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June 25, 2012

Memorandum

To: Dr. Lixing Wang, Editor of *"Water, climate, and vegetation: ecohydrology in a changing world"* special issue of *Hydrology and Earth System Sciences*

Subject: Revision of hessd-2012-132

Dear Dr. Lixing Wang:

We have carefully revised our manuscript hessd-2012-132 entitled "Coupling the modified SCS-CN and RUSLE models to simulate hydrological effects of restoring vegetation in the Loess Plateau of China" after considering all the comments made by you, two anonymous reviewers and Luca Brocca. The comments have helped us improve the overall quality of the manuscript. The following is the point-point response to all the comments. Please refer the marked version of the revised manuscript to find the page and line numbers in the following response.

Response to Editor:

1. Comment:

Thanks for submitting your work to our HESS special issue. I received review reports from three experts. Overall, all of them are positive but reviewers offer some constructive comments. Based on these and my own reading, I would be pleased to accept this manuscript for publication if you could consider the review comments and revise your manuscript accordingly.

Reply: *All the review comments have been carefully considered and corresponding revision have been made (see the replies to the comments of Anonymous Referee #1 and #2, and Luca Brocca).*

2. Comment:

In addition, please carefully proofread your manuscript before submitting the revised version. There are some grammar issues which could be improved. For example, Page 3 Line 3 "limited" should be "limiting". Furthermore, to increase relevance of this manuscript to the overall special issue theme, it would be great if you could check the following link for all the available papers of this special issue in HESSD and cross-reference them as you see fit. http://www.hydrol-earth-syst-sci-discuss.net/special_issue74.html.

Reply: *We have double checked the manuscript and corrected some grammar mistakes. We have also cross-referenced several papers of this special issue to strengthen relevance of this manuscript to the theme of this special issue.*

Response to Anonymous Referee #1:

1. Comment:

This paper contributes to prediction of soil erosion rates by simple approaches based on not novel but still widely used methodologies. In my opinion, the approach developed by the Authors is generally correct and interesting. In general, the manuscript represents a valuable contribution to soil loss prediction by technicians and professionals, although the results have only a local validity. I believe that a few points should be better discussed. Some improvements and developments are also necessary.

Reply: *Thanks very much for this nice comment. All the points below have been carefully discussed, and corresponding improvements and developments have been necessarily made in the revised manuscript (see the following point-to-point replies to the comments).*

2. Comment:

I am a little puzzled about measurement of runoff and soil loss. A reason is that the Authors do not give any information on the characteristics of the system used to both intercept and store runoff and the associated sediments. Another reason is that a drying period of eight hours at 105 ^{o}C could be too short to remove all water from the collected sediments. Did the Authors control that this duration was appropriate?

Reply: *We have given a detailed description of the system to intercept and store runoff and the associated sediments in the revised version (see P.12, Lines 9-13).*

The collected sediment was first air-dried for more than 24 h and dried in an oven at 105 ^{o}C for larger than 8 h until constant weight was achieved, which ensured that all water was removed from the collected sediments. We have addressed the detailed procedures to collect and measure runoff and sediment (see P.13, Lines 8-14).

3. Comment:

The Authors should justify the choice of plot lengths varying from 5 to 13 m, also taking into account that different erosive mechanisms can be expected in the different plots. In particular, occurrence of interrill erosion alone can be presumed for the shortest plots whereas both rill and interrill processes are expected on the longest plots.

Reply: *The erosion status was observed at the end of each erosive event. There was only little rill generated in Plot 13 as it had the longest length and smallest vegetation cover. Sheet or interrill erosion dominated in the other runoff plots. Therefore, the choice of plot lengths varying from 5 to 13 m was justified, and the effect of specific erosion processes on soil loss can be ignored in the soil loss simulation.*

We have incorporated above statements into revised version to address this comment (P.13, Line 21 to P.14, Line 2).

4. Comment:

According to the USLE/RUSLE scheme, soil loss per unit area should increase with plot length but scientific literature shows many examples of situations where this increasing relationship was not detected. The data collected by the Authors are usable to check the soil loss per unit area vs. plot length relationship in the sampled area. This point should be examined to establish consistency of the data with the USLE/RUSLE model. Maybe, the Authors could give a look at the following papers which, in my opinion, are very interesting: Moreno-de las Heras M., Nicolau J.M., Merino-Martín L., Wilcox B.P. (2010) Plot-scale effects on runoff and erosion along a slope degradation gradient. Water Resources Research, 46, W04503, and Yair A., Raz-Yassif N. (2004) Hydrological processes in a small arid catchment: scale effects of rainfall and slope length. Geomorphology, 61, 155-169.

Reply: *First, we have given the observed plot-scale results of soil loss from the above two references and field experiment in this study, which was not totally consistent with the USLE/RUSLE scheme. Thus, we addressed the reasons contributing to the complex plot-scale effects of soil loss. Finally, we have discussed the applicability of the modified RUSLE model to incorporate the scale variations of sediment yield.*

We have addressed this comment in detail from P.26, Line 25 to P.27, Line 23.

5. Comment:

Another point related to plot length to be discussed is the suitability of the data to check the applicability of the different versions of the SCS-CN model. More precisely, the Authors should support the suitability of data collected on very short plots (e.g., 5 m) to check the model.

Reply: *We have pointed out and discussed the limitation of using data collected at relatively short plots to check the applicability of the different versions of the SCS-CN model (see P.26, Lines 12-17).*

6. Comment:

Another question still concerning plot lengths is that the Authors successfully developed a modified SCS-CN model but the applicability of this and alternative SCS-CN models was assessed only with reference to short plots (i.e., not longer than 13 m). There is some evidence that runoff decreases with plot length (examples are Joel, A., Messing, I., Seguel, O., Casanova, M. (2002) Measurement of surface water runoff from plots of two different sizes. Hydrological Processes 16, 1467-1478, and Parsons, A.J., Brazier, R.E., Wainwright, J., Powell, D.M. (2006) Scale relationships in hillslope runoff and erosion. Earth Surface Processes and Landforms 31, 1384-1393). Moreover, agricultural fields are generally longer, even much longer, than 13 m. Therefore, some comment on the applicability of the developed model on relatively long fields should be included.

Reply: *We have stated the effects of plot-scale on runoff from the three group plots and the above two references. In fact, the modified SCS-CN model did not consider the plot-scale effects for runoff simulation. One available way to account for plot-scale effects is to incorporate established scale-parameter relationships into the modified SCS-CN model.*

We have incorporated above statements into the revised version to address this comment, and indicated that the applicability of the developed SCS-CN model on relatively long fields should be tested (see P.26, Lines 11-24).

7. Comment:

Eq.(14) by the Authors differ from both the USLE-M by Kinnell and the USLE-MM by Bagarello et al.. In the USLE-M, the proportionality between soil loss per unit area (Ae) and the erosivity term QREI30 is direct, i.e. the coefficient "b" is equal to one. In the USLE-MM, "b" is greater than one but the "a" coefficient is considered to be representative of soil erodibility. Eq.(14) has a "b" value greater than one but it also considers separately soil erodibility. In other terms, the erosivity index is QREI30 according to Kinnell, (QREI30)ˆb according to Bagarello et al., and a(QREI30)ˆb according to the Authors. This point should be considered and discussed also taking into account that, according to Kinnell and Risse (1998: USLE-M: Empirical modelling rainfall erosion through runoff and sediment concentration. Soil Science Society of America Journal, Vol.62, 1667-1672), changing the erosivity term implies that the original soil erodibility factor, and other original factors of the USLE, cannot be used to predict soil loss.

Reply: *In the modified RUSLE (Eq. (14)), the original soil erodibility was used and the coefficient "a" was used to account for the consequences of changing rainfall erosivity from* EI_{30} *on the other factors. The* $(Q_REI_{30})^b$ *term with "b" greater than one performed satisfactorily for soil loss prediction as indicated by Bagarello et al. (2010). We have explicitly demonstrated the differences between the modified RUSLE in this study and the USLE-M by Kinnell (1998) and the USLE-MM by Bagarello et al. (2010). The modified RUSLE model can encompass both the USLE-M and USLE-MM, and it incorporates the effects from event rainfall and runoff on soil loss as well as the impact of event erosivity index on other factors. (see P.10, Lines 12-25).*

8. Comment:

In any case, I have seen that the "b" exponent by the Authors (1.55) is close to the "b" value obtained by Bagarello et al. (2010) in Italy on plots varying in length from 11 to 44 m (1.47). Probably, this point needs some comment by the Authors.

Reply: *We have compared the obtained "a" value in the modified RUSLE model with the ratio between the soil erodibility of the USLE-M (*K_{UM}*) and USLE (K) in Kinnell and Risse (1998), as well as the "b" values obtained from this study and Bagarello et al. (2010) (see P.21, Lines 20-25). The indications of the compared results were discussed (see P.21, Line 25 to P.22, Line 3).*

We also pointed out that systematic field experimental studies should be conducted to install quantitative relationships between the empirical coefficients and knowable variables such as soil texture, land cover, plot length and slope as it is difficult to independently determine the coefficients (see P.28, Lines 3-7).

9. Comment:

In the manuscript, the Authors tested eq.(14) with only the estimated QR. In my opinion, also using the equation with the measured runoff ratio is necessary to separately establish the approximations attributable to the model's structure (i.e., eq.14) and the ones due to the unavoidable uncertainties associated with runoff estimation.

Reply: *This is a good suggestion. We have used Eq. (14) with the measured runoff ratio to simulate the event soil loss, and compared it with those from Eq. (14) using the estimated Q_R. The effects of the model's structure and the unavoidable uncertainties associated with runoff estimation on soil loss prediction were discussed. (see P.22, Line 18 to P.23, Line 5)*

Response to Anonymous Referee #2:

General comments:

In this manuscript, the modified SCS-CN and RUSEL models were coupled for predicting the event runoff and soil erosion. The objectives and relevant scientific questions addressed in this paper are within the scope of HESS. The scientific methods and assumptions are valid and clearly outlines, while the results are sufficient to support the interpretations and conclusions. Before it is accepted for publication, the following suggestions should be considered and some modifications should be done.

Reply: *Thanks very much for this nice comment. All the suggestions have been carefully considered and modifications have been done accordingly (see the following point-to-point replies to the comments).*

1. Comment:

In the standard SCS-CN method, the initial abstraction ratio is assumed to be 0.2. But many researchers observed the initial abstraction ratio in the range of 0.0 to 0.3. For example, Mishra and Singh (1999) obtained values of the initial abstraction ratio ranging from 0.000 to 0.042 for three watersheds less than 1 km^2 in the USA and for one 3124 km^2 watershed located in India, respectively, while Huang et al (2007) optimized the initial abstraction ratio of 0.001 for four plots. The initial abstraction ratio represents the effects of soil and cover characteristics on the runoff process, and might not be a constant. In this manuscript, authors compared two initial abstraction ratios of 0.2 and 0.05, and found that the modified SCS-CN model with the initial abstraction ratio of0.05 could improve model precision. The reviewer suggests that authors should consider to optimize the initial abstraction ratio using the measured the rainfall-runoff data, and to obtain a reasonable value for the studied plots.

Reply: *The statements about the initial abstraction ratio in this comment are correct. We have incorporated them into the revised manuscript (see P.14, Lines 9-15).*

In this study, the initial abstraction ratio was not optimized as suggested in this comment, and two commonly used values (λ=0.05, 0.2) were directly applied in the SCS-CN model as a result of following three reasons. First, λ was assumed to be equal to 0.2 in its original development, and many studies in the Loess Plateau and other regions have indicated that with λ=0.05 the simulation accuracy of

SCS-CN model could improve greatly (see P.14, Lines 15-20). $\lambda=0.05$ and 0.2 are the commonly used values for SCS-CN model. Second, if the value of λ is optimized using the measured rainfall-runoff data, it can not adequately examine the applicability of the modified SCS-CN model. Furthermore, the obtained optimization value is only reasonable for the studied plots, which limits the applications of the model in other areas (see P.14, Lines 20-23). A key point to text one model is to independently determine model parameters, but not optimize them with measured data, which can strengthen the convincing and application of the model. This is one main advantage of the modified SCS-CN model in this study (see P.25, Lines 3-6). Third, the simulation results have proved that $\lambda=0.05$ is a reasonable value for the initial abstraction coefficient in the study area.

2. Comment:

In Table 1, authors should provide the standard value of CN_2 for each group.

Reply: *The standard CN_{II} value for each runoff plot has been provided in Table 1 (see P.15, Lines 6-7, and P.48, Table 1).*

3. Comment:

The statistical characteristics of rainfall for the simulated runoff events are very helpful for readers to understand your simulations. Reviewer suggests that authors should add them in manuscript.

Reply: *We have added a new table in the revision version to show the statistical characteristics of the rainfall for the simulated runoff events (see P.13, Lines 15-20, and P.50, Table 3).*

4. Comment:

The DISCUSSION section is very limited in this manuscript. Some results, such as the simulated efficiency, should be compared with other researchers using the SCS-CN method.

Reply: *General and detailed discussion have been done in the revised version to substantially address the main advantages, limitations and further investigation scopes of the proposed approach. The DISCUSSCION part has been extended from one page to nearly four pages in the revised manuscript (see "4.4 Discussion of the proposed approach" subsection from P.24, Line 20 to P.28, Line 13).*

We have also compared the simulated efficiency of the modified SCS-CN model with other researchers using the SCS-CN method to simulate event plot runoff in the Loess Plateau (see P.21, Lines 2-15).

Response to short comment of Luca Brocca:

1. Comment:

I enjoyed reading the paper by Gao et al. and I believe that the coupling of simple rainfall-runoff (as Soil Conservation Service - Curve Number, SCS-CN) and erosion (as Universal Soil Loss Equation, USLE) models is a good approach for the estimation of event soil loss. In fact, potentially, it can provide a simple tool to be applied in different regions and climates. Moreover, I fully agree with the authors that the soil moisture conditions prior the rainfall events play a significant role for the estimation of runoff and, hence, erosion.

Reply: *Thanks very much for this nice comment. The emphasis of the developed SCS-CN model in this study is to explicitly incorporate the soil moisture conditions prior the rainfall events in the estimation of runoff and, hence, erosion.*

2. Comment:

It is just for this reason for which I decide to post this (very) short comment that mainly deals with the hydrological part (SCS-CN method) of the paper. The method used by the authors to incorporate the Antecedent Moisture Conditions (AMCs) in the SCS-CN method is not clear. Basically, the antecedent 5-day rainfall, P5, is used as indicator of the antecedent soil moisture conditions but (if I well understood) it is employed both for M estimation (equation (9)) and for modulating the CNI and CNI I I values (equations (16) and (17)). So, AMCs are updated continuously through equation (9) and with sudden jumps through equations (16) and (17).This procedure seems to me quite confusing. Moreover, by reading the paper results it can’t be understood which is the effect of different AMCs for the rainfall-runoff events analyzed. For instance, how do the AMCs vary from event to event? Is this variability significant for runoff estimation? This is one of the main aspects of the paper but it is only marginally considered in the description of the results.

Reply: *In the modified SCS-CN model, the AMCs were updated continuously in runoff calculation through Eqs. (7) and (9), but with sudden jumps in the values of CN parameter. We have discussed this limitation of the modified SCS-CN model only using the antecedent 5-day rainfall, P_5, to determine antecedent moisture amount (see P.25, Lines 11-17).*

We have also described the AMCs of the rainfall-runoff events analyzed, and discussed the effects of AMCs on runoff production and simulation (see P.20, Lines 3-16).

3. Comment:

Additionally, there are several studies that attempted to incorporate actual soil moisture observation for the direct estimation of the Soil Potential Maximum Retention parameter, S, in the classical formulation of the SCS-CN method by assuming a simple linear relation (Brocca et al., 2009a) that is more clear of the approach used in the paper. In particular, the use of in situ (and modelled) soil moisture observations have been compared with the other indices based on antecedent rainfall, initial discharge and groundwater table for the estimation of S (Brocca et al., 2009a; Tramblay et al., 2010; Tramblay et al., 2011; Coustau et al., 2012). Additionally, satellite-derived soil moisture observations have been also employed for this purpose (Brocca et al., 2009b; 2011b; Beck et al., 2010). In all these studies the common aspect is that actual soil moisture observations (by in situ and remote sensing measurements) are the best indicators of the catchment wetness conditions providing a significant improvement for runoff estimation through the SCS-CN method. Based on that, the linear relation has been also incorporated in a continuous rainfall-runoff model (Brocca et al., 2010; 2011a) to obtain a low parameterized but reliable modelling tool aimed at flood simulation.

Reply: *Yes, it is not adequate to represent antecedent moisture condition only by the antecedent rainfall. We have incorporated this comment and the references into the revised version to discuss the ability of using soil moisture observations to represent varying soil moisture conditions, the relationships between soil moisture and S or CN values as well as relevant runoff simulation work (see P.25, Line 18 to P.26, Line 10).*

4. Comment:

I believe the authors could try to test this simple approach in their study thus obtaining, in my opinion, more robust and easy to understand findings.

Reply: *Actually, this is a good suggestion. However, it needs large amount of soil moisture and rainfall-runoff data to establish the relationship between soil moisture and S or CN values. Unfortunately, as the soil moisture data is not available from the field experiment, it is difficult to incorporate the above approach into the modified SCS-CN model in this study. We will consider it as a future study scope. (see P.26, Lines 8-10)*

5. Reference:

Beck, H.E., de Jeu, R.A.M., Schellekens, J., van Dijk, A.I.J.M. and Bruijnzeel, L.A (2010) Improving Curve Number based storm runoff estimates using soil moisture proxies. IEEE J. Sel. Top. Applied Earth Observation and Remote Sensing, 2(4), 1939-1404.

Brocca, L., Melone, F., Moramarco, T., Morbidelli, R. (2009a). Antecedent wetness conditions based on ERS scatterometer data. Journal of Hydrology, 364 (1-2), 73-87, doi:10.1016/j.jhydrol.2008.10.007.

Brocca, L., Melone, F., Moramarco, T., Singh, V.P. (2009b). Assimilation of observed soil moisture data in storm rainfall-runoff modelling. Journal of Hydrologic Engineering, 14 (2), 153-165, doi:10.1061/(ASCE)1084-0699(2009)14:2(153).

Brocca, L., Melone, F., Moramarco, T., Wagner, W., Naeimi, V., Bartalis, Z., Hasenauer, S. (2010). Improving runoff prediction through the assimilation of the ASCAT soil moisture product. Hydrology and Earth System Sciences, 14, 1881-1893, doi:10.5194/hess-14-1881-2010.

Brocca, L., Melone, F., Moramarco, T. (2011a). Distributed rainfall-runoff modeling for flood frequency estimation and flood forecasting. Hydrological Processes, 25 (18), 2801-2813, doi:10.1002/hyp.8042.

Brocca, L., Melone, F., Moramarco, T., Wagner, W. (2011b) What perspective in remote sensing of soil moisture for hydrological applications. In: C.M.U. Neale, A. Maltese, K. Richter (Eds), Remote Sensing for Agriculture, Ecosystems, and Hydrology XIII, Proc. of SPIE, Vol. 8174, 81740A (12 pp), doi: 10.1117/12.898034.

Coustau, M., Bouvier, C., Borrell-Estupina, V., and Jourde, H. (2012) Flood modeling with a distributed event-based parsimonious rainfall-runoff model: case of the karstic Lez river catchment, Nat. Hazards Earth Syst. Sci., 12, 1119-1133, doi:10.5194/nhess-12-1119-2012.

Tramblay, Y., Bouvier, C., Martin, C., Didon-Lescot, J.F., Todorovik, D. and Domergue, J.M. (2010) Assessment of initial soil moisture conditions for event-based rainfall-runoff modelling. J. Hydrol., 380(3-4), 387, 176-187.

Tramblay Y., Bouvier C., Ayral P.A., Marchandise A. (2011) Impact of rainfall spatial distribution on rainfall-runoff modelling efficiency and initial soil moisture conditions estimation. Natural Hazards and Earth System Sciences, 11, 157-170. doi: 10.5194/nhess-11-157-2011.

Reply: *All these references have been cited in appropriate places in the revised version.*

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

Sincerely Yours,

Dr. Guangyao Gao (gygao@rcees.ac.cn)

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

Coupling the modified SCS-CN and RUSLE models to simulate hydrological effects of restoring vegetation in the Loess Plateau of China

A revised manuscript submitted to the *"Water, climate, and vegetation: ecohydrology in a changing world"* special issue of *Hydrology and Earth System Sciences* *(hess-2012-132)*

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Correspondence to: B. J. Fu (bfu@rcees.ac.cn)

Abstract

Predicting event runoff and soil loss under different land covers is essential to quantitatively evaluate the hydrological responses of vegetation restoration in the Loess Plateau of China. The Soil Conservation Service Curve Number (SCS-CN) and Revised Universal Soil Loss Equation (RUSLE) models are widely used in this region to this end. This study incorporated antecedent moisture condition (AMC) in runoff production and initial abstraction of the SCS-CN model, and considered the direct effect of runoff on event soil loss by adopting a rainfall-runoff erosivity factor in the RUSLE model. The modified SCS-CN and RUSLE models were coupled to link rainfall-runoff-erosion modeling. The effects of AMC, slope gradient and initial abstraction ratio on curve number of SCS-CN, as well as those of vegetation cover on cover-management factor of RUSLE were also considered. Three runoff plot groups covered by sparse young trees, native shrubs and dense tussock, respectively, were established in the Yangjuangou catchment of Loess Plateau. Rainfall, runoff and soil loss were monitored during the rainy season in 2008-2011 to test the applicability of the proposed approach. The original SCS-CN model significantly underestimated the event runoff, especially for the rainfall events that have large 5-day antecedent precipitation, whereas the modified SCS-CN model could predict event runoff well with Nash-Sutcliffe model efficiency (EF) over 0.85. The original RUSLE model overestimated low values of measured soil loss and under-predicted the high values with EF only about 0.30. In contrast to it, the prediction accuracy of the modified RUSLE model improved satisfactorily with EF over 0.70. Our results indicated that the AMC should be explicitly incorporated in runoff production, and direct consideration of runoff should be included in predicting event soil loss. Coupling the modified SCS-CN and RUSLE models appeared to be appropriate for evaluating hydrological effects of restoring vegetation in the Loess Plateau. The main advantages, limitations and future study scopes of the proposed

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1 Introduction

Flash flood and soil erosion affect adversely the natural and human-management ecosystems. In arid and semi-arid regions, water shortage is the key limiting factor (Wang et al., 2012). Changes in anthropogenic (e.g. land use) and natural (e.g. climate change) forcings will further affect hydrological cycles and water availability at all scales in these regions (Wang et al., 2012; Feng et al., 2012). Therefore, modeling of the event based rainfall-runoff and soil erosion processes under different land use conditions has significant importance. It has been recognized to be fundamental to a range of applications in hydrological practices.

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The Soil Conservation Service Curve Number (SCS-CN) model is a simple and empirical model with clearly stated assumptions and few data requirements to estimate runoff for a given rainfall event (Ponce and Hawkins, 1996). It accounts for the major runoff producing characteristics including soil type, land use/treatment, surface condition and soil moisture condition, and incorporates them in a single CN parameter (Ponce and Hawkins, 1996). Mishra and Singh (2003) summarized the application of the SCS-CN model in storm water modeling for single rainfall events, long-term hydrologic simulation as well as predicting infiltration and rainfall-excess rates, and discussed its potential to simulate sediment yield and transport of urban pollutants. The SCS-CN model has also been adopted by many hydrological and ecological models to determine runoff, such as CREAMS (Knisel, 1980), ANSWERS (Beaslry et al., 1980), AGNPS (Young et al., 1989), EPIC (Sharply and Williams, 1990) and SWAT (Neitsch et al., 2005).

On the other hand, the SCS-CN has its own perceived disadvantages. One of the main weak points is that there exists no explicit guideline on how to vary the antecedent moisture condition (AMC) with the antecedent rainfall of certain duration (Ponce and Hawkins, 1996). The standard SCS-CN model incorporates an empirical method to classify AMC into three distinct levels, viz., AMC I (dry), AMC Π (normal) and AMC Ш (wet), based on the amount of 5-day antecedent precipitation (P_5). However, this method usually led to poor results and failure of SCS-CN model to predict runoff (Mishra and Singh, 2002; Huang et al., 2007). Therefore, many studies aimed at improving the method and finding a better way to incorporate the AMC (e.g., Mishra and Singh, 2002; Mishra et al., 2006a; Michel et al., 2005; Huang et al., 2007; Sahu et al., 2010).

The Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1978) and its revised version (RUSLE, Renard et al., 1997) are the most widely used empirical models to predict annual soil loss at field scale resulting from sheet and rill erosion. The USLE/RUSLE models have their advantages over the physically process-based models such as WEPP and EUROSEM because they combine acceptable accuracy with a perceived ease of parameterization and use. However, their applications to storm-based events usually led to large errors (Kinnell, 2005). Risse et al. (1993) and Tiwari et al. (2000) observed that the USLE/RUSLE models overestimated low values of measured soil loss and under-predicted the high values. This result was mainly due to that runoff and soil loss were considered as separate entities without reference to any intrinsic link between them (Kinnell, 2009). In reality, the linkage between runoff and soil loss is quite fundamental as the soil lost from the areas being considered is usually that discharged across the downslope boundary with surface-water flow (Kinnell, 2010). Therefore, the accuracy of USLE/RUSLE models can be improved if they are coupled with a hydrologic rainfall-excess model.

Mishra et al. (2006b) coupled the SCS-CN method with USLE model for computing the lumped quantity of event sediment yield from a number of watersheds. The coupling in Mishra et al. (2006b) was based on three hypotheses needing further verification, especially those that the potential maximum retention parameter (S) of SCS-CN model can be expressed in terms of the USLE parameters and the sediment delivery ratio is equal to the runoff coefficient (Kinnell, 2009). In reality, the logical way to link soil loss and the parameter *S* should be through the effect of *S* in predicting runoff ratios rather than through attempts to signify *S* using USLE (Kinnell, 2009). To consider direct effect of runoff on predicting soil loss, Kinnell (2007) included the runoff ratio in rainfall erosivity index of RUSLE, and applied it to predict event soil loss (Kinnell, 2010; Bagarello et al., 2008, 2010). However, runoff and soil loss modeling was decoupled in their studies as the runoff volume was obtained from measurements, not by model prediction. In addition, the approach was only used in bare plots. Its application in plots with different vegetation types needs further investigation.

The Loess Plateau region is located in the middle reaches of the Yellow River basin in Northern China and experiences arid and semi-arid climate condition over an area greater than 600,000 km^2 (Lü et al., 2012). It is one of the most severely eroded areas in the world due to highly erodible loessial soil, steep landscape, frequent large rainfall storms in summer months, and low vegetable cover stemming from intensive cultivation and improper land uses (Zhang and Liu, 2005). In order to alleviate soil erosion and improve environmental quality in the Loess Plateau, a series of soil conservation practices such as Grain-for-Green project have being implemented to augment vegetation recovery. Vast areas of cropland in sloping areas were converted into forestland or grassland in the gully and hilly zones of the Loess Plateau, which altered the land use pattern greatly (Cao et al., 2009; Feng et al., 2012). The revegetation resulted in increase of vegetation cover, improvement of soil nutrient levels and recovery of soil properties (Liu et al., 2012). These changes caused significant responses in hydrological function and soil erosion to cropland abandonment for revegetation (Feng et al., 2012). As runoff and soil erosion in the Loess Plateau are often dominated by a few storms with high intensity or high precipitation amount in summer (Wei et al., 2009a, 2009b), it is essential to predict event runoff and soil loss under different land covers, which is of great importance for land use planning and water resources management. The SCS-CN and RUSLE models have been applied at plot (Shen et al., 2003; Huang et al., 2006, 2007; Fu et al., 2011) and watershed scales (Fu et al., 2005; Xiao et al., 2011) in the Loess Plateau. After carefully checking these studies, one can find that there is rarely study to explicitly incorporate AMC in SCS-CN model except that Huang et al. (2007) developed an equation between curve number and soil moisture to account for AMC. There is no study to include direct consideration of runoff in predicting event soil loss and link runoff with soil loss simulation, which will be the focus of this investigation.

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The objectives of this study are as follows. First is to incorporate AMC in runoff production and initial abstraction of the SCS-CN model, and consider the direct effect of runoff on event soil loss by adopting a rainfall-runoff erosivity factor in the RUSLE model. Second is to couple the modified SCS-CN and RUSLE models to link the rainfall-runoff-erosion modeling. Third is to apply the proposed approach to predict event runoff and soil loss from restoring vegetation plots in the Loess Plateau of China.

2 Model theory

2.1 Rainfall-runoff modeling

2.1.1 Original SCS-CN model

The SCS-CN method is based on the principle of the water balance and two fundamental assumptions (Mishra and Singh, 2002). The first assumption is that the ratio of direct runoff to potential maximum runoff is equal to the ratio of infiltration to potential maximum retention. The second assumption states that the initial abstraction is proportional to the potential maximum retention. The water balance equation and the two assumptions are expressed mathematically respectively, as:

$$P = I_a + F + Q \qquad (1)$$

$$\frac{Q}{P-I_a}=\frac{F}{S} \tag{2}$$

$$I_a=\lambda S \tag{3}$$

where P is the total precipitation (mm), I_a is the initial abstraction before runoff (mm), F is the cumulative infiltration after runoff begins (mm), Q is direct runoff (mm), S is the potential maximum retention (mm), and λ is the initial abstraction coefficient. Combination of Eqs. (1) and (2) leads to the popular form of the original SCS-CN method:

$$\begin{aligned} Q&=\frac{\left(P-I_a\right)^2}{P-I_a+S}, &&\text{for } P>I_a \\ Q&=0, &&\text{for } P\le I_a \end{aligned} \tag{4}$$

The parameter S can vary in the range of $0\le S\le\infty$, and it directly linked to the curve number CN as:

$$S=\frac{25400}{\mathrm{CN}}-254 \tag{5}$$

where the CN is a dimensionless variable, and it depends on land use, hydrological soil group, hydrologic condition, and antecedent moisture condition.

2.1.2 Modified SCS-CN model

The variability of antecedent rainfall and the associated soil moisture amount is an important source of the inherent curve number variability encountered in applications of the SCS-CN method (Ponce and Hawkins, 1996). The incorporation of antecedent moisture in the original SCS-CN method in terms of three AMC levels permit unreasonable sudden jumps in the CN-variation, which results in corresponding jumps in computed runoff (Mishra et al., 2006a). To circumvent these problems, Mishra and Singh (2002) suggested an SCS-CN-based equation incorporating antecedent moisture and P_5 for computation of runoff.

Using the C=S_r concept, where C is the runoff coefficient (=$Q/(P-I_a)$) and S_r is the degree of saturation, Mishra and Singh (2002) modified the original SCS-CN method for accounting antecedent moisture M as:

$$\frac{Q}{P-I_a}=\frac{F+M}{S+M} \tag{6}$$

where M is antecedent moisture representing the amount of moisture available in the soil profile before the start of the storm (mm).

Upon substituting Eq. (6) into Eq. (1) leads to:

$$Q=\frac{(P-I_a)(P-I_a+M)}{P-I_a+M+S} \tag{7}$$

The M on the day of onset of rainfall is assumed to be the amount of water infiltrated due to the antecedent 5-day rainfall ($M=F$), priori to which the soil is completely dry:

$$M=P_5-I_a-Q \tag{8}$$

Assuming the antecedent moisture condition to be dry for 5 days before the onset of the considered rain storm, substituting Eq. (4) into Eq. (8) results in the expression of M (Mishra and Singh, 2002):

$$M=\frac{(P_5-\lambda S_{\mathrm{I}})S_{\mathrm{I}}}{P_5+(1-\lambda)S_{\mathrm{I}}} \tag{9}$$

where S_{I} is the potential maximum retention corresponding to the AMC I condition (mm).

Since $S_{\mathrm{I}}=S+M$, it follows:

$$M=0.5\left[-(1+\lambda)S+\sqrt{(1-\lambda)^2S^2+4P_5S}\right] \tag{10}$$

Here + sign before the square root is retained for $M \geq 0$, and $P_5 \geq \lambda S$.

In the original SCS-CN method, I_a is given by Eq. (3), which does not incorporate M. In reality, the initial abstraction, which represents losses due to interception, surface storage, evaporation, and infiltration, varies inversely with the antecedent moisture. The higher the antecedent moisture, the lower will be the initial abstraction, and vice versa (Mishra et al., 2006a). Mishra et al. (2006a) modified Eq. (3) to the following non-linear I_a-S relation incorporating antecedent moisture:

$$I_a = \frac{\lambda S^2}{S+M} \tag{11}$$

For a completely antecedent dry condition or M=0, I_a=λS, which is the same as Eq. (3). Substituting Eq. (11) into Eq. (7), one can obtain the simulated event runoff of the modified SCS-CN method:

$$Q = \frac{(P - \frac{\lambda S^2}{S+M})(P - \frac{\lambda S^2}{S+M} + M)}{P - \frac{\lambda S^2}{S+M} + M + S} \tag{12}$$

2.2 Soil loss modeling

2.2.1 Original RUSLE model

The USLE/RUSLE models predict long-term average annual soil loss using six factors that are associated with climate, soil, topography, vegetation and management. They have also been used for time intervals shorter than the mean annual one, such as the event scale (Kinnell, 2005; Bagarello et al., 2010):

$$A_e = R_e KLSCP \tag{13}$$

where A_e is the event soil loss (t ha^{-1}), R_e is the event rainfall erosivity factor (MJ mm ha^{-1} h^{-1}) given by the product of total kinetic energy of the rainstorm (E, MJ ha^{-1}) and maximum 30-min intensity during the event (I_{30}, mm h^{-1}) (R_e=EI_{30}), K is the soil erodibility factor (t h MJ^{-1} mm^{-1}), LS is the slope-length and steepness factor, C is the cover-management factor, and P is the conservation support-practice factor.

2.2.2 Modified RUSLE model

Many studies have indicated that the USLE/RUSLE overestimated low event soil losses and underestimated high event soil losses (Kinnell, 2005, 2007, 2010). The failure to consider runoff explicitly is a primary factor for USLE/RUSLE model to produce systematic errors in the prediction of event erosion (Kinnell, 2005). In reality, erosion is a hydrologically driven process, and it is well known that event soil loss is given by the product of the runoff amount and bulk sediment concentration for an event (Kinnell, 2005; Bagarello et al., 2010). Modern understanding of rainfall erosion processes recognizes that runoff is a primary independent factor in modeling rainfall erosion. To directly consider the effect of runoff, Kinnell (2007) proposed the event rainfall-runoff erosivity index ($Q_R EI_{30}$, Q_R is the runoff ratio) to replace the USLE/RUSLE rainfall erosivity factor (EI_{30}), and substantial improvement of prediction accuracy was obtained (Kinnell, 2007, 2010). Bagarello et al. (2008, 2010) found that the event soil loss was proportional to the power function of $Q_R EI_{30}$ term. In terms of above results, the following modified RUSLE model is used to predict event soil loss:

$$A_e = a(Q_R EI_{30})^b KLSCP \tag{14}$$

where a and b are empirical coefficients.

Eq. (14) differs from both the USLE-M by Kinnell (1998) and the USLE-MM by Bagarello et al. (2010). In the USLE-M, the proportionality between A_e and the erosivity term $Q_R EI_{30}$ is direct, i.e. the coefficient b is equal to one. The USLE-MM includes an exponent for the $Q_R EI_{30}$ term with b greater than one. As noted by Kinnell (1998, 2010), changing the event rainfall-runoff factor from the EI_{30} index has consequences on a number of the other factors used in the model, in particular the original soil erodibility factor can not be used to predict soil loss. In the USLE-M, a new value of the soil erodibility (K_{UM}) is used, while in the USLE-MM the a coefficient is considered to be representative of soil erodibility. However, it is difficult to directly determine the new soil erodibility. In Eq. (14), the original soil erodibility is used, and the coefficient a is used to account for the effects of changing rainfall erosivity in a simple way. In this way, the modified RUSLE model can encompass both the USLE-M and USLE-MM.

In the modified RUSLE model, the effects from event rainfall and runoff on soil loss as well as the impact of event erosivity index on other factors are explicitly considered. The

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predicted event runoff of the modified SCS-CN method is substituted into Eq. (14) to determine Q_R. In this way, the event rainfall-runoff-erosion modeling is directly coupled, which is very useful for practical application.

3 Model application

3.1 Study area

The study area is the Yangjuangou catchment (36°42′N, 109°31′E) located in the middle part of the Loess Plateau, Shaanxi Province, China (Fig. 1). The catchment has a total area of 2.02 km^2 with elevation ranging from 1050 m to 1298 m. It is a typical gully and hilly area with a gully density of 2.74 km km^{-2}, and the slope gradients range from 10° to 30° (Li et al., 2003). The area has a semi-arid continental climate with an average annual rainfall of 535mm. The rainfall is mainly concentrated between June and September with large inter-annual variations. Soil in the study area is mainly derived from loess, which is fine silt to silt in texture. The soil type is Calcaric Cambisol characterized by a uniform texture and weak structure, and it is vulnerable to water erosion (Li et al., 2003). The average erosion rate of the Yangjuangou catchment is 90.42 t ha^{-1} yr^{-1} between 1980 and 1990 and 62.73 t ha^{-1} yr^{-1} during 1992-1996 (Li et al., 2003), and 36.41 t ha^{-1} yr^{-1} in 2006 (Wang et al., 2009).

Before the 1980s, the land use in the Yangjuangou catchment was dominated by croplands. Reforestation began in the 1980s on infertile and steep cultivated lands with low crop yields. Driven by the implementation of the Grain-for-Green project since 1998, most of the cultivated lands on steep slopes were abandoned for natural or artificial revegetation. At present, the main land use types are grassland, forestland and shrubland formed at different restoration stages. The main forest species in the Yangjuangou catchment is acacia (*Robinia pseudoacacia*), which was planted in the 1980s or after 1999. The dominant grass species are *Artemisia sacrorum*, *Stipa bungeana* and *Artemisia scoparia*. The main shrub species are *Prunus armeniaca* and *Hippophae rhamnoide*. As a result of human disturbances and changes of the natural environmental conditions, mosaic of patchy land cover is the typical landscape pattern in the Yangjuangou catchment.

3.2 Data collection

Three runoff plot groups with different land cover types were installed in the catchment in 2008 (Figs. 1 and 2). Each group included three closed runoff plots with a fixed width of 2 m and lengths of 5, 9 and 13 m, respectively. Two numbers were used to define the runoff plot. For example, plot 11, plot 12 and plot 13 indicated that these plots belonged to Group 1 and their lengths were 5, 9 and 13 m, respectively. The slope gradients of all plots were somewhat different (see Table 1). Each plot was surrounded by inserting galvanized iron sheets into soil with depth of 10 cm on the upper and side boundaries. The lower boundary of the plots was made of gutter which collected and channeled water leaving the plot. A stock tank was connected to the gutter with plastic pipe to store runoff. The stock tanks were covered by a plate in order to avoid direct entrance of rainfall.

Group 1 plots were at the initial stage of revegetation and had been abandoned for 8 years. Group 2 and Group 3 plots had been revegetated for 25 years. The vegetation of Group 1 plots was sparse apricot (*Armeniaca vulgaris*) planted in rows at interval distances of 2.5 or 5 m. Patchy biological crusts covered most of the soil surface of plots in Group 1. Dense native shrubs (*Spiraea pubescens Turcz.*) with an arborous layer of sparse artificial acacia covered plots of Group 2. Plots of Group 3 were dominated by dense tussock (*A. scoparia*) and beard grass (*Andropogon L.*). Liu et al. (2012) used a digital camera (Finepix S1000, Fujifilm) and a 50×50 cm subplot mesh to perpendicularly photograph the surface of each runoff plot. The resulting images were transferred to digital vegetation cover maps in ArcMap. The vegetation cover ratio of each runoff plot could be easily obtained from these maps. Table 1 shows the main characteristics of each runoff plot.

Twenty-seven samples of topsoil (0-10 cm) were collected from each plot group. Soil texture was analyzed using a Mastersizer 2000 particle analyser (Malvern Instruments Ltd., Worcestershire, UK). Bulk density (BD), Total Kjeldhal nitrogen (TN), total carbon (TC), total phosphorous (TP), soil organic carbon (SOC), electrical conductivity (EC) and pH were tested using standard soil testing methods (Liu et al., 1996). Soil properties of each runoff plot group are shown in Table 2.

Rainfall, runoff and erosion of the nine runoff plots were monitored during the rainy season in 2008, 2009, 2010 and 2011. Rainfall depth was measured with an accuracy of 0.2 mm using a tipping bucket rain gauge that was connected to a data logger. The runoff mixed with the sediment discharged from each plot was collected after each rainfall event, and the volume was measured. After settling for 24 h, sediment was separated from water. Sediment from the gutters was also collected and added to the stock tank sediment since this was also output from the plot. The collected sediment was first air-dried for more than 24 h, and dried in an oven at a temperature of 105 °C for larger than 8 h until constant weight was achieved. Calculations of runoff in mm and erosion rate in t/ha were obtained for each event. Totally, there were 21 and 16 rainfall events that produced runoff and sediment, respectively. Table 3 provided the statistical characteristics of the rainfall for the simulated runoff events. The largest rainfall event occurred on 15 Jun, 2008 with rainfall depth of 76.4 mm, and the most intensive storm was on 25 Aug, 2009 with rainfall intensity of 30.72 mm/h. The largest I_{30} reached 52.8 mm/h on 28 Jun, 2008, and the rainfall event on 19 Jul, 2009 had the largest P_5 (79.6 mm).

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It is generally accepted that different erosive mechanisms can be expected in plots with different lengths. In particular, occurrence of interrill erosion alone can be presumed for the short plots, whereas both rill and interrill processes are expected on longest plots. In this study, the erosion status was observed at the end of each erosive event. There was only little rill generated in Plot 13 as it had the longest length and smallest vegetation cover. Sheet or interrill erosion dominated in the other runoff plots. Therefore, the effect of specific erosion processes on soil loss can be ignored in the soil loss simulation.

3.3 Determination of model parameters

3.3.1 Parameters for rainfall-runoff modeling

There are two parameters in the original or modified SCS-CN model. One is the initial abstraction coefficient λ, and the other is the curve number CN. λ was assumed to be equal to 0.2 in its original development. However, the assumption of λ=0.2 has frequently been questioned for its validity and applicability, invoking a critical examination of the I_a-S relationship for pragmatic applications (Pronce and Hawkins, 1996; Baltas et al., 2007). The initial abstraction ratio represents the effects of soil and cover characteristics on the runoff process, and theoretically it is not a constant in different areas and for different rainfall events. It is generally accepted that the λ value lies in the range of 0 to 0.3. Mishra and Singh (1999) obtained values of λ from 0 to 0.042 for three watersheds less than 1 km^2 in the USA and for one 3124 km^2 watershed located in India, respectively. Huang et al. (2007) optimized the λ value to be 0.001 for four plots in the Loess Plateau. Fu et al. (2011) found that the prediction accuracy for λ=0.05 was greater than that for λ=0.2 using SCS-CN method to simulate plot runoff of 757 rainfall events in Zizhou and Xifeng cities located in the Loess Plateau of China. Similar results have been obtained from plots or watersheds in USA (Hawkins et al., 2002), semi-arid tropical highlands of northern Ethiopia (Descheemaeker et al., 2008) and the Three Gorges area of China (Shi et al., 2009). In this study, the value of λ is not optimized using the measured rainfall-runoff data as optimization of parameters can not adequately examine the applicability of the modified SCS-CN model. Furthermore, the obtained optimization value is only reasonable for the studied plots, which limits the applications of the model in other areas. Therefore, the two commonly used values (λ=0.05, 0.2) are directly applied in the SCS-CN model for comparison.

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For the CN value, it needs the following steps to determine it with considering the effect of AMC, slope gradient and initial abstraction ratio. First, in terms of the hydrologic soil group (set to B) and hydrologic condition (determined by the measured vegetation cover), the CN_{Π} value for the normal AMC (AMC Π) can be determined from USDA-NRCS handbook with land cover and hydrologic soil-cover complexes of each runoff plot (see runoff curve numbers for arid and semiarid ranges as shown in Table 9-2 of USDA-NRCS, 2004). The CN_{Π} value for each runoff plot is listed in Table 1.

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Second, the CN_{Π} value obtained from the USDA-NRCS handbook corresponds to a slope of 5%, and it should be adjusted to the actual slope. Huang et al. (2006) used SCS-CN method to evaluate an 11-year runoff plot experiment with slopes ranging from 14% to 140% in Xifeng city located in the Loess Plateau of China, and proposed the following equation to consider the effect of slope on CN_{Π} value:

$$\mathrm{CN}_{\mathrm{II}\alpha}=\mathrm{CN}_{\mathrm{II}}\frac{322.79+15.63\alpha}{\alpha+323.52} \tag{15}$$

where $\mathrm{CN}_{\Pi\alpha}$ is the slope-adjusted CN_{Π} value, and α is the slope steepness (%).

Third, the above determined $\mathrm{CN}_{\Pi\alpha}$ value is the median CN value taken as a representative value for the AMC Π condition. It should be converted to AMC I (dry) or AMC Ш (wet) condition depending on the magnitude of P_5 with the following relations (Hawkins et al., 1985):

$$\mathrm{CN}_{\mathrm{I}\alpha}=\frac{\mathrm{CN}_{\mathrm{II}\alpha}}{2.281-0.0128\mathrm{CN}_{\mathrm{II}\alpha}} \tag{16}$$

$$\mathrm{CN}_{\mathrm{III}\alpha}=\frac{\mathrm{CN}_{\mathrm{II}\alpha}}{0.427+0.00573\mathrm{CN}_{\mathrm{II}\alpha}} \tag{17}$$

where $\mathrm{CN}_{\mathrm{I}\alpha}$ and $\mathrm{CN}_{\mathrm{III}\alpha}$ are the slope-adjusted CN values corresponding to the AMC I and AMC Ш condition, respectively.

Finally, if λ=0.05 is used in SCS-CN method, a new set of curve numbers must be developed (Hawkins et al., 2002). Hawkins et al. (2002) developed the following relationship that converted the 0.20-based CN to 0.05-based CN from model fitting results using rainfall-runoff data:

$$\mathrm{CN}_{0.05} = \frac{100}{1.879\left[\frac{100}{\mathrm{CN}_{0.20}} - 1\right]^{1.15} + 1} \quad (18)$$

$$S_{0.05} = 0.8187 S_{0.20}{}^{1.15} \quad (19)$$

where $\mathrm{CN}_{0.05}$ and $S_{0.05}$ (mm) are the CN and potential water storage values with λ=0.05, respectively, and $\mathrm{CN}_{0.20}$ and $S_{0.20}$ (mm) are the values with λ=0.2.

3.3.2 Parameters for soil loss modeling

In the original or modified RUSLE model, the six erosivity factors are determined in the following. The event rainfall erosivity factor (R_e) is calculated as follows (Brown and Foster, 1987):

$$R_e = EI_{30} = \left(\sum_{r=1}^{n} (e_r v_r)\right) I_{30} \quad (20)$$

where e_r and v_r are the unit rainfall energy (MJ ha^{-1} mm^{-1}) and the rainfall volume (mm) during a time period r, respectively. The unit rainfall energy (e_r) is calculated for each time interval as (Brown and Foster, 1987):

$$e_r = 0.29[1 - 0.72\exp(-0.05 i_r)] \quad (21)$$

where i_r is the rainfall intensity during the time interval (mm h^{-1}).

This study employs the method developed from EPIC by Sharply and Williams (1990) to estimate the soil erosivity K factor. The calculation formula is as follows:

$$K = \left\{0.2 + 0.3\exp[-0.0256 S_a (1 - S_i/100)]\right\}\left(\frac{S_i}{Cl + S_i}\right)^{0.3}\left[1 - \frac{0.25C}{C + \exp(3.72 - 2.95C)}\right] \left[1 - \frac{0.7S_n}{S_n + \exp(-5.51 + 22.9S_n)}\right] \quad (22)$$

where S_a is the sand content (%); S_i is the silt content (%); Cl is the clay content (%); C is the organic carbon content (%); and S_n=1-S_a/100.

For each plot, a value of the topographic factor, *LS*, is calculated according to the following relationships (Nearing, 1997; Renard et al., 1997):

$$L = \left(\frac{\lambda}{22.13}\right)^m \tag{23}$$

$$S = -1.5 + \frac{17}{1 + \exp(2.3 - 6.1 sin\beta)} \tag{24}$$

$$m = \frac{F}{1+F} \tag{25}$$

$$F = \frac{sin\beta / 0.0896}{3(sin\beta)^{0.8} + 0.56} \tag{26}$$

where λ is the slope length (m), m is the slope-length exponent, and F is the ratio of rill erosion to interrill erosion which depends on the slope angle, β (°).

Vegetation type and vegetation cover play major roles in controlling soil loss, especially in the restoration lands of arid and semi-arid regions. Many experimental studies have verified that soil loss exponentially decreased with vegetation cover ratio for a specific vegetation type (Moreno-de las Heras et al., 2009; Bartley et al., 2010; Garcia-Estringana et al., 2010; Podwojewski et al., 2011). Based on numerous observed plot data in Ansai city located in the middle part of the Loess Plateau of China, Jiang et al. (1996) proposed the following exponential functions to describe the relationship between the cover-management C factor and cover ratio of woodland and grassland:

$$C_{grassland} = \exp\left[-0.0418(V_{cover} - 5)\right] \tag{27}$$

$$C_{woodland} = \exp\left[-0.0085(V_{cover} - 5)^{1.5}\right] \tag{28}$$

where $C_{grassland}$ and $C_{woodland}$ are the cover-management factor of woodland and grassland, respectively, V_{cover} is vegetation cover (%). The above relationships have also been verified by Zhang et al. (2003) with observation data from thirty three plots with nine types of grassland and woodland in the Loess Plateau of China. In this study, Eqs. (27) and (28) are used to determine the C factor of the nine plots. As there is no soil conservation practice for all the plots, the P factor is set to be 1 (P=1).

In the modified RUSLE model, there is no independently method to determine the introduced empirical coefficients a and b. In this study, the observed event soil loss data from all plots in 2008 are fitted by the modified RUSLE model to determine a and b. After model calibration, the modified RUSLE model is used to predict the event soil loss in the rest of three years (2009, 2010 and 2011).

3.4 Model performance evaluation criteria

In this study, the following four popular statistical criteria are used to measure the agreement between predicted and observed values of event runoff and soil loss. A good agreement indicates a good model performance, and vice versa.

$$\mathrm{EF} = 1 - \frac{\sum_{i=1}^{N}(O_i - P_i)^2}{\sum_{i=1}^{N}(O_i - \overline{O})^2} \tag{29}$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(O_i - P_i)^2} \tag{30}$$

$$\mathrm{NRMSE} = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}(O_i - P_i)^2}}{\overline{O}} \tag{31}$$

$$e = \frac{1}{N}\sum_{i=1}^{N}(P_i - O_i) \tag{32}$$

where EF is the Nash-Sutcliffe model efficiency, RMSE is the root mean square error, NRMSE is the normalized root mean square error, e is the bias, O_i and P_i are the observed and predicted runoff or soil loss of the ith rainfall event, respectively, $\overline{O}$ is the average observed runoff or soil loss, N is the total number of rainfall events that producing runoff or soil loss. EF=1 indicates a perfect agreement between observed and predicted values, and its decreasing values indicate poor agreement. A higher RMSE or NRMSE value indicates poor model performance. Bias represents the average differences between the predicted and observed values.

4 Results and discussion

4.1 Prediction results of event runoff

There are four rainfall-runoff models including the original SCS-CN model (λ=0.2), the original SCS-CN model (λ=0.05), the modified SCS-CN model (λ=0.2) and the modified SCS-CN model (λ=0.05) to predict event runoff. Figures. 3, 4 and 5 show the comparison between the observed and predicted event runoff of the Group 1, Group 2 and Group 3 plots, respectively. It should be noted that the runoff of one event in these figures is the average value of the three plots belonged to same group as the SCS-CN model can not consider the effect of plot length. It can be found from Figs. 3a, 4a and 5a that the original SCS-CN model (λ=0.2) significantly underestimates the observed runoff. There are many rainfall events that produce small runoff, but the simulation results of the original SCS-CN model (λ=0.2) for these events are almost equal to 0. The original SCS-CN model (λ=0.05) can predict the low event runoff well, whereas it underestimates the high event runoff, especially for the rainfall events that have large P_5 (Figs. 3b, 4b and 5b). Although the predicted runoff of large rainfall events by the modified SCS-CN model (λ=0.2) are more close to the observed results compared to the original SCS-CN model (λ=0.2 or 0.05), the modified SCS-CN model (λ=0.2) still underestimates the high event runoff (Figs. 3c, 4c and 5c). Furthermore, it predicts no runoff for the small rainfall event, which is similar to the original SCS-CN model (λ=0.2). Compared to the above three models, the prediction results of the modified SCS-CN model (λ=0.05) are in good agreement with the observations, having a ratio close to 1:1, as shown in

Figs. 3d, 4d and 5d. This result indicates that the modified SCS-CN model (λ=0.05) can adequately predict both the small and large event runoff well.

Based on the amount of P_5, the AMCs of the observed twenty-one rainfall-runoff events are determined. Only four rainfall events have normal soil moisture condition (AMC Π, 36 mm <P_5< 53mm). There are thirteen and four rainfall events having the AMC I (P_5< 36 mm) and AMC Ш (P_5> 53 mm) conditions, respectively. The observed results (not shown here) indicate that most of the rainfall events with AMC I condition produce small or no runoff, whereas those with AMC Π and AMC Ш conditions result in significant runoff. As shown in Figs. 3, 4 and 5, the original SCS-CN models underestimate the observed event runoff, especially those with AMC Π and AMC Ш conditions, although the original SCS-CN model (λ=0.05) can well predict the runoff events with AMC I condition. Compared to them, the simulation results of the modified SCS-CN models are more close to the observed event runoff with AMC Π and AMC Ш conditions, especially that the modified SCS-CN model (λ=0.05) can adequately describe almost all the runoff events. The above results indicate that the AMC plays a significant role for rainfall-runoff production and estimation, and the modified SCS-CN model (λ=0.05) can substantially account for different AMC conditions.

Table 4 compares the evaluation criteria of event runoff prediction performance of the four models. The prediction results of modified SCS-CN model (λ=0.05) provide a greater model efficiency (EF) and a lower RMSE, NRMSE and bias compared to the original SCS-CN model (λ=0.2 or 0.05) and the modified SCS-CN model (λ=0.2). The EF values of the modified SCS-CN model (λ=0.05) to predict event runoff of the Group 1, Group 2 and Group 3 plots are 0.899, 0.892 and 0.879, respectively. The bias values of the other three models are negative (most of them are less than -1 mm, see Table 4), indicating that these three models substantially underestimate the event runoff, as evident from Figs. 3, 4 and 5. The above comparison results of the model performance evaluation criteria further prove the

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superiority of the modified SCS-CN model (λ=0.05) with respect to other three models.

The simulated efficiency of the modified SCS-CN model is also compared with other researchers using the SCS-CN method to simulate event plot runoff in the Loess Plateau. Fu et al. (2011) used SCS-CN with λ=0.05 to simulate runoff from farmland plots in Zizhou (205 rainfall events) and Xifeng (552 rainfall events) experiment stations, and the EF values were only 0.25 and 0.51, respectively. In the study of Huang et al. (2006), the EF value of the SCS-CN method with the slope-adjusted CN equation (Eq. (15)) to simulate runoff from pasture and alfalfa plots in Xifeng was 0.826. The EF value of the SCS-CN method in which the CN value was a non-linear equation of surface soil moisture was 0.779 in the city of Suide (Huang et al., 2007). It should be noted that the parameters of the non-linear equation and λ in Huang et al. (2007) were determined by optimization, whereas in this study all the parameters in the SCS-CN model were independently determined. It can be found that the model efficiency of the modified SCS-CN model (λ=0.05) is better than other forms of SCS-CN method in above previous researches, as both of the effects of antecedent moisture condition and slope gradient are explicitly considered in the modified SCS-CN model.

4.2 Prediction results of event soil loss

The simulated event soil loss of the three runoff plot groups in 2008 are compared with the measurements for calibration of the modified RUSLE model (Fig. 6). The estimated values of the empirical coefficients *a* and *b* in the modified RUSLE model are 1.723 and 1.548, respectively. The *a* value lies in the range of the ratio between the soil erodibility of the USLE-M and USLE (1.40-3.87) obtained by Kinnell and Risse (1998). Furthermore, as noted by Bagarello et al. (2010), after using an exponent of the event rainfall-runoff erosivity ($Q_R EI_{30}$) term in the soil loss model, the calculated soil erodibility factor is representative of an intrinsic soil property. The *b* value is close to that obtained by Bagarello et al. (2010) in Italy on bare plots varying in length from 11 to 44 m (1.47). The above results indicate that the obtained coefficients have robust physical meanings, and they can incorporate the impact of changing the event rainfall erosivity factor on soil erodibility and the direct effect of runoff on soil loss. Figure 6 shows that the simulated event soil loss agrees well with the measured values. The EF, RMSE, NRMSE and *e* values of modified RUSLE model simulation results are 0.810, 0.163 t/ha, 0.231 t/ha and 0.033 t/ha, respectively. This again reflects that the modified RUSLE model is well calibrated.

Figures 7, 8 and 9 shows the comparison between the observed and predicted event soil loss of the Group 1, Group 2 and Group 3 runoff plots during the rainy season of 2009-2011, respectively. It can be found that the predicted event soil loss of the original RUSLE model depart significantly from the observed ones. In general, the original RUSLE model overestimates low event soil losses and underestimates high event soil losses (figs. 7a, 8a and 9a), which has been also indicated by Kinnell (2005, 2007, 2010). With respect to the original RUSLE model, the predicting results of the modified RUSLE model are more satisfactory as evident from figs. 7b, 8b and 9b. The better performance of the modified RUSLE model is also supported by its larger EF and smaller RMSE, NRMSE and *e* values than those of the original RUSLE model, as shown in Table 5. The EF values of the modified RUSLE model are over 0.70, whereas those of the original RUSLE are only about 0.30.

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Besides using the estimated Q_R from the modified SCS-CN model, we also used Eq. (14) with the measured runoff ratio to simulate the event soil loss. This is necessary to separately establish the approximations attributable to the modified RUSLE model's structure and the ones due to the unavoidable uncertainties associated with runoff estimation. The EF values of the modified RUSLE model with measured runoff ratio for Group 1, Group 2 and Group 3 runoff plots are 0.816, 0.865 and 0.847, respectively. The performance of the modified RUSLE model with the measured runoff ratio improves to some degree with respect to that with the estimated runoff ratio. Furthermore, with the measured runoff ratio, the modified

RUSLE model can better account for observed variations in sediment yield between plots with different lengths. This result indicates that including runoff coefficient in the erosivity term is inherent to the satisfactory performance of the modified RUSLE model, and developing procedures for accurately estimating the runoff coefficient is desirable as it can further improve the soil loss prediction and has practical importance.

4.3 Physical interpretation of model performance

The substantial underestimation of event runoff by the original SCS-CN model (λ=0.2) is due to that it overestimates the initial abstraction with λ=0.2 and does not explicitly consider the effect of antecedent moisture amount in soil on production of runoff. For the rainfall events that have large P_5, considerable amount of moisture have existed in soil before the start of rainstorm, which can reduce infiltration and enhance runoff. Whereas the original SCS-CN model assumes that the soil is complete dry (Eq. (2)), the effect of antecedent moisture is ignored. Therefore, even the initial abstraction can be reasonably estimated with λ=0.05, the original SCS-CN model can only predicts the low event runoff well before which there is small or no antecedent moisture, but it still underestimates the event runoff produced by the rainfall events that have large P_5. After consideration of the antecedent moisture, the prediction performance of modified SCS-CN model can substantially improve with λ=0.05, but there is still considerable errors for the modified SCS-CN model with λ=0.2. Therefore, the antecedent moisture should be directly incorporated into the SCS-CN model (Eq. (6)) and λ=0.05 is suitable for the initial abstraction coefficient in the study area. Combined actions of above two factors result in the satisfactory performance of the modified SCS-CN model (λ=0.05) compared to other three models.

In rainfall erosion, soil particle detachment is caused by raindrops impacting the soil surface and by flow shear. Sediment downslope transport is mainly driven by the interaction between raindrop impact and flow (raindrop-induced saltation and rolling) or by flow alone (flow-driven saltation and rolling) (Kinnell, 2010). Therefore, rainfall drives the start of soil loss, but both of the rainfall and runoff play an important role in producing sediment yield across the downslope boundary of an area. Although empirical relationships tend to exist between runoff amount and E, and between peak runoff rate and I_{30}, this implicit embedding through the EI_{30} index in the original RUSLE model can not deal with the effect of runoff on soil loss and the response of soil loss to changes in the initial soil moisture status (Kinnell, 2010). This is the reason for the failure of original RUSLE model to predict event soil loss well. The overestimation of low event soil losses and underestimation of high event soil loss by the original RUSLE model may be due to that there is a threshold that rainfall or runoff play dominant role on affecting soil loss. The detailed reason needs further investigation.

The better performance of the modified RUSLE model is attributable to two points. First, the effect of runoff is directly considered in it through the rainfall-runoff erosivity index (Eq. (14)). Second, the prediction accuracy level of event runoff achieved by the modified SCS-CN model (λ=0.05) is sufficient, which ensures the ability of $Q_R EI_{30}$ index to predict event erosion. Moreover, as indicated by Kinnell (2010), including direct consideration of runoff in the event rainfall-runoff factor enhances the ability of the modified RUSLE model to account for variations in event soil loss. It may also improve the potential of the model to react to spatial variations in runoff and soil loss results from spatial variations in soil and vegetation (Kinnell, 2010).

4.4 Discussion of the proposed approach

删除的内容: **Advantages and limitations**

The proposed approach in this study coupled the modified SCS-CN and RUSLE models to link the rainfall-runoff-erosion modeling. It has the following main advantages. First, it substantially incorporates AMC in runoff production and includes direct consideration of runoff in soil loss to overcome the main weak points of the traditional SCS-CN and RUSLE models. Second, main stand and vegetation conditions of runoff plot (e.g., soil property, plot scale, plot slope, vegetation type, and vegetation cover) which are critical to runoff and soil loss are explicitly incorporated into the model parameters. Third, compared to models like WEPP and EUOSEM, the proposed approach is simple, and almost all of the parameters (only empirical coefficients *a* and *b* in the modified RUSLE model are optimized) can be independently determined from observations without using measured rainfall-runoff and soil loss data. Finally, it can satisfactorily predict event runoff and soil loss of different restoring vegetations in the Loess Plateau which has complex geographical and climatic conditions. One can expect that good results can be obtained in other regions. These advantages ensure that the proposed approach is useful for the general application. However, the approach still has its own limitations.

First, the physical base of determining antecedent moisture amount with P_5 is not robust and clear (Michel et al., 2005; Sahu et al., 2010), and it is not adequate to represent antecedent moisture condition only by the antecedent rainfall (Ali and Roy, 2010). In this study, the P_5 was used as indicator of the antecedent soil moisture conditions. It was employed both for *M* estimation (Eq. (9)) and for modulating the CN_I and CN_{III} values (Eqs. (16) and (17)). In this way, AMCs were updated continuously in runoff calculation through Eqs. (7) and (9), but with sudden jumps in the values of CN parameter.

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Many studies have compared the use of in situ (and modelled) soil moisture observations with the other indices based on antecedent rainfall, baseflow and groundwater table for the estimation of *S* (Brocca et al., 2009a; Tramblay et al., 2010; Tramblay et al., 2011; Coustau et al., 2012). Additionally, satellite-derived soil moisture observations have been also employed for this purpose (Brocca et al., 2009b; 2011b; Beck et al., 2010). In all these studies the common aspect is that actual soil moisture, especially the moisture of surface soil layer, is the best indicators of soil wetness conditions and is more correlated with the *S* or CN parameters of the SCS-CN model than antecedent precipitation (Huang et al., 2007; Tramblay et al.,

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2010). Therefore, it is necessary to estimate *S* or CN values continuously to allow representation of varying soil moisture conditions. Huang et al. (2007) proposed a non-linear equation between the measured CN values and soil moisture values in the top 15 cm of soil in the runoff plots of the Loess Plateau, China. Brocca et al. (2009a) incorporated actual soil moisture observation for the direct estimation of the *S* parameter by assuming a simple linear relationship in central Italy, which has been also used in a continuous rainfall-runoff model to obtain a low parameterized but reliable modelling tool aimed at flood simulation (Brocca et al., 2010; 2011a). Unfortunately, as the soil moisture data is not available from the field experiment to directly determine *S* or CN values, it is difficult to incorporate the above approach into the modified SCS-CN model in this study.

Second, the developed models can not substantially account for plot-scale effects of runoff and soil loss, and its applicability should be further verified at long plots. For runoff simulation, the SCS-CN model was originally proposed for catchment scale hydrologic modeling. Although it has been applied at plot scale (Shen et al., 2003; Huang et al., 2006, 2007; Fu et al., 2011), the suitability of using data collected at relatively short plots (not longer than 13 m in this study) to check the applicability of the SCS-CN model needs further investigation. Furthermore, the study of Liu et al. (2012) indicated that the runoff coefficient increased with plot length in Group 1 plots, while it decreased with increasing plot length in Group 2 and Group 3 plots. There is also some evidence that runoff decreases with plot length (Joel et al., 2002; Parsons et al., 2006). However, the SCS-CN model can not explicitly consider the effect of plot length on runoff. One available way to account for this problem is to incorporate established scale-parameter relationships into the model. Moreover, agricultural fields are generally longer. The applicability of the developed SCS-CN model on relatively long fields should be tested.

According to the USLE/RUSLE scheme, soil loss per unit area should increase with plot length. However, scientific literature showed many examples of situations where this increasing relationships was not detected. For example, field observations in the Negev Highlands showed that frequency and magnitude of the specific runoff yield decreased with increasing area as a result of flow discontinuity and deposition processes along the hillslope (Yair and Raz-Yassif, 2004). Moreno-de las Heras M et al. (2010) observed that unit area sediment yield declined with increasing plot length for the undisturbed and moderately disturbed sites, but it actually increased for the highly disturbed sites which was especially clear under high-intensity rainfall conditions in a Mediterranean-dry environment. Thus, the plot-scale effects of runoff and erosion was dependent on the extent of degradation. Liu et al. (2012) found that soil loss rates decreased with the plot area in Group 2 and Group 3 plots with longer restoration time, but it increased over an area threshold in Group 1 plot located at the early stage of revegetation, which was not totally consistent with the USLE/RUSLE model. One of the main reasons for the complex plot-scale effects of soil loss is the connectivity and distribution of runoff and sediment source and sink areas on hillslope (Yair and Raz-Yassif, 2004; Parsons et al., 2006; Moreno-de las Heras M et al., 2010). Thus, not only plot length, but the other factors such as rainfall regime, soil property, and vegetation cover also contribute to scale variations of runoff and soil loss. Considering the runoff coefficient as a factor can capture the plot-scale effects of soil loss to some extent as indicated by Kinnell (2008) and the simulation results of modified RUSLE model with the measured runoff ratio in this study. However, as a conceptual model, the physical base and model structure make the modified RUSLE model difficult to fully incorporate the scale variations of sediment yield, and further studies are needed to test its applicability on long plots.

Besides above two main limitations, there are several issues still needing further investigations for the developed models. First, rainfall intensity and rainfall duration have

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great impact on the quantity of runoff, but there were not considered in the modified SCS-CN model. More efforts are needed to account for the temporal variation of rainfall, such as done in Mishra et al. (2008) and Suresh Babu and Mishra (2011). Second, it is difficult to independently determine the introduced empirical coefficients in the modified RUSLE model. Systematic field experimental studies should be conducted to install quantitative relationships between the empirical coefficients and knowable variables such as soil texture, land cover, plot length and slope. Third, sediment deposition due to changes in slope gradient was ignored in the modified RUSLE model. More attentions should be paid to couple the modified RUSLE model with an appropriate sediment transport model, as done in RUSLE2. Finally, further studies are needed to extend the modified SCS-CN and RUSLE models to catchment or watershed scale for long-term continuous and spatial distributed hydrologic simulation, which is very useful for evaluating the impacts of land use and climate change on hydrological cycles.

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5 Conclusions

In this study, the modified SCS-CN and RUSLE models were coupled to predict event runoff and soil loss from restoring vegetation plots in the Loess Plateau of China. The effects of antecedent moisture condition on runoff production (Eq. (6)) and initial abstraction (Eq. (11)) were explicitly accounted for in the modified SCS-CN model. Antecedent moisture condition, slope gradient and initial abstraction ratio were incorporated to determine the curve number, and two initial abstraction coefficient values (λ=0.05, 0.2) were used in the SCS-CN model. In the modified RUSLE model, direct effect of runoff on event soil loss was considered by adopting a rainfall-runoff erosivity index ($Q_R EI_{30}$) to replace the traditional rainfall erosivity factor (EI_{30}) (Eq. (14)). The rainfall-runoff-erosion modeling was linked by determining the runoff ratio Q_R with predicted runoff of the modified SCS-CN model.

The simulation results indicated that the original SCS-CN model (λ=0.05, 0.2) and modified SCS-CN model (λ=0.2) underestimated the event runoff, especially for the rainfall events that have large 5-day antecedent precipitation. Compared to these three models, the modified SCS-CN model (λ=0.05) satisfactorily predicted event runoff with Nash-Sutcliffe model efficiency (EF) larger than 0.85. The original RUSLE model overestimated low values of measured soil loss and under-predicted the high values, whereas the modified RUSLE model could well predicted both the small and large event soil loss with EF over 0.70.

It can be found from this study that the antecedent moisture should be directly incorporated into the SCS-CN model and λ=0.05 is suitable for the initial abstraction coefficient in the study area. Direct consideration of runoff in the event rainfall-runoff erosivity can substantially improve the capacity of the RUSLE model to predict event soil loss. Coupling the modified SCS-CN and RUSLE models has great practical importance for runoff and soil loss simulation in the Loess Plateau. The main advantages, limitations and future study scopes of the proposed models were also discussed in detail. This evaluation is useful to shed lights on model applications and additional model development.

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Acknowledgments

This research was financially supported by the National Natural Science Foundation of China (Grant Nos. 41101096, 40930528 and 41171156), Open Fund from State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau (Grant No. 10501-280), and the CAS/SAFEA International Partnership Program for Creative Research Teams of "Ecosystem Processes and Services". We thank two anonymous reviewers and Luca Brocca for their constructive comments which improve the overall quality of the manuscript.

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Figure captions

Fig. 1 Location of the study area and distribution of the three runoff plot groups

Fig. 2 Pictures of runoff plot in the three groups

Fig. 3 Comparison between observed and predicted event runoff using (a) Original SCS-CN (λ=0.2), (b) Original SCS-CN (λ=0.05), (c) Modified SCS-CN (λ=0.2) and (d) Modified SCS-CN (λ=0.05) models for Group 1 runoff plots

Fig. 4 Comparison between observed and predicted event runoff using (a) Original SCS-CN (λ=0.2), (b) Original SCS-CN (λ=0.05), (c) Modified SCS-CN (λ=0.2) and (d) Modified SCS-CN (λ=0.05) models for Group 2 runoff plots

Fig. 5 Comparison between observed and predicted event runoff using (a) Original SCS-CN (λ=0.2), (b) Original SCS-CN (λ=0.05), (c) Modified SCS-CN (λ=0.2) and (d) Modified SCS-CN (λ=0.05) models for Group 3 runoff plots

Fig. 6 Comparison between observed and simulated event soil loss using observed data of the three runoff plot groups in 2008 to calibrate the Modified RUSLE model

Fig. 7 Comparison between observed and predicted event soil loss during 2009-2011 using (a) Original RUSLE and (b) Modified RUSLE models for Group 1 runoff plots

Fig. 8 Comparison between observed and predicted event soil loss during 2009-2011 using (a) Original RUSLE and (b) Modified RUSLE models for Group 2 runoff plots

Fig. 9 Comparison between observed and predicted event soil loss during 2009-2011 using (a) Original RUSLE and (b) Modified RUSLE models for Group 3 runoff plots

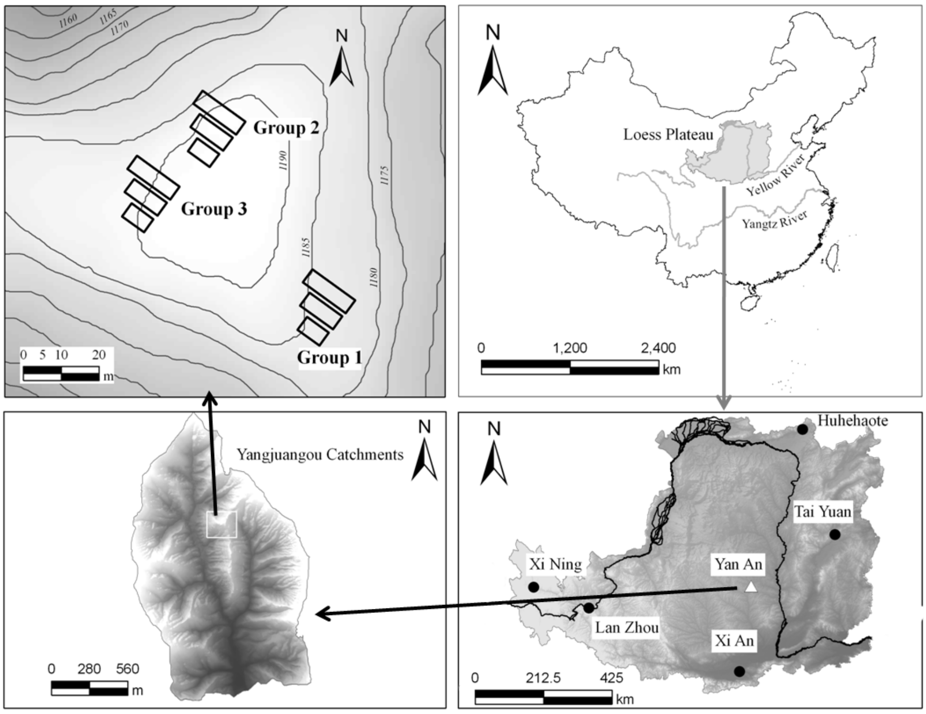


Fig. 1. Location of the study area and distribution of the three runoff plot groups

Group 1

Group 2

Group 3

Fig. 2. Pictures of runoff plot in the three groups

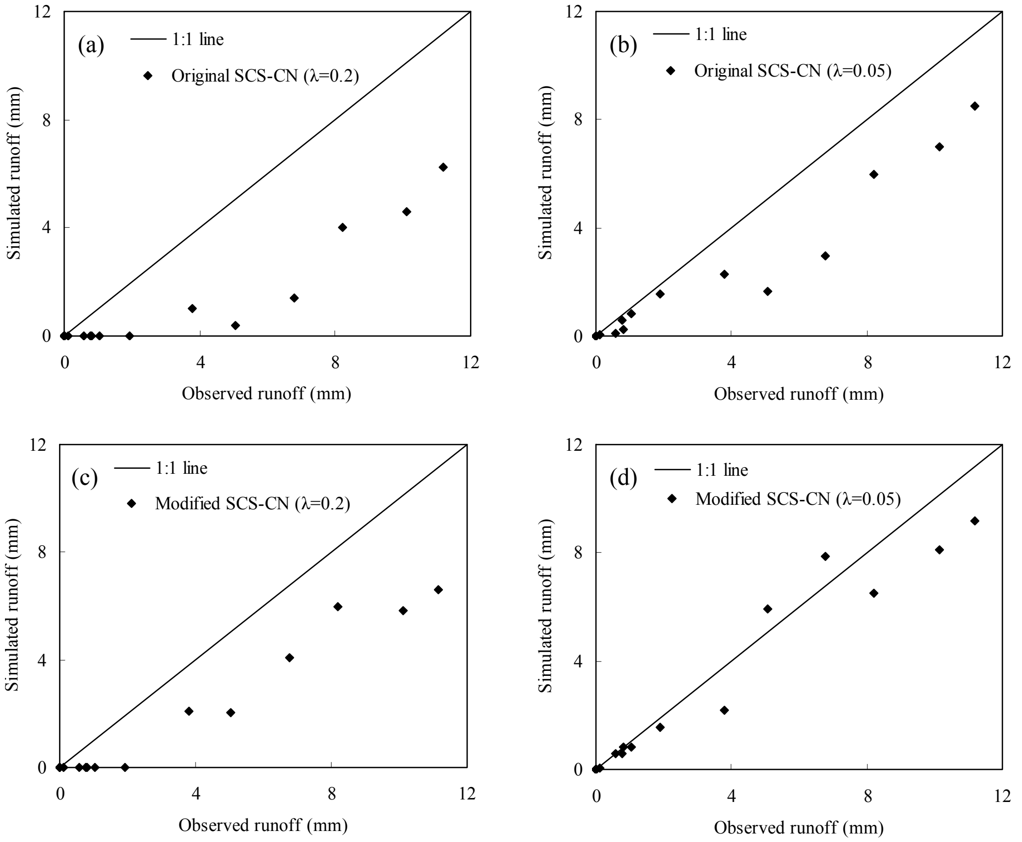
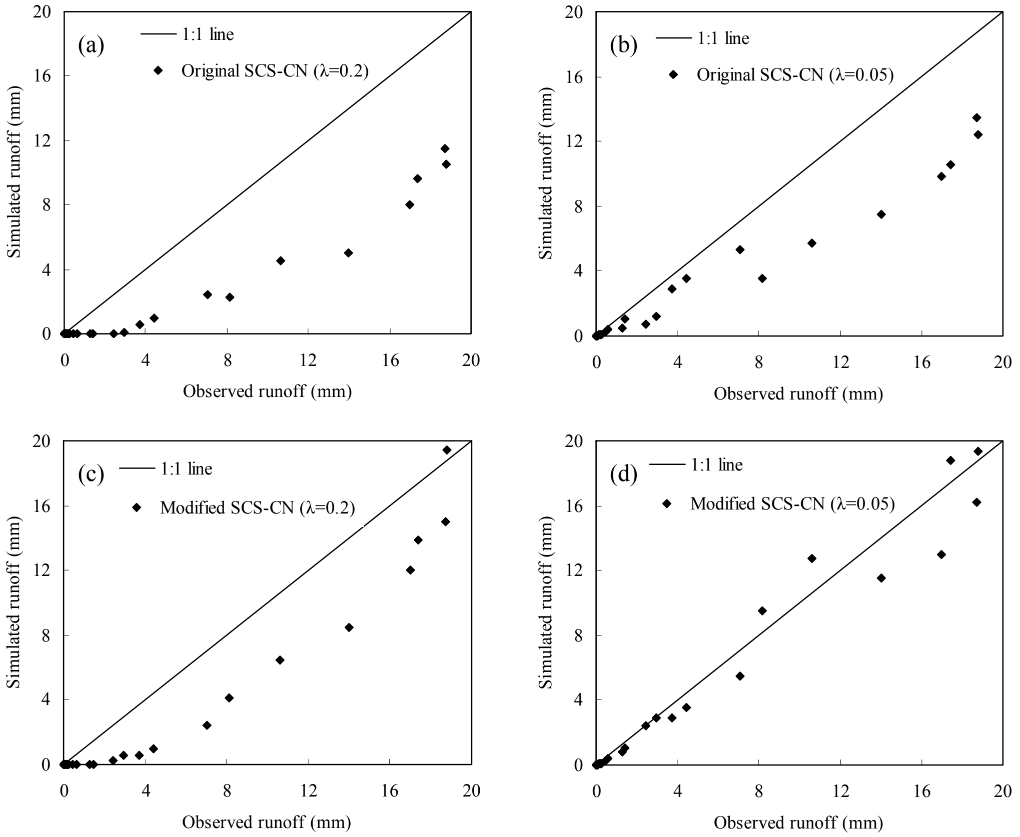


Fig. 3. Comparison between observed and predicted event runoff using (a) Original SCS-CN (λ=0.2), (b) Original SCS-CN (λ=0.05), (c) Modified SCS-CN (λ=0.2) and (d) Modified SCS-CN (λ=0.05) models for Group 1 runoff plots



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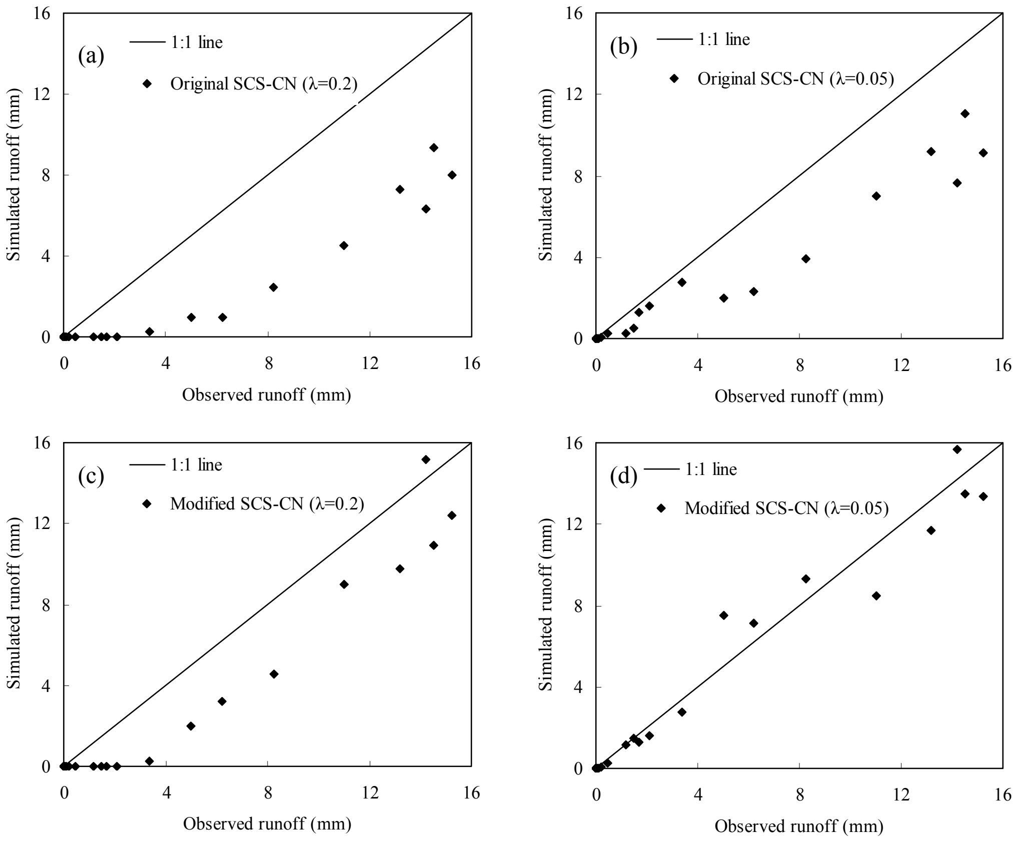

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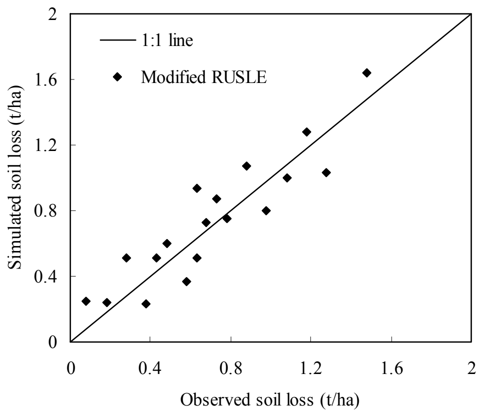

Fig. 6. Comparison between observed and simulated event soil loss using observed data of the three runoff plot groups in 2008 to calibrate the Modified RUSLE model

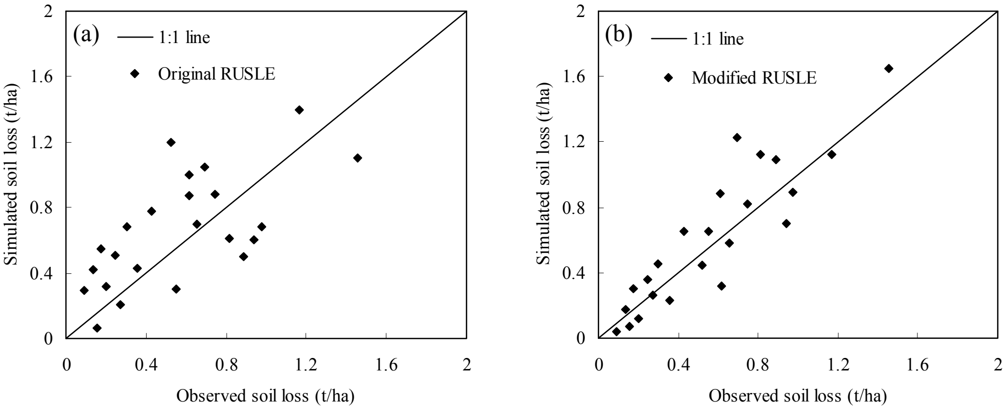

Fig. 7. Comparison between observed and predicted event soil loss during 2009-2011 using (a) Original RUSLE and (d) Modified RUSLE models for Group 1 runoff plots

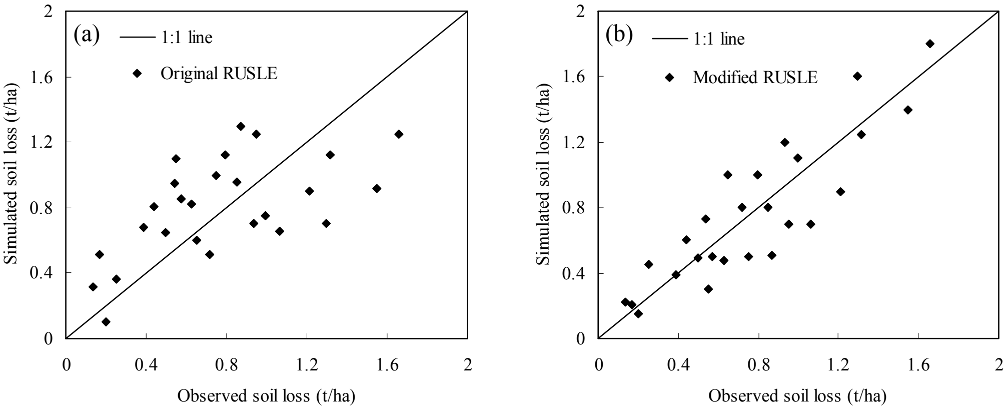

Fig. 8. Comparison between observed and predicted event soil loss during 2009-2011 using (a) Original RUSLE and (b) Modified RUSLE models for Group 2 runoff plots

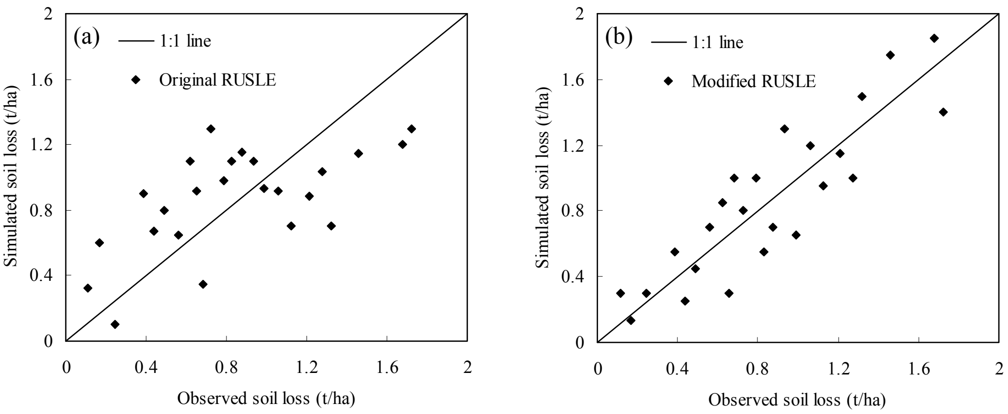

Fig. 9. Comparison between observed and predicted event soil loss during 2009-2011 using (a) Original RUSLE and (b) Modified RUSLE models for Group 3 runoff plots

Table 1. Main characteristics of each runoff plot in the three groups

	Group 1			Group 2			Group 3		
	Plot 11	Plot 12	Plot 13	Plot 21	Plot 22	Plot 23	Plot 31	Plot 32	Plot 33
Length (m)	5	9	13	5	9	13	5	9	13
Width (m)	2	2	2	2	2	2	2	2	2
Slope gradient (°)	19	19	19	25	25	25	21	22	23.5
Revegetation time (y)	8	8	8	25	25	25	25	25	25
Main vegetation type	*Armeniaca vulgaris*			*Spiraea pubescens Turcz.*			*A. scoparia, Andropogon L.*		
Vegetation cover (%)	40.6	54.8	29.0	76.5	71.5	72.5	71.2	71.6	89.1
Hydrologic condition	Fair	Fair	Poor	Good	Good	Good	Good	Good	Good
CN_{II} value	58	58	73	68	68	68	62	62	62

Table 2. Soil properties of the three runoff plot groups

	Group 1	Group 2	Group 3
Sand (%)	22.83	24.40	24.39
Silt (%)	72.96	71.25	71.10
Clay (%)	4.21	4.36	4.5
BD [a] (g cm^{-3})	1.04	1.30	1.17
TN (%)	0.06	0.12	0.10
TC (%)	1.91	2.53	2.22
SOC (g kg^{-1})	7.41	16.44	20.05
TP (g kg^{-1})	0.61	0.65	0.62
pH	8.42	8.28	8.32
EC (μs cm^{-1})	133.03	153.80	139.00

[a] *BD*: bulk density

Table 3. Statistical characteristics of rainfall for the simulated runoff events

	Rainfall depth (mm)	Rainfall intensity (mm/h)	I_{30} [a] (mm/h)	P_5 [b] (mm)
Mean	38.46	5.32	22.32	22.75
Max	76.40	30.72	52.80	79.60
Min	15.80	1.52	2.76	0.00
SD	18.52	6.30	17.08	25.73

[a] I_{30}: maximum 30-min intensity during the event.
[b] P_5: 5-day antecedent precipitation.

Table 4. Values of model performance evaluation criteria to predict event runoff of the three runoff plot groups

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Plot type	Model	EF	RMSE (mm)	NRMSE (mm)	*e* (mm)
Group 1	Original SCS-CN (λ=0.2)	0.545	2.116	1.378	-1.030
	Original SCS-CN (λ=0.05)	0.697	1.578	1.028	-0.794
	Modified SCS-CN (λ=0.2)	0.642	1.833	1.163	-0.898
	Modified SCS-CN (λ=0.05)	0.899	0.838	0.616	-0.115
Group 2	Original SCS-CN (λ=0.2)	0.591	3.288	0.862	-2.094
	Original SCS-CN (λ=0.05)	0.672	2.561	0.672	-1.427
	Modified SCS-CN (λ=0.2)	0.719	2.141	0.561	-1.372
	Modified SCS-CN (λ=0.05)	0.892	0.859	0.325	-0.209
Group 3	Original SCS-CN (λ=0.2)	0.559	3.095	1.016	-1.763
	Original SCS-CN (λ=0.05)	0.709	2.318	0.761	-1.192
	Modified SCS-CN (λ=0.2)	0.732	1.688	0.554	-0.960
	Modified SCS-CN (λ=0.05)	0.879	0.86	0.317	-0.202

Table 5. Values of model performance evaluation criteria to predict event soil loss of the three runoff plot groups

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Plot type	Model	EF	RMSE (t/ha)	NRMSE (t/ha)	*e* (t/ha)
Group 1	Original RUSLE	0.272	0.302	0.533	0.102
	Modified RUSLE	0.704	0.192	0.339	0.050
Group 2	Original RUSLE	0.331	0.330	0.430	0.036
	Modified RUSLE	0.746	0.203	0.265	-0.010
Group 3	Original RUSLE	0.373	0.347	0.409	0.022
	Modified RUSLE	0.743	0.222	0.262	0.012