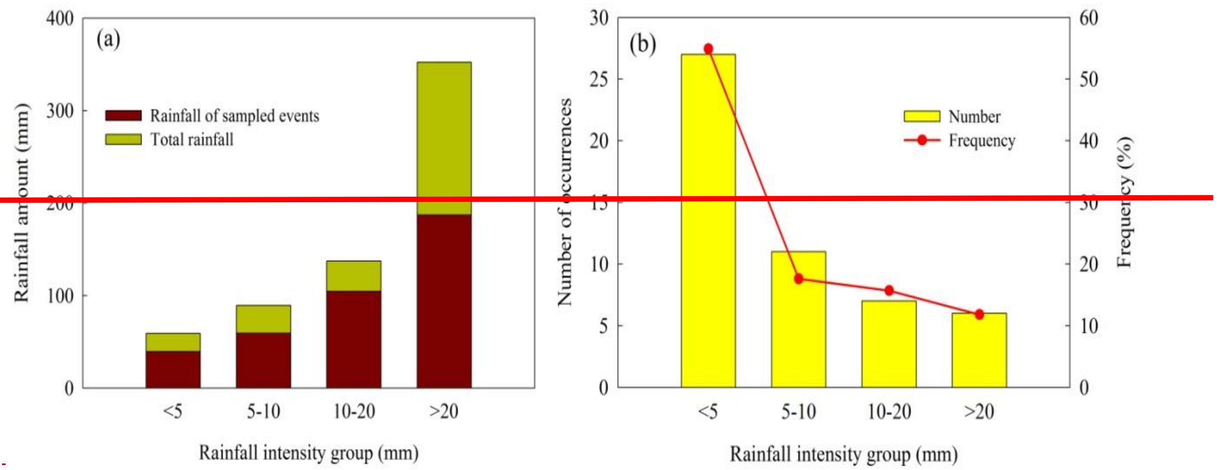
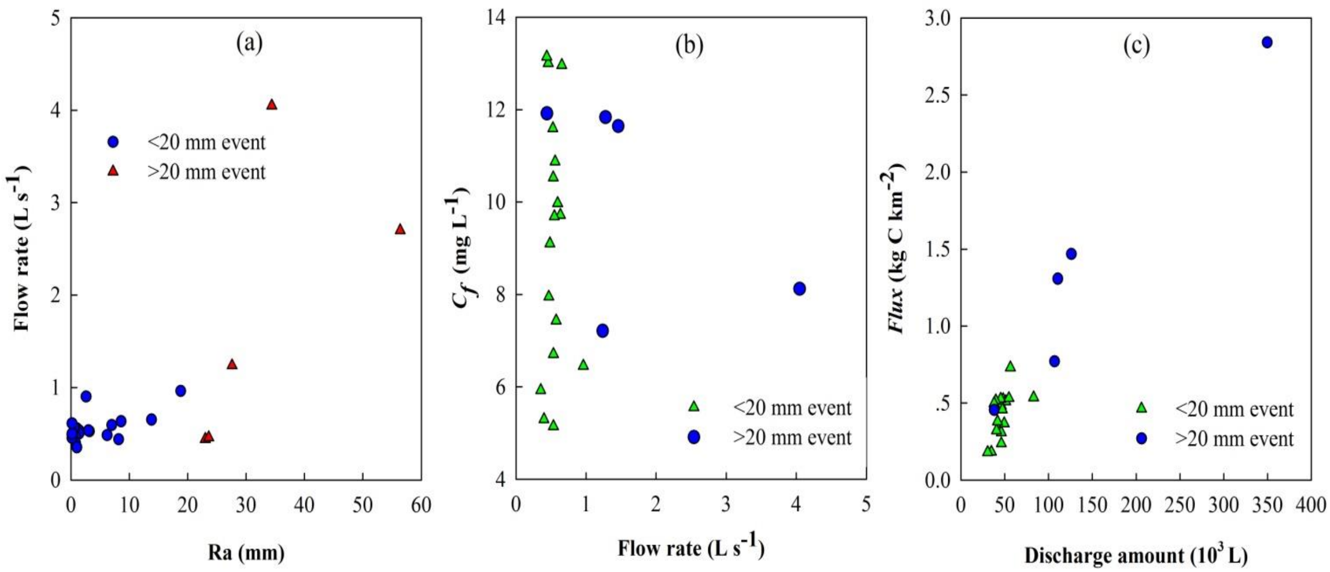
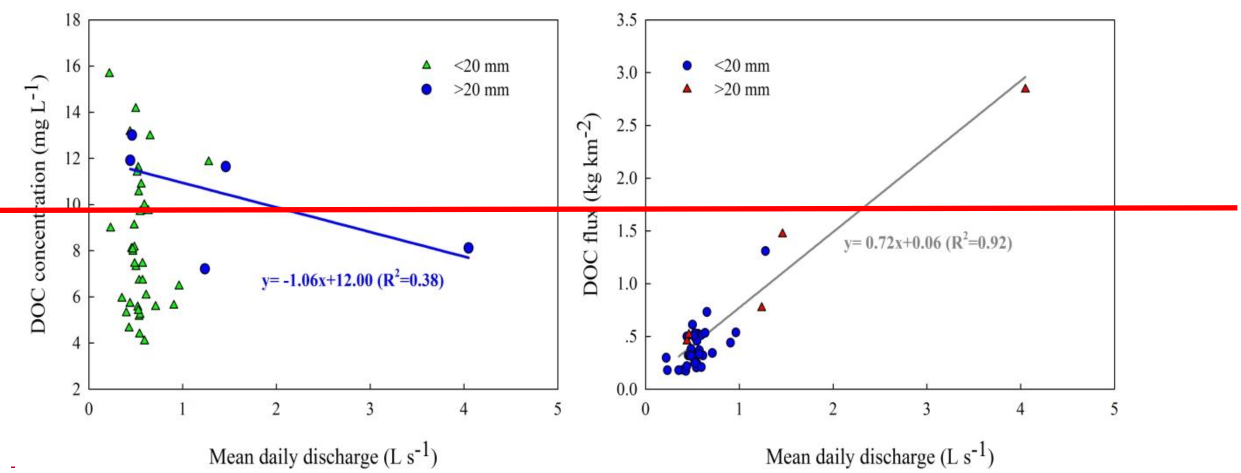

(a)
Rainfall of sampled events
Total rainfall
Rainfall amount (mm)
400
300
200
100
0
<5
5-10
10-20
>20
Rainfall intensity group (mm)
(b)
Number
Frequency
Number of occurrences
Frequency (%)
30
25
20
15
10
5
0
60
50
40
30
20
10
0
<5
5-10
10-20
>20
Rainfall intensity group (mm)

Figure 4

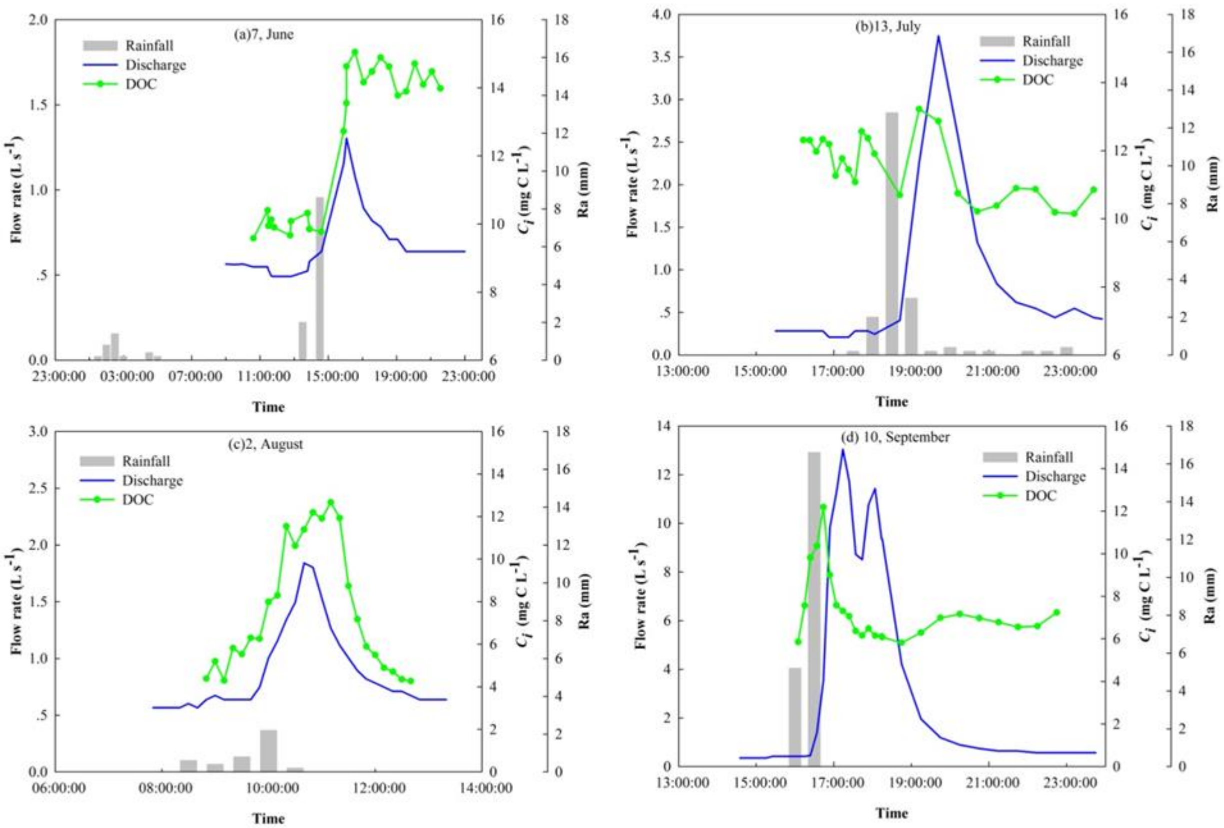


(a)
<20 mm event
>20 mm event
Flow rate (L s-1)
Ra (mm)
(b)
<20 mm event
>20 mm event
Cf (mg L-1)
Flow rate (L s-1)
(c)
<20 mm event
>20 mm event
Flux (kg C km-2)
Discharge amount (10³ L)



<20 mm
>20 mm
DOC concentration (mg L-1)
y= -1.06x+12.00 (R²=0.38)
Mean daily discharge (L s-1)
<20 mm
>20 mm
DOC flux (kg km-2)
y= 0.72x+0.06 (R²=0.92)
Mean daily discharge (L s-1)

Figure 5



(a)7, June
Rainfall
Discharge
DOC
Flow rate (L s-1)
Ci (mg C L-1)
Ra (mm)
Time
23:00:00
03:00:00
07:00:00
11:00:00
15:00:00
19:00:00
23:00:00
(b)13, July
13:00:00
15:00:00
17:00:00
19:00:00
21:00:00
23:00:00
(c)2, August
06:00:00
08:00:00
10:00:00
12:00:00
14:00:00
(d) 10, September

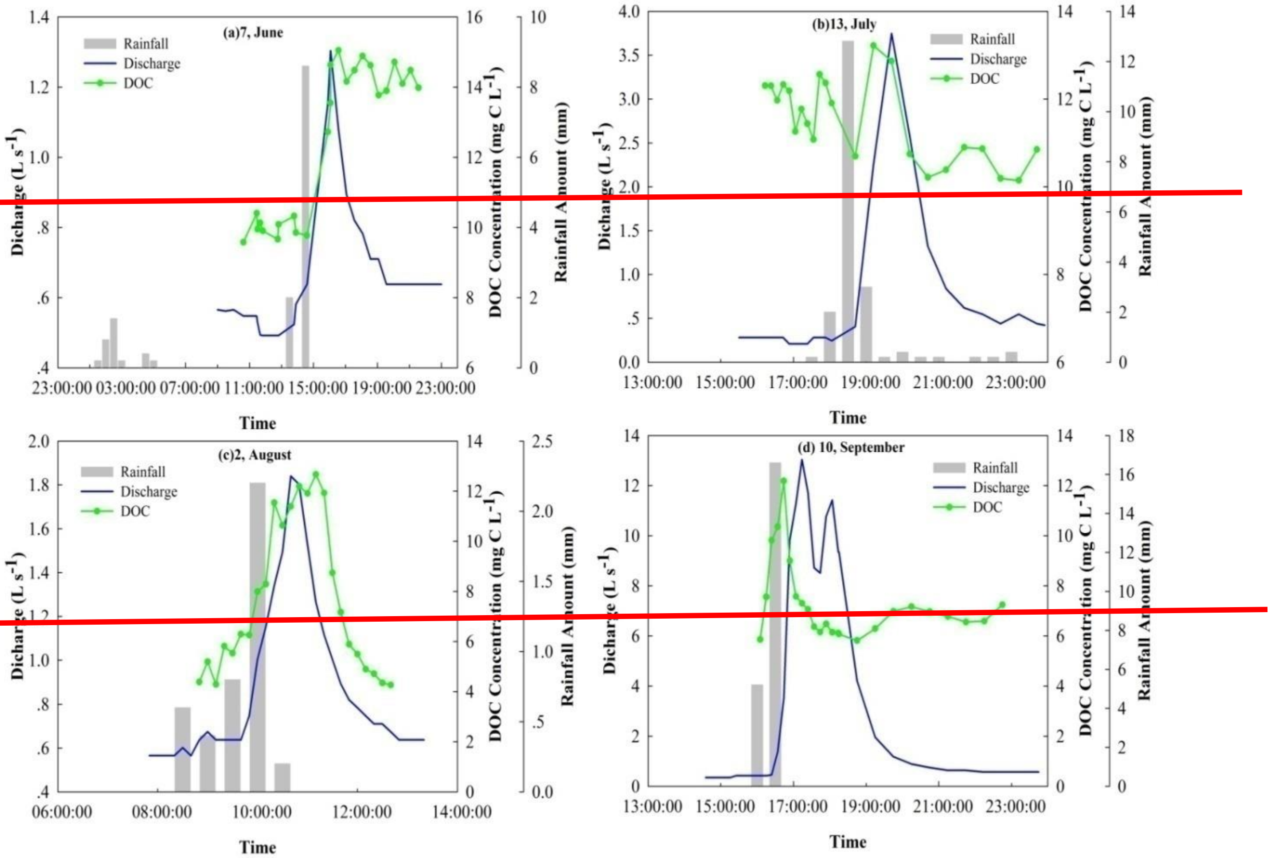
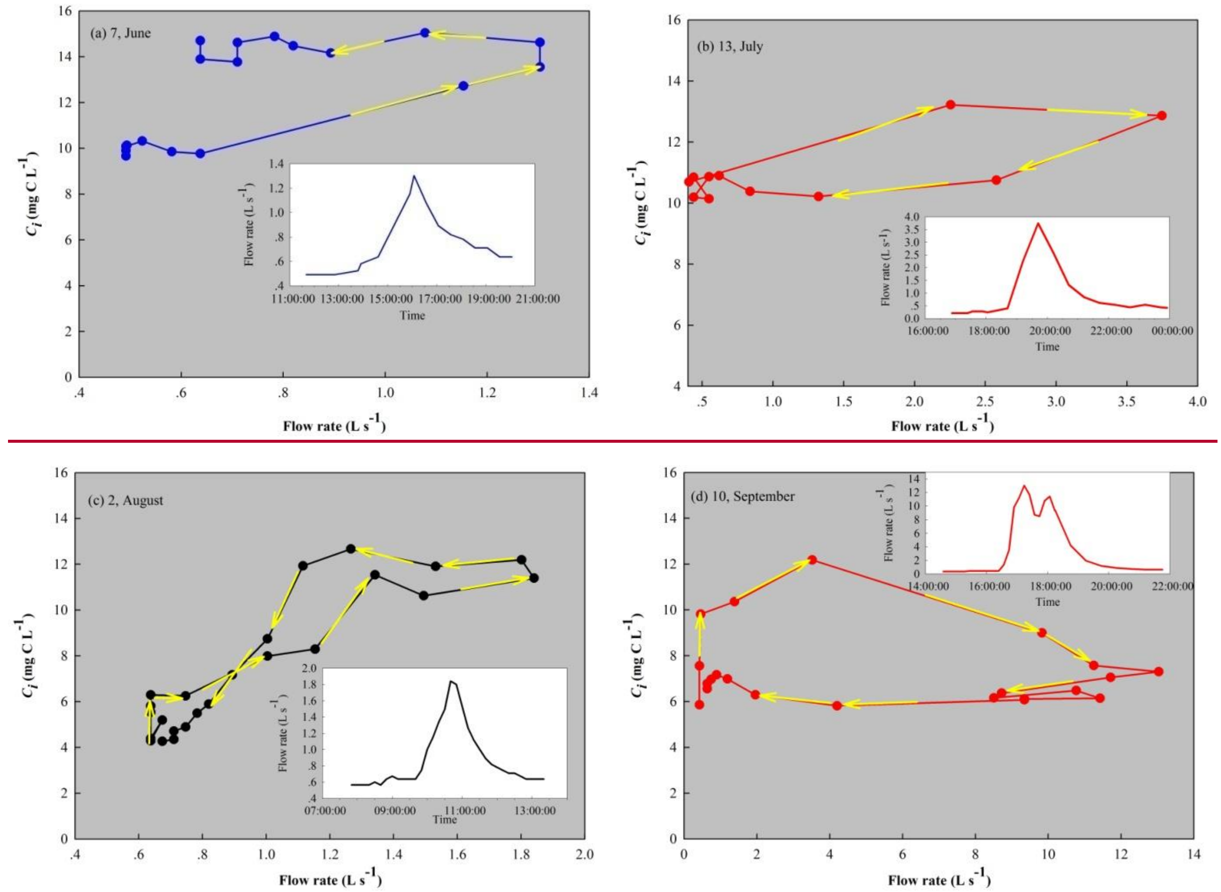
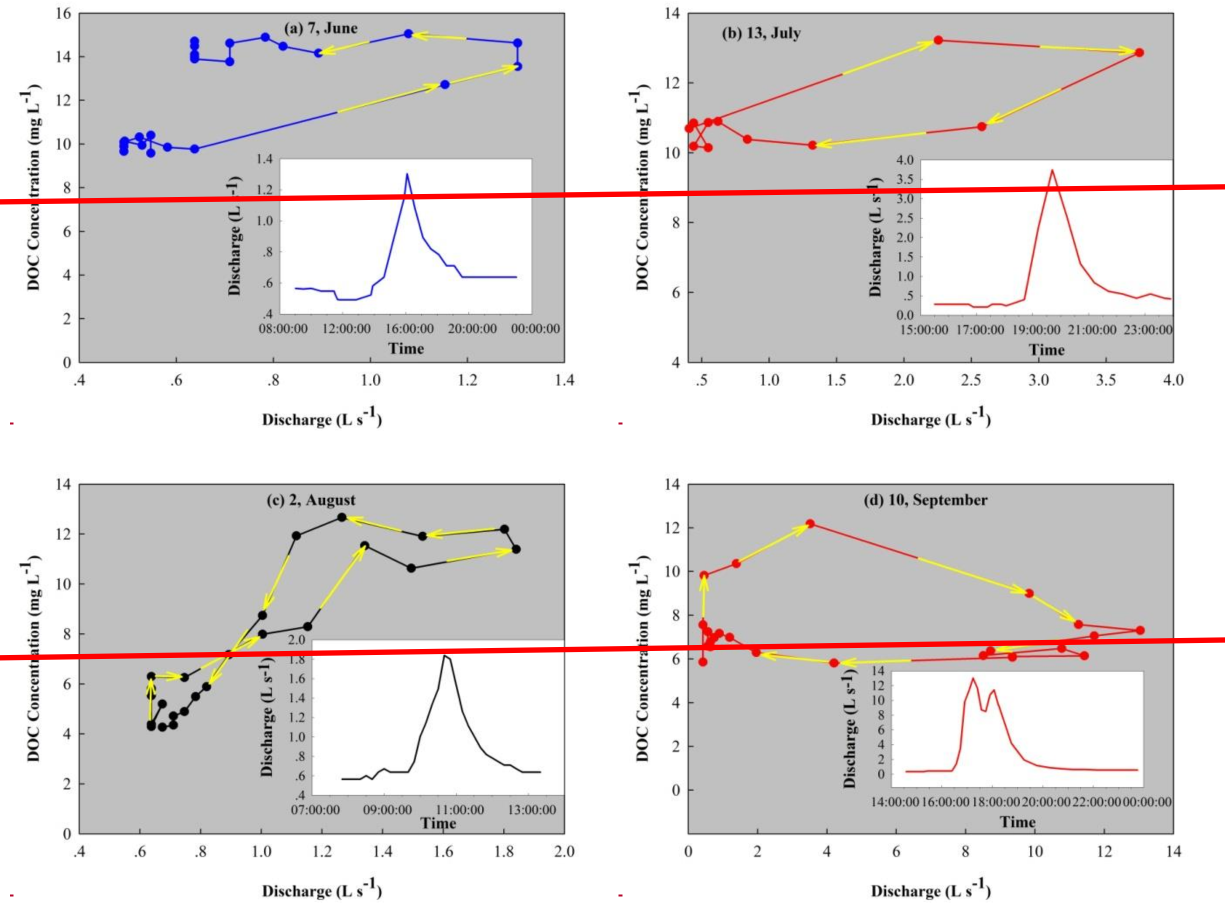

(a)7, June
(b)13, July
(c)2, August
(d) 10, September
Rainfall
Discharge
DOC
Dicharge (L s-1)
DOC Concentration (mg C L-1)
Rainfall Amount (mm)
Time

Figure 6



1570


(a) 7, June
(b) 13, July
(c) 2, August
(d) 10, September
DOC Concentration (mg L-1)
Discharge (L s-1)
Time
08:00:00
12:00:00
16:00:00
20:00:00
00:00:00
15:00:00
17:00:00
19:00:00
21:00:00
23:00:00
07:00:00
09:00:00
11:00:00
13:00:00
14:00:00
16:00:00
18:00:00
20:00:00
22:00:00
00:00:00

~~Figure 7~~

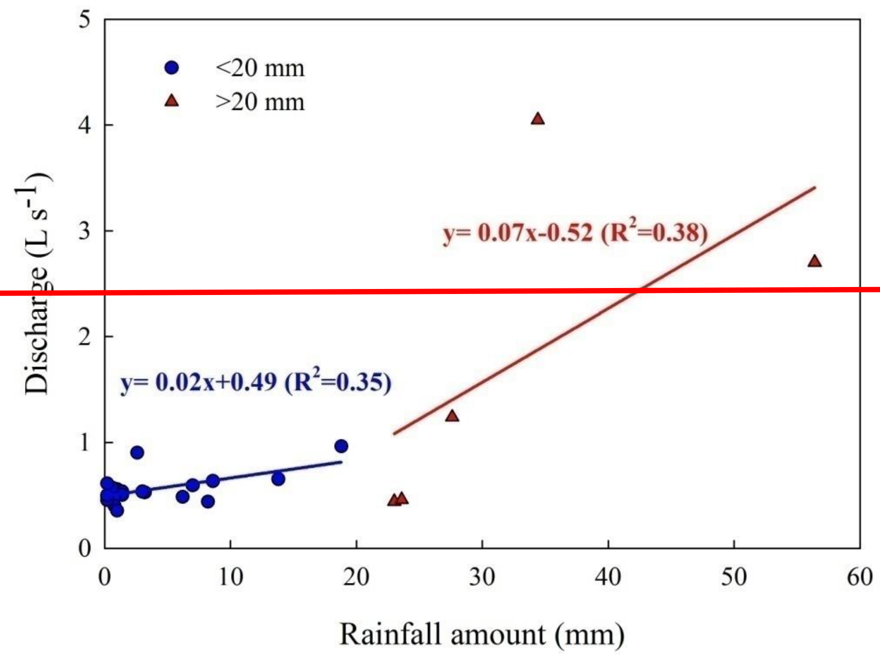
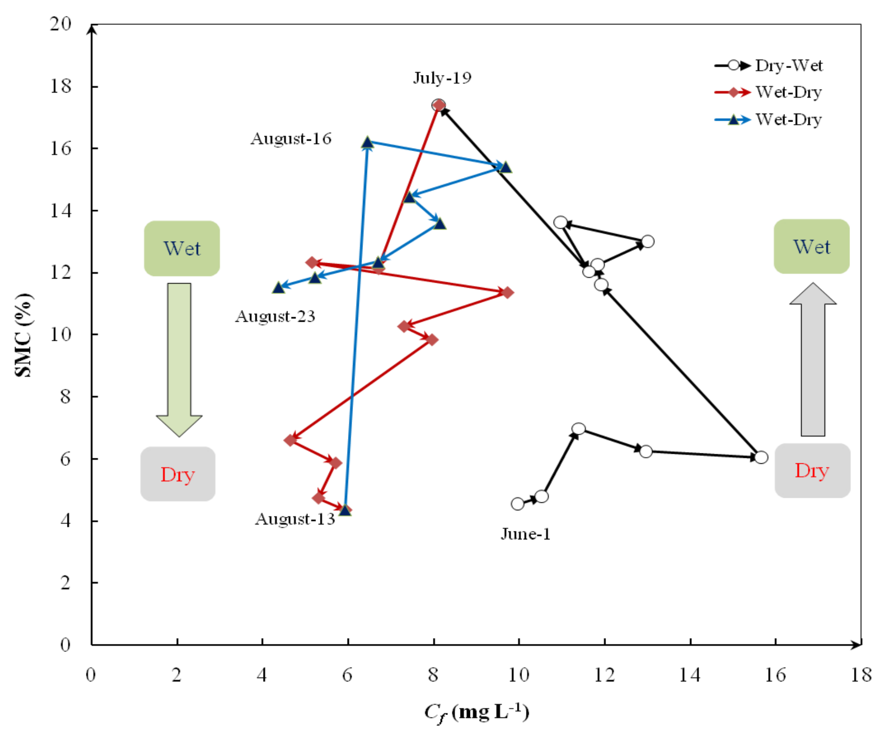


Figure ~~8~~7



1585