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Quantifying the effect of ecological restoration on runoff and sediment yields: A meta-analysis for the Loess Plateau of China

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I Introduction

Soil erosion by water has been a serious environmental problem and a threat to the sustainability and productive capacity of agro-ecosystems (Lal, 1987; Pimentel et al., 1995; Pimentel and Kounang, 1998). Ecological restoration is an important approach for controlling land degradation caused by soil erosion and for improving soil ecological function. In semi-arid and arid regions, ecosystem services that promote water provision and soil retention by ecological restoration initiatives are critical to ensure the sustainability of socio-ecological systems. Water provisioning and soil retention services are closely related to water and soil processes, especially runoff and sediment processes which are extremely sensitive to land use and vegetation cover changes arising from ecological restoration initiatives (Brauman et al., 2007; Robinson et al., 2013).

Historically, field observation has been the most commonly used and reliable method for determining the effect of ecological restoration on runoff and sediment yields. Specifically, runoff experimental plots are used to conduct field observations where vegetation, soil, and topography were considered to be relatively homogeneous (Kinnell, 2016). Studies have revealed that land use types, the magnitude and timing of rainfall, soil erodibility, and micro-topology can each have important impacts on runoff and sediment processes at the plot scale (Boix-Fayos et al., 2006). The formation of vegetation patch patterns, a complex canopy structure, high soil hydraulic conductivity, and increases in plant functional diversity have been found to promote soil and water retention when ecological restoration has altered the bio-physical environment through natural succession (Imeson and Prinsen, 2004; Hou and Fu, 2014a; Hou et al., 2014a; Zhou et al., 2016). The implementation of ecological restoration interventions can also incur synergies and tradeoffs among multiple soil- and water-related ecosystem services (Power, 2010; Jia et al., 2014; Fu et al., 2015). Coarse indicator-based methods have been used to estimate potential tradeoffs between water yield and soil retention, but can suffer from insufficient support from field observations (Dymond et al., 2012; Trabucchi et al., 2013; Zheng et al., 2014; Hao et al., 2017). Observations from field runoff plots on hill-slopes can provide the basis of a more accurate and direct method for choosing optimal land use types for ecological restoration, with the objective of promoting soil and water conversation. Plot scale studies have used runoff cost for sediment control as a simple indicator to quantify the effect of different tillage and biological measures on the tradeoff between runoff yields and soil loss (Yan et al., 2012; Yan et al., 2015). However, it is often difficult to scale up plot or field observations to regional processes, even from multiple field sites, because the sites may not adequately sample (or represent) the region. For example, they may employ different measurement methods, perform experiments over different time periods or have insufficient treatment repetitions (Boix-Fayos et al., 2006; Garcia-Ruiz et al., 2015; Labriere et al., 2015).

One way to develop regional-scale understandings of soil and erosion processes through field scale studies is through a meta-analysis. This approach synthesizes and analyzes available data from multiple sites and other sources, and attempts to overcome variations in study contexts and inconsistencies in their conclusions. Meta-analysis is an effective tool for exploring the regional impacts of local land use change together with soil and water conservation interventions on runoff and soil erosion processes. A meta-analysis approach has been used to investigate the effects of land use types on annual soil loss, annual runoff, and annual runoff coefficients from field-scale data in Europe and the Mediterranean region (Maetens et al., 2012). It has also been used to study the effectiveness of soil and vegetation management on soil erosion control in the humid tropics where soil erosion was found to be concentrated both spatially (over the landscape elements of bare soil) and temporally (e.g., during crop rotation) (Labriere et al., 2015).

Although many descriptive reviews and perspectives on soil erosion and conservation exist (Chen et al., 2007; Haregeweyn et al., 2015), no quantitative meta-analysis has been done to integrate plot scale data and findings, in support of a broader understanding of land use change and its hydrological and soil erosion impacts for the Loess Plateau in China. The Loess Plateau has a well-known and long history of heavy soil erosion due to an increasing amount of susceptible land use types, such as bare land, sloped cropland, and abandoned land. It has been a research hotspot for soil erosion studies and has been subjected to many soil and water conservation measures since the early years of New China (Chen et al., 2007; Chen et al., 2015; Zhuang et al., 2015). During the past decades, many soil and water retention and ecological restoration projects have been implemented to reduce soil erosion and to promote vegetation recovery, especially through the "Grain-for-Green" project launched in 1999 (Chen et al., 2007). These projects promote the transition from degradation susceptible land to degradation-resistant land types such as artificial or natural grassland, shrubland, and forest, which has made the Loess Plateau the most significant vegetation greening zone in China (Lu et al., 2015; Vina et al., 2016). These land use transitions effectively control soil erosion and reduce runoff in this water-limited area (Chen et al., 2015; Feng et al., 2016; Wang et al., 2016). In addition, observations at extensively distributed field plots have been widely used to directly monitor runoff and sediment yields on the Loess Plateau (Chen et al., 2007). Studies have focused primarily on the effect of land use types on runoff and sediment production at the local scale (Kang et al., 2001; Fu et al., 2004; Wang et al., 2011; Zhang et al., 2015; Zhou et al., 2016). However, current studies have paid little attention to the regional effects of ecological restoration on soil and water retention, regardless of sufficient support by observation data.

Thus, in this study, we integrated field plot scale monitoring to quantify the effect of ecological restoration on hydrological and soil erosion via a meta-analysis. Our main objectives were to: (a) determine the impact of land use type on runoff and sediment yields across the entire Loess Plateau; (b) identify the tradeoffs and synergies between runoff production and soil erosion under different land use types; and (c) evaluate the overall and land use specific effectiveness of ecological restoration on soil and water retention. Such an approach can inform and support an improved understanding of the effects of regional-scale land use transitions and can facilitate future large-scale ecological restoration planning and sustainable management. At the same time, this study can complement global-scale studies, especially in other loess regions around the world.

II Material and methods

1 Literature search and data extraction

To collect the meta-analysis data, we searched peer-reviewed journal articles published both in English and in Chinese using the ISI Web of Science and China National Knowledge Infrastructure (CNKI) (from Jan. 1990 to May 2016). We used the following search-term combinations: “runoff” or “streamflow” or “discharge” or “water yield” or “water provision,” and “soil erosion” or “sediment load” or “sediment delivery” or “sediment discharge” or “sediment yield*” or “sediment*”. We then refined our search with keywords "Loess Plateau" or "* middle * Yellow River". EndNote X7 software was used to manage documents, remove duplicates, and screen titles, abstracts and full texts in order to include or exclude studies. Engauge Digitizer software was used to help with extracting numerical data from scatter-plot, box-plot, and bar-plot figures. In addition, we considered further studies cited in the references and studies published as dissertations. A final set of 43 articles and 331 plots were included in our meta-analysis (see Appendices 1 and 2) that met the following criteria for inclusion:

1. The experiments were conducted in the region of the Loess Plateau and in the middle reach of the Yellow River;
2. The experiments were conducted in the field under natural rainfall events;
3. The spatial scale of observation was the runoff experimental plot, with relatively homogeneous site conditions and responses to different land cover transitions;
4. The study at least partly recorded variables describing runoff or sediment and the following associated factors: land use type, area, slope length, slope steepness, soil properties, and restoration duration;
5. Means, standard deviations or standard errors, or sample sizes of treatments and controls were directly reported or could be determined from the main text of the articles.

The 43 selected studies were mainly conducted in the hilly-gully region of the Loess Plateau (Figure 1) and were diverse in their specific characteristics: the duration of monitoring, the number of land use types, and site conditions (see Appendix 2). Because runoff and erosion events happen mainly during the growing season (from Jun. to Sept.) on the Loess Plateau, we focused on the growing season and associated runoff events and soil erosion events. Annual runoff and sediment yields were obtained by summing rainfall event runoff and sediment yields for the entire growing season. The growing season and event rainfall were used to calculate a runoff coefficient to describe the likelihood of runoff.

[insert Figure 1.]

2 Data characteristics and preprocessing

The first stage of the analysis was to determine the characteristics of the data sources and the data. The year of publication indicated that research articles were concentrated in 2004, 2006 and the last five years (Figure 2(a)). Although, the duration of the 43 studies ranged from one to 14 years, most took fewer than five years (Figure 2(b)). The number of land use types was generally less than four and all studies examined two temporal scales: years and rainfall events (Figure 2(c) and (d)). The research sites were distributed across four provinces (Shanxi, Shaanxi, Ningxia, and Gansu) and across 21 counties (Ansai, Baota, Changwu, Dingxi, Fu, Fugu, Guyuan, Huining, Ji, Lishi, Pingshuo, Shenmu, Shouyang, Tianshui, Wuqi, Xifeng, Yanggao, Yichuan, Yongshou, Yulin, and Zizhou) (Figure 2(e)). Using the classification of annual soil erosion rates from Jing (1986), most of the annual soil erosion rates were found to be less than 20 t/ha among 7 land use types, but for bare land, abandoned land and cropland, large rates were found at 20-50 t/ha, 50-100 t/ha and more than 100 t/ha. Abandoned land had the highest annual soil loss rate of more than 100 t/ha (Figure 2(f)). The compiled datasets were considered sufficiently rich and representative to be used for a meta-analysis.

Land use transition types and land use types adopted in our study can be found in Table 1. Each land use type was occupied by a different dominant plant species. Forage grass species (e.g., *Astragalus adsurgens, Medicago sativa, and Astragalus complanatus* R. Ex Bge.) was commonly found on artificial grassland plots, whereas natural grassland plots were occupied through natural succession mainly by wild species, including *Agropyron cristatum* (Linn.) Gaertn., *Cleistogenes squarrosa* (Trin.) Keng, *Heteropappus altaicus* (Willd) Novopokr, *Setaria viridis* (L.) Beauv., *Stipa capillata* Linn., *Artemisia scoparia* waldst.et Kit and *Stipa bungeana* Trin. and so on. Forest plots mainly included tall trees, such as *Pinus tabulaeformis* Carr., *Armeniaca sibirica* (L.) Lam., *Populus simonii* Carr., and *Robinia pseudoacacia* Linn.. Shrubland plots mostly contained shorter shrub species such as *Caragana korshinskii* Kom., *Hippophae rhamnoides* Linn., *Spiraea pubescens* Turcz., *Lespedeza davurica* (Laxm.) Schindl., and *Amorpha fruticosa* Linn.. Crops such as millet, potato, sorghum, and soybean were cultivated on sloped cropland, and newly abandoned land that was farmland or fallow over a relatively short time period and had relatively low vegetation coverage. Most of the bare land plots had no plant cover and vegetation coverage was approximately zero.

[insert Table 1.]

[insert Figure 2.]

3 Data analysis

Before conducting a detailed analysis, all data were transformed to uniform units to make runoff and soil erosion data comparable across all studies. Here, the runoff unit and soil erosion rate were transformed to mm and g/m^2, respectively. Next, descriptive statistics were generated to visualize the interactions between land use, runoff and soil loss, using box-plots grouped by land use type (Figures 3). Then, runoff and soil erosion rates were $\log_{10}$ transformed to normalize their distribution. One-way analysis of variance (ANOVA) and Tukey's HSD (honest significant difference) were used to test for differences (significance level at $p < 0.05$) in runoff and soil loss with land use type (Figure 3).

A range of indicators were used to quantify runoff and soil loss reduction effectiveness and runoff cost of sediment control with land use, with each land use type considered as a separate vegetation management factor, and compared with the case of bare land where plant cover was approximately zero (Figure 4 and Table 2). In order to explore overall and individual soil and water retention effectiveness via a meta-analysis, the land use types were divided into two transition types according to their soil and water retention measures (Table 1). Firstly, ecological restoration types (ERT) are essential soil and water conservation measures leading to land use transitions from cultivated sloping croplands to artificial grassland, natural grassland, shrubland, and forest in the Loess Plateau. Secondly, land degradation types (LDT) are the main sources of soil loss and have poor water conservation potential, which included bare land, newly abandoned land, and cropland. Finally, we determined the soil and water retention effectiveness of the four ERTs by contrasting them with the three LDTs via a meta-analysis.

Specific criteria were used to expand the datasets and to calculate the effect of runoff and soil erosion rate for the meta-analysis. LDTs were treated as controls or reference scenarios, whereas ERTs containing artificial grassland, natural grassland, shrubland, and forest were regarded as treatments. We chose the natural log of the response ratio to calculate the effect size, as an alternative to the standardized mean difference (e.g., Hedges'*d*), which is a more restrictive method (Koricheva J., 2013). Thus, the effect size can be calculated by the natural log of the response ratio (ln*RR*)：

$$\ln RR = \ln\left(\frac{\overline{Y_1}}{\overline{Y_2}}\right) = \ln\overline{Y_1} - \ln\overline{Y_2}$$

with variance

$$\vartheta_{\ln RR} = \frac{s_1^2}{n_1 \overline{Y_1}} + \frac{s_2^2}{n_2 \overline{Y_2}}$$

where n_1, $\overline{Y}_1, s_1$ were the sample size, mean and standard deviation of the variable related to the ERTs, respectively; n_2, $\overline{Y}_2, s_2$ were the sample size, mean and standard deviation of the variable relevant to the LDTs, respectively. Details on the meta-analysis data are provided in the supplementary material (see Appendix 2).

We determined the coarse spatial variability of effect size (lnRR) with longitude, latitude, mean annual precipitation (MAP) and mean annual temperature (MAT) via a regression analysis (see Appendix 3). In the meta-analysis process, model fit statistics (e.g., log-likelihood, deviance, Bayesian information criterion, and Akaike information criterion) were used to evaluate the optimal model. Model availability can be determined by the funnel and Q-Q plot between the standard error and overall effect model residuals, which can be useful for diagnosing the presence of heterogeneity and certain forms of publication bias (Viechtbauer, 2010) (see Appendix 4). The ratio of the runoff plot area, slope length, and slope steepness between ERT and LDT were regarded as continuous (numerical) moderator variables, whereas ERTs were treated as categorical moderator variables. Consequently, a generalized linear mixed meta-regression model was chosen with a restricted maximum likelihood estimator, to evaluate the mean effect size and its 95% confidence intervals (CIs), considering the impact of ERT and topologic characteristics on the effectiveness of soil and water retention (Tables 3 and 4). To characterize soil and water conservation effectiveness under different ERTs, the value of the overall mean effect size and the 95% CIs were transformed to estimate the percentage change and other variables relative to the control percentage, using $(e^{lnRR} - 1) \times 100\%$ (Figure 5). All of the reference lines in Figure 5 were at zero referring to a zero effect, and any CI (95%) crossing the reference line indicates a statistically insignificant result. According to vegetation management factors for the revised universal soil loss equation (RUSLE), we also calculated the ratio of the annual soil erosion rate per cover-management factor to soil loss on bare land for temperate, humid tropics, and Loess Plateau regions (Figure 6) (Renard, 1997; Labriere et al., 2015). Due to the absence of abandoned land in RULSE's vegetation management factors, the annual soil erosion ratio of cropland and abandoned land to bare land had the same relative ratio from the temperate region and the humid tropic region (Figure 6). Data transformations and statistical analyses were conducted using the R statistical software and the "metafor" R package was used to conduct the meta-analysis (Viechtbauer, 2010; R Core Team, 2013).

[insert Table 2.]

III Results

1 Impacts of land use type on runoff and soil erosion

Average runoff depths and runoff coefficients among the seven land use types were calculated at the annual and the event scale (Figures 3). Abandoned land, bare land, and cropland had significantly higher annual runoff depths than natural grassland, shrubland, and forest (p<0.05). Abandoned land had the highest annual runoff depth compared to other land cover types, and bare land ranked second for runoff yield. The annual runoff depth of artificial grassland was significantly higher than that of forest and lower than that of abandoned land (p<0.05), whereas those of artificial grassland, natural grassland, and shrubland had no significant difference (Figure 3(a)). On the rainfall event scale, bare land had the highest runoff depth than those of other land use types (p<0.05), whereas the runoff depths of shrubland and forest were significantly lower than those of artificial grassland, bare land, cropland, and natural grassland (p<0.05), with the exception of abandoned land, which had a higher runoff depth than shrubland and forest (Figure 3(b)). In addition, the annual runoff coefficients of artificial grassland, shrubland, and forest were significantly lower than those of abandoned land, bare land, and cropland (p<0.05), whereas the annual runoff coefficients of abandoned land, bare land, and cropland had no significant difference. Abandoned land also had the highest annual runoff coefficient, whereas the annual runoff coefficients of artificial grassland, natural grassland, shrubland, and forest had no significant difference (Figure 3(c)). Bare land had a significantly higher event runoff coefficient than artificial grassland, cropland, natural grassland, shrubland, and forest (p<0.05), whereas the event runoff coefficients of shrubland and forest were significant lower than those of abandoned land, bare land, and cropland. The event runoff coefficient of shrubland was also significantly lower than that of artificial grassland and forest (p<0.05) (Figure 3(d)). These results revealed that abandoned land, bare land, and cropland had relatively higher runoff yields than artificial grassland and natural grassland, whereas shrubland and forest had the lowest runoff yields but high water retention functions.

Also presented in Figure 3 are the average soil erosion rates among the seven land use types at the annual and the event scale. Artificial grassland, abandoned land, bare land, and cropland had higher annual soil erosion rates compared to natural grassland, shrubland, and forest, while those of artificial grassland and cropland were significantly lower than those of abandoned land (p<0.05). Furthermore, the mean annual soil erosion rate of abandoned land was very close to that of bare land while artificial grassland, bare land, and cropland had no significant difference in their annual soil erosion rates (Figure 3(e)). In addition, bare land and cropland, had significantly higher event soil erosion rates than those of abandoned land, artificial grassland, natural grassland, shrubland, and forest. Also, the event soil erosion rate for cropland was the highest, with bare land second (Figure 3(f)). Although abandoned land had a relatively low event soil erosion rate, this land use had a higher ability of yielding annual runoff than cropland. At the same time, abandoned land can accumulate more soil loss at the annual scale due to abandoned land that was fallowed from cropland (Figure 3(e) and

3(f)). Results showed that natural grassland, shrubland, and forest are preferable land use types for retaining soil and water, and artificial grassland also showed a degree of improved soil and water retention effectiveness, compared to abandoned land, bare land, and cropland.

[insert Figure 3.]

2 Soil and water reduction effectiveness and its tradeoff under different land use types

Using bare land as a reference, we calculated the runoff and sediment reduction effectiveness on the annual and event scales across six land use types (Table 2; Figure 4). We found that artificial grassland, natural grassland, shrubland, and forest had relatively high annual effectiveness in retaining water. The annual runoff retention effectiveness of shrubland and forest was more than 70%, whereas that of cropland and abandoned land were about 37% and -15%, respectively (Figure 4(a)). All six land use types had relatively high event effectiveness in retaining water compared to bare land. The event runoff retention effectiveness of shrubland and forest was more than 70%, and that of cropland and natural grassland was more than 49% (Figure 4(b)). All six land use types had positive annual soil retention effectiveness compared to bare land. Except for abandoned land, with its low annual soil retention effectiveness (less than 18%), the annual soil erosion reduction effectiveness of artificial grassland, cropland, natural grassland, shrubland, and forest was more than 65%. Shrubland had the highest annual soil retention effectiveness (96.51%) (Figure 4(c)). In addition, abandoned land, natural grassland, and shrubland had relatively high event soil loss retention effectiveness (>95%), whereas that of cropland was about -150% (Figure 4(d)). These results indicated that artificial grassland, natural grassland, shrubland and forest can be considered as effective measures for retaining runoff and sediment, whereas abandoned land had low effectiveness in retaining runoff, and cropland was found to weakly decrease event sediment yields.

The runoff cost of sediment control was used to determine the tradeoffs of different land use types at a hillslope scale for soil and water conservation, with reference to bare land (Figure 4). On an annual scale, natural grassland, shrubland, and forest had relatively high runoff costs, and that of artificial grassland was the highest (4.88 m^3/t). Abandoned land was associated with greater annual runoff compared to bare land (Figure 4(e)). On the event scale, artificial grassland, forest, and shrubland had relatively higher water costs, and cropland had lower water costs than abandoned land (Figure 4(f)). These results showed that shrubland and forest significantly reduced sediment yields with relatively high runoff costs, whereas natural grassland was optimal for balancing runoff production and soil conservation and artificial grassland was also found to be effective.

[insert Figure 4.]

3 Evaluation of soil and water retention effectiveness between ERT and LDT

Considerable spatial variability in the effect size (i.e. various lnRRs) was found along longitudinal and latitudinal gradients (see Appendix 3). Overall annual runoff depth rate (lnRR) significantly decreased with an increase in latitude (p<0.05), whereas overall event soil erosion rate (lnRR) increased significantly with both latitude (p<0.01) and longitude (p<0.001). This spatial trend was also evident for the event soil erosion rate (lnRR). However, both the event runoff depth (lnRR) and the event soil erosion rate (lnRR) of artificial grassland significantly decreased with increased longitude (p<0.01). These results indicated that the effect size of event runoff and soil erosion were more sensitive to changes of longitude and latitude, whereas the effect size of annual runoff was more limited to variation in latitude, only. In addition, the effect of MAP and MAT on the variability of the effect size can be found in Appendix 4. Clearly, it is critical to consider spatial heterogeneity when quantifying the overall effect of ecological restoration on runoff and soil erosion over large regions.

Ecological restoration activities had a positive effect on soil and water retention. In contrast with LDTs, ERTs significantly reduced annual runoff by 72.18% (p<0.01) and decreased annual soil erosion by 99.9% (p<0.0001), whereas the event runoff was reduced by 39.26%, and event soil loss was not significantly decreased (Figure 5 (a) and (c)). Moderator variables effectively improved our meta-analysis model, which included the ratios of runoff plot area, slope length, and slope steepness between ERT and LDT (see Appendix 4). The overall event runoff reduction effectiveness was significantly influenced by the ratio of slope steepness and the ratio of area. The ratios of slope length were more important factors impacting the overall results for event soil erosion (Table 3). The individual effect of the annual runoff reduction effectiveness of artificial grassland, natural grassland, shrubland, and forest were 71.89%、50.60%、73.18%, and 73.08%, respectively. The combined effect of all the ecological restoration measures significantly reduced annual soil erosion by about 100% ($p<0.0001$). However, event runoff reduction effectiveness of artificial grassland, natural grassland, shrubland, and forest were 56.41%、21.97%、56.97%（$p<0.05$）, and 36.68%, respectively. Event sediments were not significantly reduced (Figure 5 (b) and (d)). In evaluating the individual effects of the ERTs, it was clear that the ratios of runoff plot area, slope length, and slope steepness have significant impacts on annual soil erosion ($p<0.0001$). Annual runoff was obviously influenced by the ratio of the runoff plot area and slope steepness ($p<0.0001$), whereas slope steepness was an important factor for event runoff ($p<0.05$). Event soil erosion was significantly impacted by the ratio of the runoff plot area ($p<0.01$) and slope length ($p<0.05$) (Table 4).

[insert Figure 5.]

[insert Table 3.]

[insert Table 4.]

IV Discussion

1 The high variability in water and sediment effects of ecological transition types

Land use that includes woody plants (forests and shrubs) and grasses has been shown to be more effective at decreasing runoff and retaining water than other land use types (Maetens et al., 2012; Garcia-Ruiz et al., 2015; Mutema et al., 2015). At the global scale, the annual mean runoff coefficient of forests has been found to be highest on the micro-plot (Slope length was less than 1 m) and on the plot (Slope length was less than 30 m), whereas the land use type with the lowest annual mean runoff coefficient has been found to be grasslands at the micro-plot scale and fallows at the plot scale, regardless of biogeographic context (e.g., climate zone) (Mutema et al., 2015). At the regional scale, plots with (semi-) natural vegetation cover have been found to have the lowest mean annual runoff coefficients, and the order of low-to-high mean annual runoff coefficients for other land use types has been found to be fallow, cropland and bare soil in Western and Central Europe (Maetens et al., 2012). Our study has also found the annual runoff coefficients of artificial grassland, forest, natural grassland, and shrubland to be significantly lower than those of other land use types in the Loess Plateau. The main reasons for differences in the annual runoff coefficients at the regional and global scales are related to (i) climate (e.g., mean annual precipitation and mean annual temperature), (ii) the spatial scale of the experiment (e.g., micro-plot, plot and watershed), and (iii) local characteristics (e.g., soil properties, slope gradient, and land use), which vary globally. There are no established protocols for standardizing measurements, and for reporting the results across studies and sites (Garcia-Ruiz et al., 2015; Mutema et al., 2015). Although Western and Central Europe have important loess regions, the Loess Plateau in China is unique in its maximum thick loess distribution area and its soil and water loss regions are wide and intensive. Runoff yields on abandoned land, bare land, and cropland in the Loess Plateau were significantly higher than that in Western and Central Europe. In addition, we found that the annual runoff coefficient on abandoned land in the Loess Plateau was significantly higher than fallow land in Western and Central Europe, and even globally. This result confirmed that unmanaged abandoned land is not beneficial for preserving water, and this land use had higher runoff yields due to the shortage of vegetation cover, loose soil and the absence of mulching practices (Lasanta et al., 2000; Prosdocimi et al., 2016). In addition, we found forest, shrubland, natural grassland, and artificial grassland had higher annual runoff reduction effectiveness than cropland and abandoned land, which had higher annual runoff yields than bare land. Therefore, ecological restoration can effectively conserve water, but with a high variability of effectiveness in different regions due to differences in climate.

Vegetation recovery can effectively control soil erosion. In our study, we found that land degradation types had significantly higher soil loss than ecological restoration types. The same conclusions have been found in the humid tropics, Western and Central Europe and in global studies (Maetens et al., 2012; Garcia-Ruiz et al., 2015; Labriere et al., 2015; Mutema et al., 2015). In a global meta-analysis, forests, shrubland, and grassland have been found to have lower annual mean sediment yields than croplands and fallows, where fallows had the highest annual mean sediment yields (Garcia-Ruiz et al., 2015; Mutema et al., 2015). In the humid topics, forest has been found to have the lowest mean annual soil loss, where the low-to-high soil loss order for other land use types were found to be shrubland, grassland, cropland, and bare soil (Labriere et al., 2015). In Western and Central Europe, plots with (semi-)natural vegetation cover have been found to have the lowest mean annual soil loss, where the low-to-high soil loss order of other land use types were found to be fallows, cropland, and bare soil (Maetens et al., 2012). Although grassland, shrubland, and forest can effectively reduce soil loss in the Loess Plateau, for humid tropical areas, Western and Central Europe, and globally, a high variability in the quantity of soil loss at regional and global scales have been observed. Compared to loess regions in Western and Central Europe, the Loess Plateau had the highest soil loss across all land use types, with bare land always having the highest soil loss rate. Although abandoned land (similar to fallows) was an important land use type for re-wilding and for conserving biodiversity, retaining soil, and restoring the ecological function by natural succession (Hou and Fu, 2014b; Queiroz et al., 2014; Corlett, 2016), unmanaged abandoned land in the early stage of ecological restoration has been found to have relatively high annual sediment yields, even exceeding the annual mean soil loss rate of cropland (Lasanta et al., 2000; Maetens et al., 2012; Mutema et al., 2015; Prosdocimi et al., 2016). In our study, the annual reduction sediment effectiveness of shrubland, natural grassland, forest, and artificial grassland was found to be higher than that of cropland and abandoned land, and overall, the effectiveness of ecological restoration land types were approximately two times that of land degradation types. Consequently, ecological restoration had a clear positive effective on decreasing sediment yields than land degradation types. Thus, directly abandoning cropland in the early stage of ecological restoration, meant that bare land and cropland were not always a good choice for mitigating water and sediment production.

2 Tradeoffs between water provisioning and soil conservation should be considered for ecological restoration in drylands

Soil erosion processes are always associated and coupled with runoff processes with increased runoff transporting more sediments into river courses. The relationships between runoff and sediment yields are complex and operate across extensive spatiotemporal scales, especially in water-limited regions (Bloschl, 2006; Boix-Fayos et al., 2006; Mutema et al., 2015; Zheng et al., 2015). In general, the reduction of runoff causes a synergistic decrease of sediment yields in drylands and many factors can contribute to reductions in runoff and sediment, such as climate change, land cover change, and ecological restoration (Liang et al., 2015; Gao et al., 2016; Wang et al., 2016; Zhang et al., 2016; Zuo et al., 2016). In our study, ecological restoration had significant effects on the reduction of water runoff and sediment yields. However, changes in land use type, as a result of ecological restoration activities, can exert differing degrees of control on the runoff and sediment yields. Controlling soil loss usually decreases water provision, particularly in dryland ecosystems (Zheng et al., 2014; Hao et al., 2017). Therefore, the land use type should be chosen to balance water provision and soil conservation from an ecosystem service perspective. Our analysis also revealed that shrubland and forest not only significantly decreased sediment yields, but also had relatively high runoff costs. Furthermore, afforestation had caused severe depletion of soil moisture content and consumed deeper soil moisture than cultivated crops, inducing soil desiccation and a dry soil layer formation in the Loess Plateau, which would be a poor choice for places in arid and semi-arid regions (Deng et al., 2016; Jia et al., 2017). Although abandoned land and cropland had a relatively weak ability to retain soil, they also can significantly increase runoff. Natural grassland was found to be the optimal vegetation type to balance the water requirement and soil conservation objectives, with artificial grassland also found to be effective. Consequently, complete conversion of cropland to forest and shrubland may not be a good strategy, especially in arid and semi-arid regions (Deng et al., 2016; Jia et al., 2017). Although the fallow period was long enough to allow abandoned land to succeed into (semi-) natural vegetation, abandoned land would have better soil and water retention effectiveness in this process (Hou and Fu, 2014a; Hou et al., 2014a; Zhao et al., 2015). Unmanaged abandoned land in the early fallow stage had high water costs for decreasing sediment and were less effective at retaining water and soil (see also, Lasanta et al., 2000; Maetens et al., 2012). Furthermore, artificial grassland had relatively higher water costs for sediment control than natural grassland and can effectively conserve soil and increase water runoff by different forage managements (Yan et al., 2015). In addition, abandoned land and cropland had the potential to conserve soil and provided water through effective land management and tillage measures (Lasanta et al., 2000; Montgomery, 2007; Yan et al., 2012; Labriere et al., 2015; Prosdocimi et al., 2016). Therefore, these results indicate the need to carefully choose ecological recovery types for soil and water conservation in the context of the tradeoff between water yield and soil conversation.

3 Regional soil erosion and advice for future research

Although large scale ecological restoration projects have been implemented for at least 15 years and have played a critical role in soil and water conservation, the Loess Plateau has experienced a relatively higher soil loss than the humid tropics and temperate regions of the world (Figure 6). For bare land, specific vegetation management factors in the Loess Plateau have higher ratios of soil loss than in the humid tropics (Labriere et al., 2015). Ratios between temperate regions and the Loess Plateau for artificial grassland, abandoned land, cropland, forest, natural grassland, shrubland, and bare land have been found to be ca. 4, 2.4, 1, 14, 1.2, and 1.6, respectively (Renard, 1997). For the field plot, the average of annual soil loss of fallows, croplands, grasslands and forests in the Loess Plateau have higher annual soil loss than that of other semi-arid and arid regions from a global analysis (Mutema et al., 2015).

Furthermore, there exists a severe conflict between water shortage and soil retention in the Loess Plateau which may be intensified by ecological restoration driven land use change in the context of climate change (Chen et al., 2015; Deng et al., 2016; Maestre et al., 2016). How to better conserve soil and improve water provisioning services are critical science and management problems. We can provide the following advice for future research on soil and water retention in the context of ecological restoration in water-limited environments, as informed by this research:

1. Optimal plant species combinations should be identified based on plant functional traits, and their ability to effectively retain soil and balance multi-ecosystem services, from simple species-based vegetation recovery to

trait-based community and ecosystem function restoration. For example, improving grass community functional diversity can reduce soil erosion in semi-arid land and grasslands which would balance the conflict between water provisioning and soil conservation in semi-arid and arid regions (Zhu et al., 2015; Maestre et al., 2016).

2. From the perspective of landscape pattern, process and function, more attention should be paid to the patterns of vegetation change arising from ecological restoration and their effects on soil and water preservation. Physical-based vegetation pattern indicators should be developed to determine the optimal mode of vegetation recovery for the control of soil and water loss. For instance, vegetation patch and landscape connectivity indices can strengthen the understanding of hydrologic and soil erosion process responses to ecological restoration (Imeson and Prinsen, 2004; Liu et al., 2013; Hou and Fu, 2014a; Hou et al., 2014a; Hou et al., 2014b; Maestre et al., 2016).

3. To implement future sustainability of vegetation recovery, ecological restoration is not simply concerned with continually increasing the area of afforestation reforestation, returning the cropland to forest and shrubland, and accelerating the rate of plant regeneration. Rather, a series of management strategies are needed to take advantage of emerging technologies to quantify the effects of different land use types and to determine the effect of these management measures on soil loss and water provisioning. This will support transparent decision making and allow the

tradeoffs between water yield and soil conversation to be understood. For example, no-till agriculture, soil management practices (e.g., mulching) and vegetation management (e.g., using local species at suitable coverage level) may be more effective for soil loss control and the protection of (semi-) natural vegetation types should be advocated (Montgomery, 2007; Chen et al., 2015; Labriere et al., 2015; Deng et al., 2016; Prosdocimi et al., 2016).

[insert Figure 6.]

V Conclusions

Ecological restoration projects in the Loess Plateau have increased vegetation cover and have led to land use transitions which have effectively controlled soil and water loss. Our study quantified the effects of ecological restoration on runoff and sediment yields by synthesizing 43 articles at different sites in the Loess Plateau using a meta-analysis. First, the effect of land use type on runoff, sediment yields and soil and water reduction effectiveness were quantified. Artificial grassland, natural grassland, shrubland, and forest were found to be more effective land use types in retaining soil and water than abandoned land, bare land, and cropland. Bare land and cropland were not found to benefit soil and water retention at any time, as was unmanaged abandoned land in the early fallowing stage. Our study found shrubland and forest to have a high runoff cost in controlling sediment. In contrast, natural grassland was found to be the optimal vegetation type to balance the water provisioning and soil retention. Artificial grassland was also found to be a good land use choice, whereas unmanaged abandoned land and cropland were found to have the weakest ability to retain soil, although they can significantly increase runoff. Second, ecological restoration effectively controlled soil erosion and retained runoff and its effect was comprehensively quantified by this meta-analysis. Finally, the Loess Plateau has a relatively high overall soil erosion. Future research is needed to examine soil and water retention from an ecological recovery perspective, including choosing optimal plant species based on plant functional traits, applying physical-based vegetation pattern indicators, and developing a range of practical managements and technologies for different land use types.

Appendices

Appendix 1. Papers included in the meta-analysis.

Appendix 2. Data source and datasets for meta-analysis.

Appendix 3. Spatial variability of effect size.

Appendix 4. Fit statistic of the optimal model and model reliability in meta-analysis.

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Figure captions

Figure 1. Location of study sites (N = 43). Some sampling points represent several references, and some references contribute more than one sampling point.

Figure 2. Frequency distribution of (a) year of publication of the contributing references (N =43), (b) length of the study, (c) number of land use types investigated per reference, and (d) land use types investigated, (e) the number of case studies located at different counties and provinces, (f) levels of year soil erosion rate under different land use types. Abbreviation of land use types can be found in Table 1.

Event: soil erosion or runoff at an event scale; Year: soil erosion or runoff at a year scale; Event and year: soil erosion or runoff at an event and year scale; AS: Ansai; BT: Baota; CW: Changwu; DX: Dingxi; F: Fu; FG: Fugu; GY: Guyuan; HN: Huining; J: Ji; LS: Lishi; PS: Pingshuo; SM: Shenmu; SY: Shouyang; TS: Tianshui; WQ: Wuqi; XF: Xifeng; YG: Yanggao; YC: Yichuan; YS: Yongshou; YL: Yulin; ZZ: Zizhou.

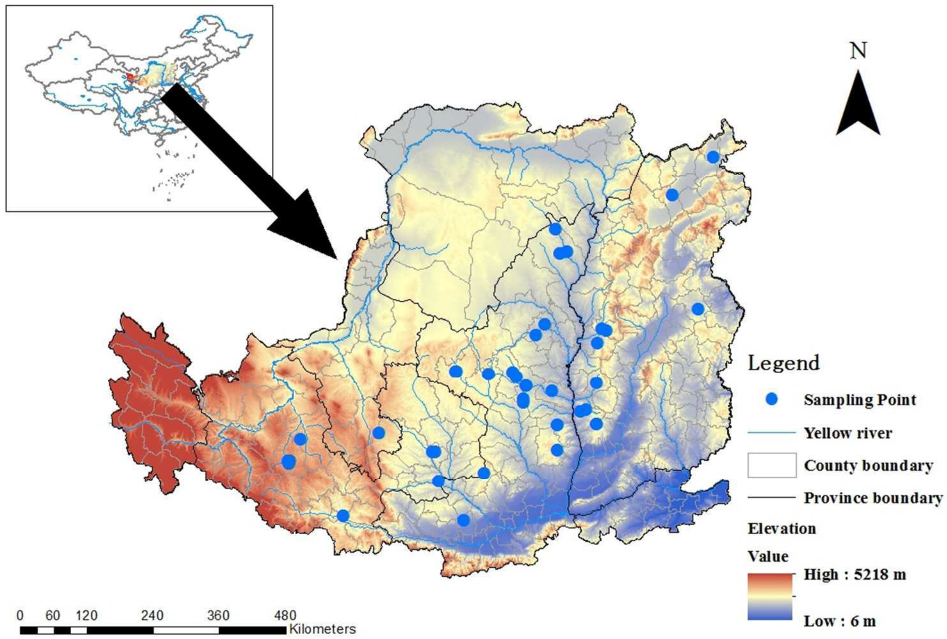
Figure 3. Boxplots of (a) annual runoff, (b) event runoff, (c) annual runoff coefficient, (d) event runoff coefficient, (e) annual soil loss rate and (f) event soil loss rate among seven land use types. In order to clarify the plot (e) and (f), y-axis breaks were set. The results of ANOVA and Tukey's HSD analysis were added in the figure and the absolutely different lowercase in land use types stand for having a significant difference while just having one same lowercase denotes no significant difference. Abbreviation of land use types can be found in Table 1.

Figure 4. Runoff and soil loss reduction effectiveness contrasting to the control of bare land and the runoff cost of sediment control at event and annual temporal scale under six land use types. Abbreviation of land use types can be found in Table 1.

RRE: Runoff reduction effectiveness; SLRE: Soil loss reduction effectiveness; R_{rs}: The runoff cost of sediment controlling of vegetation management factors.

Figure 5. The impact of overall and individual ecological restoration types on (a) annual runoff, (b) annual soil erosion, (c) event runoff and (d) event soil erosion. Significant levels as follows, 0.0001-'***', 0.001-'**', 0.01-'*', 0.05-'.', 0.1-' '.

Figure 6. Comparison of ratio of annual soil erosion rate per land use type to soil loss on bare land in three regions. Data on temperate and humid tropic regions were cited from Renard (1997) and Labriere (2015). Abbreviation of land use types can be found in Table 1.



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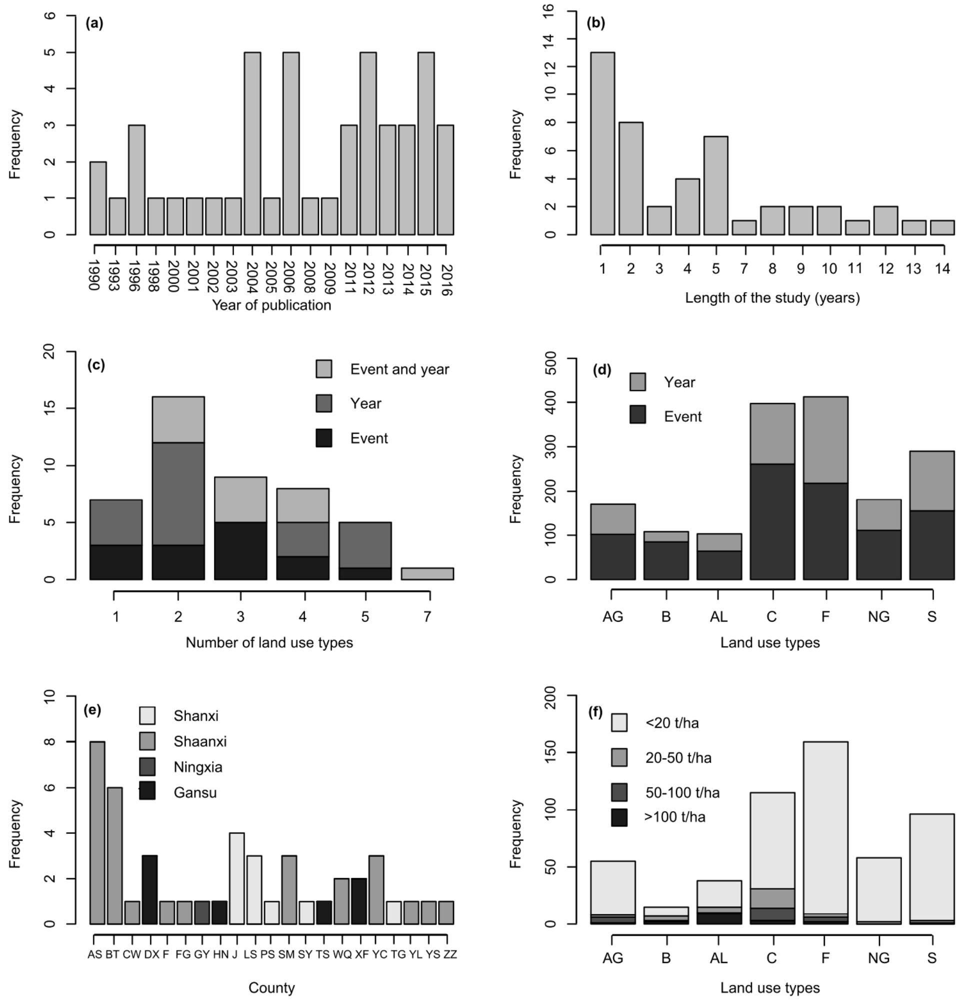

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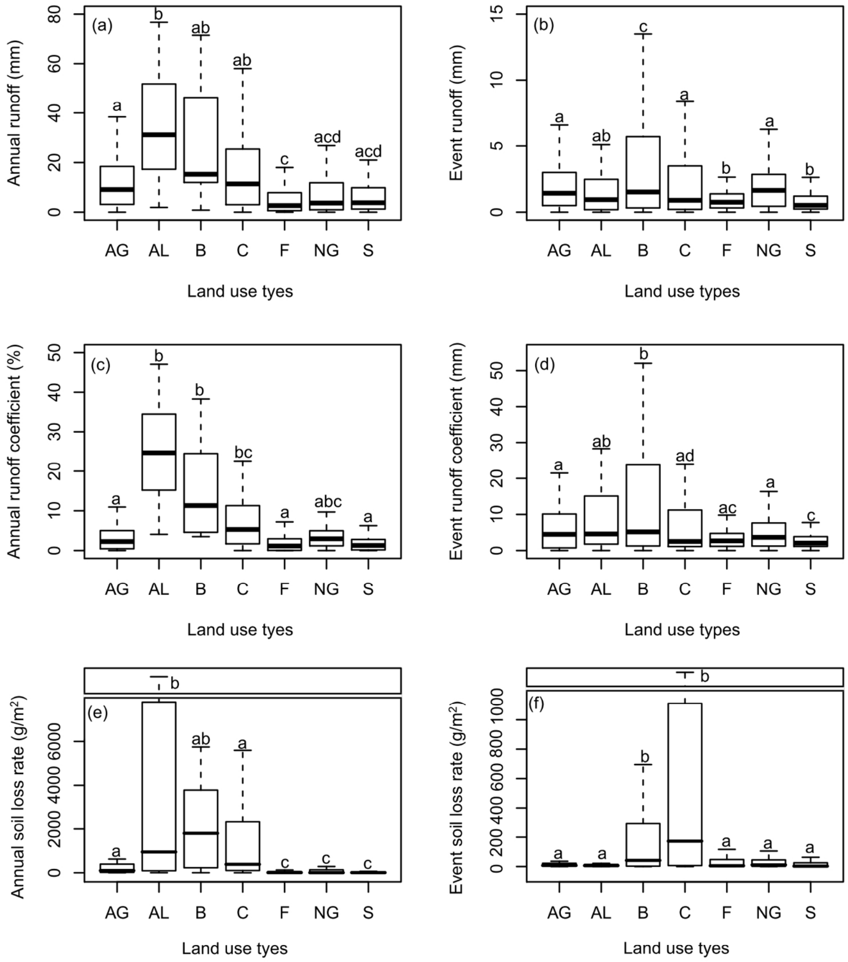

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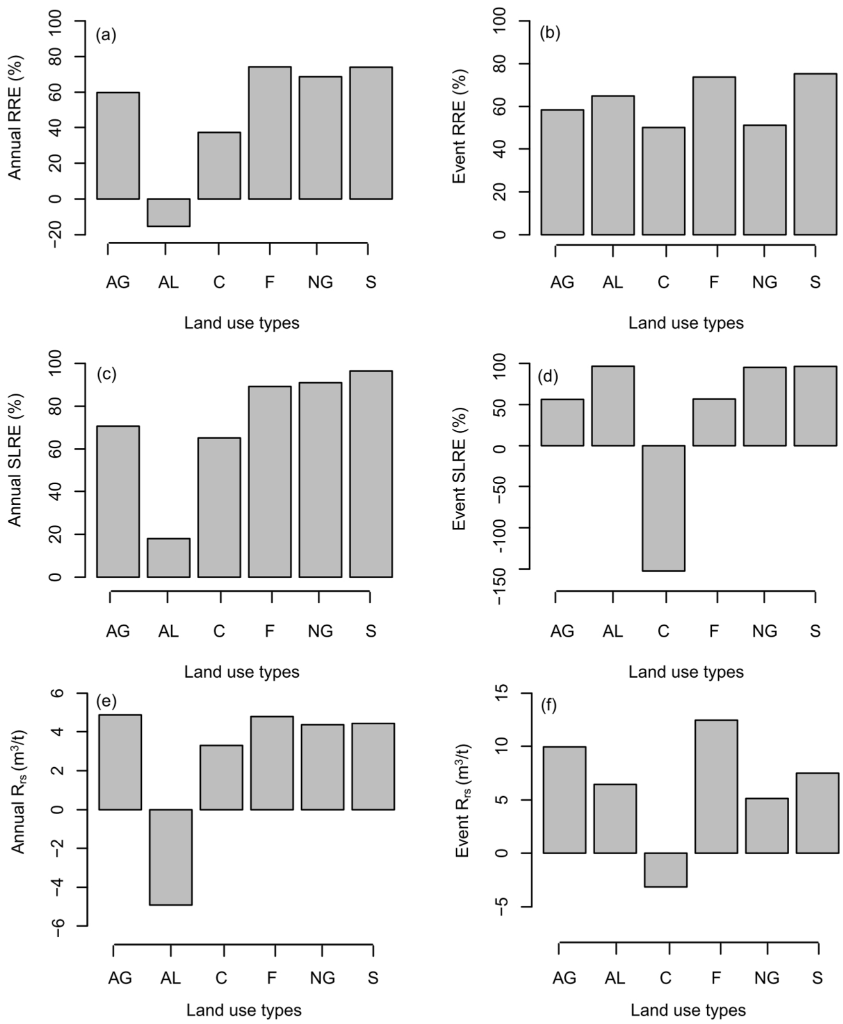

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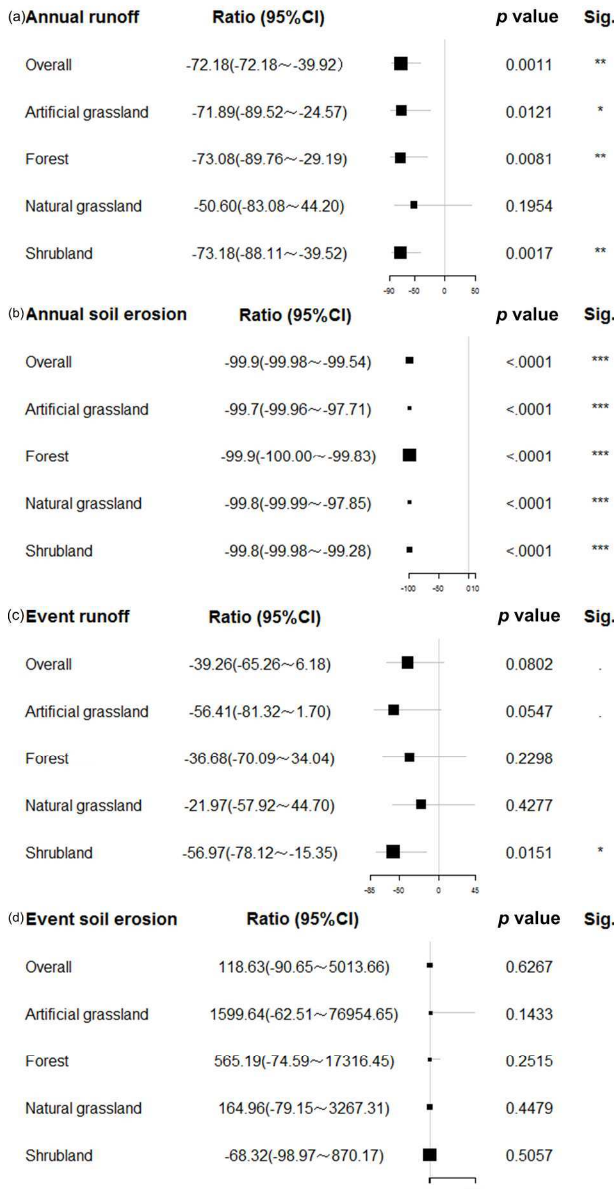

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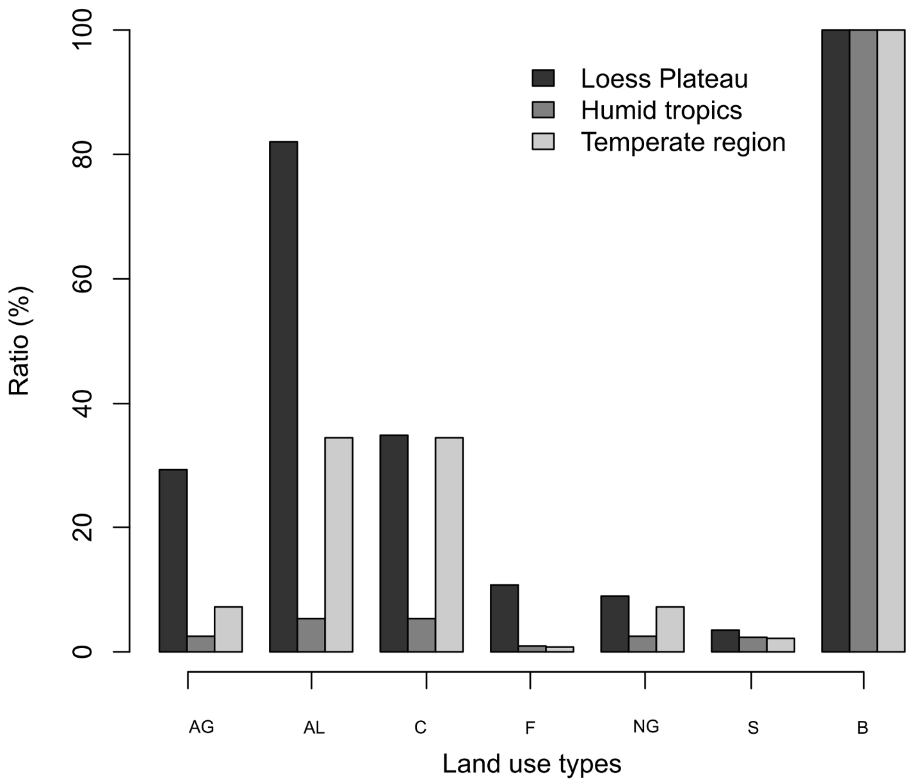

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Tables

Table 1. The description and relationship between land use transition types and land use types.

Table 2. Indicators of soil and water reduction effectiveness and its tradeoff.

Table 3. Meta-regression results of ratio of runoff plot area, slope length and slope steepness on effect size (lnRR) between ERT and LDT.

Table 4. Meta-regression results of ratio of runoff plot area, slope length and slope steepness and ecological restoration types on effect size (lnRR).

Table 1.

Land use transition types	Land use types	Abbreviation	Definition
Ecological restoration types (ERT)	Artificial grassland	AG	Land is used for grazing and managed through agricultural practices such as seeding, irrigation and use of fertilizer. Main plant species are *Medicago sativa* and *Astragalus adsurgens*.
	Natural grassland	NG	Land is unmanaged and has no trees or shrubs. For example, slope wasteland， rangelands.
	Forest	F	Ground is covered with natural vegetation dominated by trees and could also include grasses, herbs and geophytes.
	Shrubland	S	Vegetation is dominated by shrubs but can also include grasses, herbs and geophytes.
Land degradation types (LDT)	Cropland	CL	Crops are sown and harvested within a single agricultural year, sometimes more than once.
	Abandoned land	AL	Farmland was abandoned or fallow at relative short time and have not enough time to succession into grass community because of runoff plot control experiment.
	Bareland	B	Land has been opened and kept bare for various reasons by artificial controlling, which have the lowest coverage approximate at 0.

Table 2.

Indicators	Abbreviation	Equation expression	Parameter meaning	Definition	Sources
Runoff reduction effectiveness	RRE (%)	$\mathrm{RRE}=\frac{R_{\mathrm{CK}}-R_{\mathrm{V}}}{R_{\mathrm{CK}}}\times 100$	R_{CK} (mm); R_{V} (mm) and SL_{CK} (g/m^2); SL_{V} (g/m^2) are runoff and soil loss in control (bareland) and treatment (vegetation management factors), respectively.	The effectiveness of water retention in vegetation management factors contrast to reference background such as bare land.	(Sutherland 1998a, b; Zhao et al, 2015; Zhu et al, 2016)
Soil loss reduction effectiveness	SLRE (%)	$\mathrm{SLRE}=\frac{SL_{\mathrm{CK}}-SL_{\mathrm{V}}}{SL_{\mathrm{CK}}}\times 100$		The effectiveness of soil retention in vegetation management factors contrast to reference background such as bare land.	
Ration of detained runoff and sediment	R_{rs} (m^3/t)	$R_{rs}=\frac{R_d}{S_d}\times 10^3$	R_d (mm) and S_d (g/m^2) refer to the reduction of runoff and sediment under vegetation management factors as opposed to reference scenario (bareland).	Retention of unit slope sediment need to relatively reduce how the amount of runoff at one vegetation management factors due to land use transition.	(Yan et al, 2012; Yan et al, 2015)

Table 3.

Categories	N	Type of evaluation	lnRR	Standard error	Lower limit of CI	Upper limit of CI	Z value	*p* value	Sig. [a]
Annual runoff	169	Overall effect	-1.28	0.39	-2.05	-0.51	-3.26	0.0011	**
		RA	-0.16	0.03	-0.21	-0.11	-5.88	<.0001	***
		RSL	0.69	0.32	0.05	1.32	2.12	0.0343	*
		RSS	0.03	0.01	0.02	0.04	4.20	<.0001	***
Annual soil erosion	132	Overall effect	-6.93	0.79	-8.49	-5.38	-8.73	<.0001	***
		RA	-4.34	0.85	-6.01	-2.67	-5.09	<.0001	***
		RSL	7.21	1.22	4.81	9.61	5.89	<.0001	***
		RSS	-1.14	0.22	-1.58	-0.70	-5.13	<.0001	***
Event runoff	117	Overall effect	-0.50	0.29	-1.06	0.06	-1.75	0.0802	.
		RA	-0.11	0.62	-1.33	1.11	-0.18	0.8608	
		RSL	-0.15	0.44	-1.01	0.71	-0.35	0.727	
		RSS	0.01	0.01	0.01	0.02	2.29	0.022	*
Event soil erosion	68	Overall effect	1.61	1.27	-0.88	4.10	1.26	0.206	
		RA	-19.26	6.77	-32.54	-5.99	-2.85	0.0044	**
		RSL	15.21	6.19	3.08	27.35	2.46	0.014	*
		RSS	-0.01	0.38	-0.75	0.73	-0.03	0.9784	

Note: a represents significance levels as follows, 0.0001-‘***’, 0.001-‘**’, 0.01-‘*’, 0.05-‘.’, 0.1-‘ ’.

ERT: ecological restoration types; LDT: land degradation types; N: sample size; RA: ratio of area; RSL: ratio of slope length; RSS: ratio of slope steepness.

Table 4.

Categories	N	Type of evaluation	lnRR	Standard error	Lower limit of CI	Upper limit of CI	Z value	*p* value	Sig. [a]
Annual runoff	169	Artificial grassland	-1.27	0.50	-2.26	-0.28	-2.54	0.0121	*
		Forest	-1.31	0.49	-2.28	-0.35	-2.68	0.0081	**
		Natural grassland	-0.71	0.54	-1.78	0.37	-1.30	0.1954	
		Shrubland	-1.32	0.41	-2.13	-0.50	-3.20	0.0017	**
		RA	-0.15	0.03	-0.21	-0.10	-5.54	<.0001	***
		RSL	0.62	0.33	-0.04	1.27	1.87	0.0635	.
		RSS	0.03	0.01	0.01	0.04	3.83	0.0002	***
Annual soil erosion	132	Artificial grassland	-5.81	1.03	-7.83	-3.77	-5.66	<.0001	***
		Forest	-8.22	0.94	-10.08	-6.37	-8.76	<.0001	***
		Natural grassland	-6.51	1.35	-9.18	-3.84	-4.83	<.0001	***
		Shrubland	-6.66	0.87	-8.39	-4.94	-7.63	<.0001	***
		RA	-3.71	0.93	-5.55	-1.86	-3.98	0.0001	***
		RSL	6.56	1.37	3.86	9.26	4.80	<.0001	***
		RSS	-1.04	0.24	-1.51	-0.57	-4.40	<.0001	***
Event runoff	117	Artificial grassland	-0.83	0.43	-1.68	0.02	-1.94	0.0547	.
		Forest	-0.46	0.38	-1.21	0.29	-1.21	0.2298	
		Natural grassland	-0.25	0.31	-0.87	0.37	-0.80	0.4277	
		Shrubland	-0.84	0.34	-1.52	-0.17	-2.47	0.0151	*
		RA	0.53	0.82	-1.10	2.15	0.64	0.5244	
		RSL	-0.61	0.56	-1.73	0.51	-1.08	0.2839	
		RSS	0.01	0.01	0	0.02	2.12	0.0365	*
Event soil erosion	68	Artificial grassland	1.99	1.51	-1.02	5.01	1.32	0.1907	
		Forest	2.05	1.37	-0.69	4.78	1.50	0.1400	
		Natural grassland	1.60	1.26	-0.92	4.12	1.27	0.2085	
		Shrubland	0.64	1.40	-2.15	3.43	0.46	0.6502	
		RA	-18.46	6.80	-32.06	-4.86	-2.71	0.0086	**
		RSL	14.64	6.16	2.32	26.96	2.38	0.0207	*

RSS	-0.06	0.37	-0.80	0.68	-0.16	0.8737

Note: a represents significance levels as follows, 0.0001-‘***’, 0.001-‘**’, 0.01-‘*’, 0.05-‘.’, 0.1-‘ ’.

N: sample size; RA: ratio of area; RSL: ratio of slope length; RSS: ratio of slope steepness.

Appendix 1. Papers included in the meta-analysis

1. Web of science core database

Feng, Q., X. D. Guo, W. W. Zhao, Y. Qiu, and X. Zhang. 2015. A comparative analysis of runoff and soil loss characteristics between "extreme precipitation year" and "normal precipitation year" at the plot scale: A case study in the Loess Plateau in China. Water 7:3343-3366.

Fu, B. J., Q. H. Meng, Y. Qiu, W. W. Zhao, Q. J. Zhang, and D. A. Davidson. 2004. Effects of land use on soil erosion and nitrogen loss in the hilly area of the Loess Plateau, China. Land Degradation & Development 15:87-96.

Gao, G. Y., B. J. Fu, Y. H. Lu, Y. Liu, S. Wang, and J. Zhou. 2012. Coupling the modified SCS-CN and RUSLE models to simulate hydrological effects of restoring vegetation in the Loess Plateau of China. Hydrology and Earth System Sciences 16:2347-2364.

Guo, Z., and M. Shao. 2013. Impact of afforestation density on soil and water conservation of the semiarid Loess Plateau, China. Journal of Soil and Water Conservation 68:401-410.

Hou, J., B. J. Fu, Y. Liu, N. Lu, G. Y. Gao, and J. Zhou. 2014. Ecological and hydrological response of farmlands abandoned for different lengths of time: Evidence from the Loess Hill Slope of China. Global and Planetary Change 113:59-67.

Huang, Z. L., L. D. Chen, B. J. Fu, Y. H. Lu, Y. L. Huang, and J. Gong. 2006. The relative efficiency of four representative cropland conversions in reducing water erosion: Evidence from long-term plots in the loess Hilly Area, China. Land Degradation & Development 17:615-627.

Jian, S. Q., C. Y. Zhao, S. M. Fang, and K. Yu. 2015. Effects of different vegetation restoration on soil water storage and water balance in the Chinese Loess Plateau. Agricultural and Forest Meteorology 206:85-96.

Jiang, N., M. A. Shao, W. Hu, and Y. Q. Wang. 2013. Characteristics of water circulation and balance of typical vegetations at plot scale on the Loess plateau of China. Environmental Earth Sciences 70:157-166.

Kang, S. Z., L. Zhang, X. Y. Song, S. H. Zhang, X. Z. Liu, Y. L. Liang, and S. Q. Zheng. 2001. Runoff and sediment loss responses to rainfall and land use in two agricultural catchments on the Loess Plateau of China. Hydrological Processes 15:977-988.

Ma, L., Y. G. Teng, and Z. P. Shangguan. 2014. Ecohydrological responses to secondary natural Populus davidiana and plantation Pinus tabulaeformis woodlands on the Loess Plateau of China. Ecohydrology 7:612-621.

Wang, L., S. P. Wei, R. Horton, and M. A. Shao. 2011. Effects of vegetation and slope aspect on water budget in the hill and gully region of the Loess Plateau of China. Catena 87:90-100.

Wang, X. Y., H. W. Gao, J. N. Tullberg, H. W. Li, N. Kuhn, A. D. McHugh, and Y. X. Li. 2008. Traffic and tillage effects on runoff and soil loss on the Loess Plateau of northern China. Australian Journal of Soil Research 46:667-675.

Yi, C. Q., and J. Fan. 2016. Application of HYDRUS-1D model to provide antecedent soil water contents for analysis of runoff and soil erosion from a slope on the Loess Plateau. Catena 139:1-8.

Zhang, K., S. Li, W. Peng, and B. Yu. 2004. Erodibility of agricultural soils on the Loess Plateau of China. Soil & Tillage Research 76:157-165.

Zhang, L., J. M. Wang, Z. K. Bai, and C. J. Lv. 2015. Effects of vegetation on runoff and soil erosion on reclaimed land in an opencast coal-mine dump in a loess area. Catena 128:44-53.

Zheng, F. L. 2006. Effect of vegetation changes on soil erosion on the Loess Plateau. Pedosphere

16:420-427.

Zheng, M., and X. Chen. 2015. Statistical determination of rainfall-runoff erosivity indices for single storms in the Chinese Loess Plateau. Plos One 10.

Zhou, J., B. J. Fu, G. Y. Gao, Y. H. Lu, Y. Liu, N. Lu, and S. Wang. 2016. Effects of precipitation and restoration vegetation on soil erosion in a semi-arid environment in the Loess Plateau, China. Catena 137:1-11.

Zhu, T. X. 2016. Effectiveness of conservation measures in reducing runoff and soil loss under different magnitude-frequency storms at plot and catchment scales in the semi-arid agricultural landscape. Environmental Management 57:671-682.

2. *Chinese national Knowledge Infrastructure*

Ai, N., T. X. Wei and Q. K. Zhu. 2013. The effect of rainfall for runoff-erosion-sediment yield under the different vegetation types in Loess Plateau of northern Shaanxi province. Journal of soil and water conservation, 27(2): 26-30,35.

Chen, Y. M., X. L. HOU and W. Z. LIU. 2000. Soil and water conservation function and ecology benefits of different types vegetation in semi-arid loess hilly region. Journal of soil and water conservation, 14(3): 57-61.

Hou, X. L. and Q. Y. Cao. 1990. Study on the benefits of plants to reduce sediment in the loess rolling gullied region of north Shaanxi. Bulletin of soil and water conservation, 10(2):33-40.

Hou, X. L., G. S. Bai and Q. Y. Cao. 1996. Study on benefits of soil and water conservation of forest and its mechanism in loess hilly region. Research of soil and water conservation, 3(2): 98-103.

Hu, M. J.. 2003. Study on water balance and soil moisture ecological characteristic of *hippophae rhamnides* and *caragana microphylla* land in loess hilly region. Northwest sci-tech university of agriculture and forestry.

Jiang, N. and M. A. Shao. 2011. Characteristic of soil and water loss of different slope land uses in small watershed on the Loess Plateau. Transactions of the CSAE, 27(6): 36-41.

Li, M., X. Y. Song, B. Shen, H. Y. Li and C. X. Meng. 2006. Influence of vegetation change on producing runoff and sediment in gully region of Loess Plateau. Journal of northwest sci-tech university of agriculture and forestry, 34(1): 117-120.

Liu, X. F.. 2009. Effect of legume on soil and water loss and soil nutrient at abandoned cropland in loess hilly-gully region, China. Gansu science and technology, 25(19): 19:58-61+93.

Luo, W. X., L. Q. Bai and X. D. Song. 1990. Runoff and scouring amount in forest and grass land with different cover rate. Acta conservationis soli et aquae sinia, 4(1):30-35.

Lv, X. Z., L. L. KANG, Z. G. Zuo, J. Sun and Y. X. Ni. Characteristics of slope runoff under different vegetation conditions in Lvergou watershed of the Loess Plateau. Ecology and Environmental Sciences, 2015, 24(7): 1113-1117.

Pan, C. Z. and Z. P. Shangguan. 2005. Generation mechanism of woodland and runoff and sediment on Loess plateau under hypo-rainfall- a case study of artificial P. tabulaeformis and secondary natural P. dadidiana stands. Chinese journal of applied ecology, 16(9): 1597-1602.

Shen, Z. Z., P. L. Liu, Y. S. Xie, S. Q. Zheng and T. J. Ju. 2006. Study of plot soil erosion characteristic under different underlying horizon. Bulletin of soil and water conservation, 26(3): 6-9,22.

Wang, Q. C., G. L. Wang, S. X. Shi, L. Zhuang and T. S. Sun. 2012. Effect of different artificial vegetation on soil and water loss and soil moisture in loess hilly area in northern Shanxi province. Journal of soil and water conservation, 26(2): 71-74,79.

Wang, X. Y., H. X. Bi, L. B. Gao, Y. F. Chang and H. S. Xu. 2014. Discrimination of factors influencing the runoffs of different spatial scales on loess region in western Shanxi. Journal of Northwest A&F University, 42(1): 159-166.

Wu, Q. X. and H. Y. Zhao. 2002. Soil and water conservation functions of Seabuckthorn and Its role in controlling and exploiting Loess Plateau. Hippophae, 15(1): 27-30.

Xu, J., P. L. Liu, R. F. Deng and D. Liu. 2012. Runoff and sediment reductions in the different stages of vegetation restoration on a loess slope. Scientia geographica sinica, 32(11): 1391-1396.

Yan, X. L.. 2012. Tests on effect of two kinds of grasses for soil and water conservation in gullied Loess Plateau. Yellow river, 34(4): 81-83.

Yu, X. X. and L. H. Chen. 1996. A study on water balance of protective forest ecosystem in loess area. Acta ecologia sinica, 16(3): 238-245.

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Zhang, J. T., J. J. Zhang and X. P. Guo. 1993. Study on the seabuckthorn's biomass and the effect of soil and water conservation in the west part of Shanxi province. Journal of beijing forestry university, 15(4): 14-20.

Zhang, Q. M. and W. T. Zhang. 1998. Research on the effect of fine pastures on soil and water conservation benefit in the loess hilly-gully area, west Shanxi province. Soil and water conversation science and technology in Shanxi, 4: 13-15.

Zhang, X. S., T. Z. Xue, C. Ma, G. X. Wei, Y. Q. Yan and Y. J. Hu. 2012. Impact of rainfall intensity and grass coverage on runoff and sediment yield on typical sloping land. Journal of arid land resources and environment, 26(6): 66-70.

Zhao, H. B., G. B. Liu, Q Y Cao and R. J. Wu. 2006. Influence of different land use types on soil erosion and nutrition care effect in loess hilly region. Journal of soil and water conservation, 20(1): 20-24+54.

Zhou, Y., T. X. Wei, J. Q. Xie, X. Shi, G. B. T. Ge, Z. Dong and Z. Q. Cheng. 2011. Different types of vegetation cover and water conservation benefits. Journal of soil and water conservation, 25(3): 12-16,21.

Appendix 2. Data source and datasets for meta-analysis

Table 5. Data source included in our meta-analysis (details about references can be founded in Appendix 1).

Number	Reference	Publication year	Longitude (°)	Latitude (°)	MAT (°C)	MAP (mm)	Land use type(s)	Case time frame(s)	Study length (year)	Number of plots	Area (m^2)	Slope length (mm)	Slope steepness (°)
1	Luo, W. X., et al.	1990	108.14	34.58	10.8	601.1	2	Event	1	12	100	20	18
2	Hou, X. L., et al.	1990	108.77	36.92	8.8	549.1	5	Year	10	14	100	20	27
3	Zhang, J. T., et al	1993	110.61	36.24	10.0	579.0	3	Event	1	3	100	20	26.6, 28.5, 28.7
4	Yu, X. X., et al.	1996	110.93	36.04	10.0	579.0	4	Year	5	6	100	20	22, 24, 27, 28
5	Hou, X. L., et al.	1996	108.77	36.92	8.8	549.1	5	Year	8	18	100	20	27
6	Zhang, J. J., et al.	1996	110.93	36.04	10.0	579.0	3	Event	1	13	100	20	26, 28
7	Zhang, Q. M., et al.	1998	111.25	37.53	8.9	500.0	2	Event and Year	1	8	59	13.34	28
8	Chen,Y. M.,et al.	2000	108.77	36.92	8.8	579.0	4	Year	1	7	100	20	23, 27
9	Wu, Q. X., et al.	2002	110.12	36.05	9.7	574.0	2	Year	7	2	100	20	25, 27
10	Hu, M. J., et al.	2003	109.32	36.86	8.8	500.0	3	Event and Year	10	6	100	20	27, 23
11	Pan, C. Z.,et al.	2005	110.12	36.05	9.7	574.0	2	Event	1	3	100	20	
12	Shen, Z. Z., et al.	2006	110.04	36.61	9.9	572.0	3	Event	2	3	32	16	21
13	Zhao, H. B.,et al.	2006	109.32	36.86	8.8	500.0	5	Event	1	11	100	20	24
14	Li,M.,et al.	2006	107.62	35.70	10.0	500.0	4	Year	12	4	30. 5, 164, 187, 695		8, 22, 24, 27.5
15	Liu, X. F., et al.	2009	104.62	35.59	6.3	427.0	2	Year	1	7	140	20	13
16	Zhou, Y., et al.	2011	108.08	36.98	7.8	478.3	2	Year	2	5	100	20	12
17	Jiang, N.,et al.	2011	110.37	38.81	8.4	437.4	3	Event and Year	1	5	100	20	11, 12, 15, 17
18	Yan, X. L., et al.	2012	107.56	35.71	10.0	500.0	2	Event	2	3	100	20	5
19	Wang, Q. C., et al.	2012	113.79	40.18	6.9	425.0	5	Year	5	6	100	20	8
20	Xu, J., et al.	2012	109.46	36.43	9.9	572.0	4	Event and Year	5	4	32	16	21

21	Zhang, X. S., et al.	2012	104.88	35.93	6. 4	373.8	1	Event	1	1	60	12	22
22	Ai, N., et al.	2013	108.10	36.98	7.8	478.3	2	Event and Year	4	5	100	20	12, 17, 28, 29
23	Lv, Y.Z., et al.	2015	105.72	34.71	11.0	533.7	2	Event and Year	2	4	100	20	23, 24, 25
24	Wang, X. Y., et al.	2014	110.73	36.27	10.3	575.9	3	Event	11	7	100	20	16, 20, 22, 23, 29, 30
25	Zhou, J., et al.	2016	109.52	36.70	9.9	535.0	3	Event	5	18	30	10	
26	Zhu, T. X.	2016	111.05	37.33	8.9	479.0	4	Event	12	4	100, 200, 399	20, 23	30, 31, 37
27	Yi, C. Q. and J. Fan	2016	110.52	38.83	8.4	437.4	1	Event	4	3	60	12	15
28	Zheng, M. and X. Chen	2015	109.97	37.68	10.7	440.0	1	Event	9	5	300	20	22
29	Zhang, L., et al.	2015	112.84	39.62	9.6	426.7	4	Event and Year	1	8	100, 161.8, 206.83	20, 40, 54	4, 38
30	Jian, S. Q., et al.	2015	104.65	35.58	6.3	420.0	2	Year	5	12	100	10	15
31	Feng, Q., et al.	2015	109.32	36.86	8.8	539.0	3	Event and Year	4	9	40	10	23
32	Ma, L., et al.	2014	110.10	35.65	9.7	574.0	2	Year	13	6	100	20	23
33	Hou, J., et al.	2014	109.52	36.70	9.9	531.0	1	Year	2	3	10	5	23, 24, 25
34	Jiang, N., et al.	2013	110.37	38.81	8.4	437.4	4	Event and Year	1	5	100	20	11, 12, 15, 17
35	Guo, Z. and M. Shao	2013	106.47	36.02	7.0	416.0	1	Year	2	5	100	20	7, 7.7, 7.8, 7.9, 8.5
36	Gao, G. Y., et al.	2012	109.52	36.70	9.8	535.0	3	Event and Year	4	9	18	9	19
37	Wang, L., et al.	2011	109.46	36.50	9.8	537.0	1	Year	2	12	400	20	23
38	Wang, X. Y., et al.	2008	113.20	37.75	7.3	518.3	1	Year	5	6	100	20	2.9
39	Fu, B. J., et al.	2004	110.97	36.68	8.8	473.9	4	Event	2	17	100	20	10, 15, 20, 24, 25, 30
40	Zheng, F. L.	2006	108.58	35.33	8.0	560.0	2	Event and Year	1	8	243.8, 253.5,	38.2, 41	39

											406.5		
41	Huang, Z. L., et al.	2006	104.64	35.55	6.3	420.0	5	Year	14	15	50, 100	10	23
42	Zhang, K., et al.	2004	109.27	36.93	8.8	541.0	2	Year	5	6	100	20	5, 10, 15, 20, 25, 28
	Zhang, K., et al.	2004	110.30	39.20	9.1	400.0	2	Year	3	1	100	20	6
	Zhang, K., et al.	2004	111.15	37.55	8.9	506.0	2	Year	8	6	100	20	5, 10, 15, 20, 25, 30
	Zhang, K., et al.	2004	109.78	37.52	9.2	420.0	2	Year	9	4	100	20	22, 31
43	Kang, S. Z., et al.	2001	107.68	35.23	9.1	541.9	7	Event and Year	3	12	27, 100, 250	9, 20, 50	0.5, 1, 3, 30, 32, 36

Note: MAT: mean annual temperature. MAP: mean annual precipitation.

Table 6. Event runoff (lnRR) and ratio of plot characteristics between ERT and LDT for meta-analysis.

ERT	LDT	lnRR	VlnRR	Ratio of area	Ratio of slope length	Ratio of slope steepness
Artificial grassland	Cropland	-0.738636	0.1197305	1	1	1
Natural grassland	Cropland	-1.204353	0.1210358	1	1	1
Shrubland	Cropland	-0.70876	0.200023	1	1	1
Shrubland	Cropland	-0.811576	0.2218719	1	1	1
Forest	Cropland	-0.263294	0.1948783	1	1	1
Shrubland	Cropland	-1.976622	0.2788845	1	1	1
Shrubland	Bareland	-0.104221	0.0742817	1	1	1
Shrubland	Bareland	-0.207037	0.0961305	1	1	1
Forest	Bareland	0.3412446	0.069137	1	1	1
Shrubland	Bareland	-1.372083	0.1531431	1	1	1
Shrubland	Cropland	-0.507343	0.2981979	1	1	2.4
Shrubland	Cropland	-0.610159	0.3200467	1	1	2.4
Forest	Cropland	-0.061877	0.2930532	1	1	2.4
Shrubland	Cropland	-1.775205	0.3770593	1	1	2.4
Shrubland	Cropland	-0.745975	0.2523903	1	1	1.6
Shrubland	Cropland	-0.848792	0.2742392	1	1	1.6
Forest	Cropland	-0.30051	0.2472456	1	1	1.6
Shrubland	Cropland	-2.013837	0.3312517	1	1	1.6
Shrubland	Cropland	-0.724858	0.2706714	1	1	1.2
Shrubland	Cropland	-0.827675	0.2925202	1	1	1.2
Forest	Cropland	-0.279393	0.2655267	1	1	1.2
Shrubland	Cropland	-1.992721	0.3495328	1	1	1.2
Shrubland	Cropland	-0.664107	0.3637007	1	1	0.96
Shrubland	Cropland	-0.766923	0.3855495	1	1	0.96
Forest	Cropland	-0.218641	0.358556	1	1	0.96
Shrubland	Cropland	-1.931969	0.4425621	1	1	0.96
Shrubland	Cropland	-0.220473	0.3901691	1	1	0.8
Shrubland	Cropland	-0.323289	0.412018	1	1	0.8
Forest	Cropland	0.224993	0.3850244	1	1	0.8
Shrubland	Cropland	-1.488335	0.4690306	1	1	0.8
Shrubland	Abandoned land	1.907595	0.469395	1	1	1.17
Shrubland	Abandoned land	1.5099182	0.5013298	1	1	1
Shrubland	Abandoned land	-1.968115	0.1793395	1	1	1
Natural grassland	Abandoned land	-0.678528	0.2995557	1	1	1
Artificial grassland	Abandoned land	-0.818321	0.1968642	1	1	1
Forest	Abandoned land	-0.052836	0.1504617	1	1	1
Shrubland	Abandoned land	-0.358751	0.1374865	1	1	1
Forest	Abandoned land	0.0778106	0.1846949	1	1	1
Shrubland	Abandoned land	-0.738224	0.1852974	1	1	1
Forest	Abandoned land	0.5865544	0.1972324	1	1	1

Forest	Abandoned land	-0.693199	0.2500938	1	1	1
Shrubland	Cropland	-3.68249	0.4519361	1	1	1
Natural grassland	Cropland	-2.392904	0.5721523	1	1	1
Artificial grassland	Cropland	-2.532697	0.4694607	1	1	1
Forest	Cropland	-1.767212	0.4230582	1	1	1
Shrubland	Cropland	-2.073127	0.410083	1	1	1
Forest	Cropland	-1.636565	0.4572914	1	1	1
Shrubland	Cropland	-2.452599	0.4578939	1	1	1
Forest	Cropland	-1.127821	0.4698289	1	1	1
Forest	Cropland	-2.407575	0.5226904	1	1	1
Forest	Abandoned land	-0.241758	0.1320939	0.56	0.56	0.9
Shrubland	Abandoned land	0.1634898	0.1173833	0.56	0.56	0.9
Natural grassland	Abandoned land	0.1556922	0.1091718	0.56	0.56	0.9
Forest	Cropland	-1.066885	0.134514	0.56	0.56	0.9
Shrubland	Cropland	-0.661637	0.1198034	0.56	0.56	0.9
Natural grassland	Cropland	-0.669434	0.1115919	0.56	0.56	0.9
Forest	Bareland	-0.780803	0.1274506	0.56	0.56	0.9
Shrubland	Bareland	-0.375554	0.1127399	0.56	0.56	0.9
Natural grassland	Bareland	-0.383352	0.1045285	0.56	0.56	0.9
Forest	Abandoned land	-0.351365	0.2071701	0.56	0.56	
Shrubland	Abandoned land	0.053883	0.1924595	0.56	0.56	
Natural grassland	Abandoned land	0.0460854	0.184248	0.56	0.56	
Forest	Abandoned land	-4.093317	0.083449	0.94	0.63	
Shrubland	Abandoned land	-3.587767	0.083073	0.94	0.63	
Natural grassland	Abandoned land	-3.058074	0.0868869	0.94	0.63	
Natural grassland	Abandoned land	-2.766294	0.1007778	0.94	0.63	
Natural grassland	Abandoned land	-2.556572	0.1204393	0.94	0.63	
Natural grassland	Abandoned land	-2.722808	0.0989565	0.94	0.63	
Forest	Bareland	-4.632361	0.0788056	0.94	0.63	
Shrubland	Bareland	-4.126811	0.0784296	0.94	0.63	
Natural grassland	Bareland	-3.597118	0.0822436	0.94	0.63	
Natural grassland	Bareland	-3.305338	0.0961344	0.94	0.63	
Natural grassland	Bareland	-3.095616	0.115796	0.94	0.63	
Natural grassland	Bareland	-3.261852	0.0943131	0.94	0.63	
Forest	Cropland	-4.918443	0.085869	0.94	0.63	
Shrubland	Cropland	-4.412893	0.0854931	0.94	0.63	
Natural grassland	Cropland	-3.883201	0.089307	0.94	0.63	
Natural grassland	Cropland	-3.59142	0.1031978	0.94	0.63	
Natural grassland	Cropland	-3.381698	0.1228594	0.94	0.63	
Natural grassland	Cropland	-3.547934	0.1013766	0.94	0.63	
Forest	Abandoned land	-4.202924	0.1585252	0.94	0.63	
Shrubland	Abandoned land	-3.697374	0.1581492	0.94	0.63	
Natural grassland	Abandoned land	-3.167681	0.1619631	0.94	0.63	
Natural grassland	Abandoned land	-2.8759	0.175854	0.94	0.63	

Natural grassland	Abandoned land	-2.666179	0.1955156	0.94	0.63	
Natural grassland	Abandoned land	-2.832415	0.1740327	0.94	0.63	
Shrubland	Abandoned land	-0.676553	0.0920319	1	1	1
Shrubland	Bareland	-1.215597	0.0873885	1	1	1
Shrubland	Cropland	-1.285368	0.1641295	1	1	1
Forest	Cropland	-2.352482	0.080316	1	1	1
Shrubland	Abandoned land	-0.569849	0.2367856	1	1	1
Forest	Abandoned land	-1.636963	0.1529721	1	1	1
Forest	Cropland	1.3913983	0.9495158	1	1	60
Forest	Cropland	1.9928003	0.9539391	1	1	64
Shrubland	Cropland	0.5444034	0.9639288	0.18	0.45	72
Natural grassland	Cropland	1.5613054	0.7267734	0.18	0.45	72
Forest	Bareland	-0.324227	0.5553121	1	1	30
Forest	Bareland	0.2771752	0.5597354	1	1	32
Shrubland	Bareland	-1.171222	0.5697251	0.18	0.45	36
Natural grassland	Bareland	-0.15432	0.3325697	0.18	0.45	36
Forest	Bareland	-0.630332	0.4893193	1	1	10
Forest	Bareland	-0.02893	0.4937426	1	1	10.67
Shrubland	Bareland	-1.477327	0.5037323	0.18	0.45	12
Natural grassland	Bareland	-0.460425	0.2665769	0.18	0.45	12
Forest	Bareland	-0.348936	0.5287184	1	1	60
Forest	Bareland	0.2524661	0.5331417	1	1	64
Shrubland	Bareland	-1.195931	0.5431315	0.18	0.45	72
Natural grassland	Bareland	-0.179029	0.305976	0.18	0.45	72
Forest	Cropland	0.7269667	0.9647656	1	1	1.09
Forest	Cropland	0.0774408	0.967794	1	1	0.86
Forest	Cropland	0.5063859	0.9664828	1	1	1.13
Forest	Cropland	0.3907228	0.97455	1	1	0.6
Forest	Cropland	0.9450145	0.96633	1	1	0.83
Shrubland	Cropland	-0.479832	0.9736005	1	1	0.75
Natural grassland	Cropland	1.3770713	0.9732783	1	1	0.83
Natural grassland	Cropland	0.6973305	1.0765146	1	1	
Forest	Cropland	0.0565513	1.0560205	1	1	
Forest	Cropland	-0.186905	1.0561837	1	1	
Forest	Cropland	-0.687068	1.133319	1	1	
Shrubland	Cropland	-0.439971	1.067138	1	1	
Shrubland	Cropland	-0.397494	1.0681651	1	1	
Natural grassland	Cropland	0.2736744	1.6565007	1	1	1.07
Shrubland	Cropland	-1.67805	1.9547895	1	1	1.08
Artificial grassland	Bareland	-0.846102	0.1164515	1	1	1
Artificial grassland	Bareland	-0.579562	0.1740925	1	1	1
Forest	Bareland	-0.495125	0.7944386	1	1	1
Artificial grassland	Bareland	-2.265232	0.9392279	1	1	1
Forest	Bareland	-1.736227	0.8407046	1.62	2	9.75

Artificial grassland	Bareland	-1.062254	0.8477191	2.07	2.7	9.75
Forest	Bareland	-0.949913	0.9317708	2.07	2.7	9.75
Forest	Bareland	-0.714355	0.6952504	1	1	1
Artificial grassland	Bareland	-2.484462	0.8400396	1	1	1
Forest	Bareland	-1.955457	0.7415163	1.62	2	9.75
Artificial grassland	Bareland	-1.281484	0.7485308	2.07	2.7	9.75
Forest	Bareland	-1.169143	0.8325825	2.07	2.7	9.75
Forest	Bareland	0.2861498	0.9035884	0.48	0.37	0.1
Artificial grassland	Bareland	-1.483958	1.0483777	0.48	0.37	0.1
Forest	Bareland	-0.954952	0.9498544	0.78	0.74	1
Artificial grassland	Bareland	-0.280979	0.9568688	1	1	1
Forest	Bareland	-0.168638	1.0409205	1	1	1
Forest	Bareland	0.2861498	0.9035884	0.48	0.37	0.1
Shrubland	Cropland	-0.843974	0.2337925	1	1	0.71
Artificial grassland	Cropland	-0.625658	0.2790812	1	1	0.71
Shrubland	Cropland	-0.772791	0.246391	1	1	0.8
Artificial grassland	Cropland	-0.554475	0.2916797	1	1	0.8
Shrubland	Abandoned land	-0.385211	0.2923681	1	1	1.09
Artificial grassland	Abandoned land	-0.166895	0.3376568	1	1	1.09
Shrubland	Abandoned land	-0.570545	6.91E-06	1	1	
Natural grassland	Abandoned land	0.0529224	3.44E-06	1	1	
Shrubland	Cropland	-0.624939	6.56E-06	1	1	
Natural grassland	Cropland	-0.001472	1.43E-07	1	1	
Shrubland	Cropland	-0.559616	1.32E-07	1	1	
Natural grassland	Cropland	0.0638515	2.54E-06	1	1	
Forest	Abandoned land	-8.699515	0.1522264	1	1	
Forest	Abandoned land	-2.090166	4.03E-07	1	1	

Note: ERT: ecological restoration types; LDT: land degradation types

Table 7. Annual runoff (lnRR) ratio of plot characteristics between ERT and LDT for meta-analysis.

ERT	LDT	lnRR	VlnRR	Ratio of area	Ratio of slope length	Ratio of slope steepness
Artificial grassland	Bareland	-0.680299	5.74E-09	1	1	1
Artificial grassland	Bareland	-0.975099	7.70E-09	1	1	1
Artificial grassland	Bareland	-0.802346	3.85E-09	1	1	1
Artificial grassland	Bareland	-0.924949	4.25E-09	1	1	1
Artificial grassland	Bareland	-0.497977	4.71E-09	1	1	1
Artificial grassland	Bareland	-0.946928	5.78E-08	1	1	1
Artificial grassland	Bareland	-0.384142	9.96E-09	1	1	1
Artificial grassland	Cropland	-0.735111	9.65E-09	1	1	1
Natural grassland	Cropland	-1.207022	5.34E-08	1	1	1
Forest	Abandoned land	2.5588236	4.68E-05	1.8	1.8	0.76
Natural grassland	Abandoned land	3.2245381	1.29E-05	1.8	1.8	0.76
Shrubland	Abandoned land	3.3435626	1.32E-05	1.8	1.8	0.76
Forest	Abandoned land	1.9878447	1.33E-07	1.8	1.8	0.79
Natural grassland	Abandoned land	2.6535592	1.35E-07	1.8	1.8	0.79
Shrubland	Abandoned land	2.7725837	3.02E-06	1.8	1.8	0.79
Forest	Abandoned land	1.8409836	1.23E-06	1.8	1.8	0.83
Natural grassland	Abandoned land	2.5066982	5.44E-06	1.8	1.8	0.83
Shrubland	Abandoned land	2.6257226	4.35E-07	1.8	1.8	0.83
Forest	Abandoned land	1.185108	1.24E-07	1.8	1.8	0.76
Natural grassland	Abandoned land	1.8508226	1.90E-06	1.8	1.8	0.76
Shrubland	Abandoned land	1.969847	3.13E-06	1.8	1.8	0.76
Artificial grassland	Cropland	-0.136475	1.91E-08	1	1	1
Forest	Cropland	-0.587786	4.48E-09	1	1	1
Natural grassland	Cropland	-1.086343	1.53E-07	1	1	1
Shrubland	Cropland	-0.246037	3.02E-08	1	1	1
Forest	Cropland	-0.012589	1.56E-08	2	1	0.65
Forest	Cropland	-0.299882	2.10E-08	2	1	0.65
Shrubland	Cropland	-0.443462	4.01E-08	2	1	0.65
Shrubland	Cropland	-0.184002	1.67E-08	2	1	0.65
Artificial grassland	Abandoned land	0.0682083	3.78E-07	1	1	1.13
Shrubland	Abandoned land	-0.77909	2.32E-07	1	1	0.8
Artificial grassland	Cropland	0.6292957	3.26E-07	1	1	1.42
Shrubland	Cropland	-0.218002	6.45E-07	1	1	1
Artificial grassland	Cropland	0.4590746	3.46E-07	1	1	1.55
Shrubland	Cropland	-0.388223	8.35E-07	1	1	1.09
Forest	Abandoned land	1.0162546	2.22E-06	1	1	60
Forest	Abandoned land	1.6176566	8.65E-06	1	1	64
Natural grassland	Abandoned land	0.7810253	1.55E-05	0.27	0.45	72
Shrubland	Abandoned land	0.1692597	9.54E-07	0.27	0.45	72
Forest	Bareland	0.6601898	2.31E-06	1	1	60

Forest	Bareland	1.2615919	3.83E-06	1	1	64
Natural grassland	Bareland	0.4249605	5.08E-06	0.27	0.45	72
Shrubland	Bareland	-0.186805	9.63E-06	0.27	0.45	72
Forest	Bareland	3.149883	0.0002917	0.4	0.4	60
Forest	Bareland	3.751285	0.0003882	0.4	0.4	64
Natural grassland	Bareland	2.9146537	0.0008823	0.11	0.18	72
Shrubland	Bareland	2.3028881	2.81E-05	0.11	0.18	72
Forest	Bareland	-0.54737	1.21E-07	1	1	30
Forest	Bareland	0.0540316	2.68E-09	1	1	32
Natural grassland	Bareland	-0.7826	2.67E-06	0.27	0.45	36
Shrubland	Bareland	-1.394365	8.71E-07	0.27	0.45	36
Forest	Bareland	-0.853475	4.23E-07	1	1	10
Forest	Bareland	-0.252073	1.17E-07	1	1	10.67
Natural grassland	Bareland	-1.088705	2.51E-07	0.27	0.45	12
Shrubland	Bareland	-1.70047	2.64E-06	0.27	0.45	12
Forest	Bareland	-0.57208	7.54E-07	1	1	60
Forest	Bareland	0.0293225	2.01E-07	1	1	64
Natural grassland	Bareland	-0.807309	1.89E-06	0.27	0.45	72
Shrubland	Bareland	-1.419074	9.59E-07	0.27	0.45	72
Forest	Cropland	1.8269157	1.35E-05	1	1	30
Forest	Cropland	2.4283178	6.40E-06	1	1	32
Natural grassland	Cropland	1.5916864	4.85E-06	0.27	0.45	36
Shrubland	Cropland	0.9799209	1.32E-05	0.27	0.45	36
Forest	Cropland	1.3667464	2.86E-06	1	1	10
Forest	Cropland	1.9681485	4.36E-07	1	1	10.67
Natural grassland	Cropland	1.1315171	1.52E-05	0.27	0.45	12
Shrubland	Cropland	0.5197515	4.51E-06	0.27	0.45	12
Forest	Cropland	1.8196781	5.55E-05	1	1	
Forest	Cropland	2.4210801	3.71E-06	1	1	
Natural grassland	Cropland	1.5844488	3.29E-05	0.27	0.45	
Shrubland	Cropland	0.9726832	3.57E-05	0.27	0.45	
Forest	Cropland	1.1682547	1.72E-06	1	1	60
Forest	Cropland	1.7696568	1.57E-05	1	1	64
Natural grassland	Cropland	0.9330254	5.66E-06	0.27	0.45	72
Shrubland	Cropland	0.3212598	6.97E-06	0.27	0.45	72
Forest	Cropland	-2.736076	0.0460995	1	1	1
Forest	Cropland	-1.869043	0.0815114	1	1	1
Shrubland	Bareland	-0.104221	0.0471129	1	1	1
Shrubland	Bareland	-0.207037	0.1002999	1	1	1
Shrubland	Bareland	-1.372083	0.4811442	1	1	1
Shrubland	Cropland	-0.70876	0.4811151	1	1	1
Shrubland	Cropland	-0.811576	0.5343022	1	1	1
Shrubland	Cropland	-1.976622	0.9151464	1	1	1
Shrubland	Cropland	-0.507343	0.3167629	1	1	2.4

Shrubland	Cropland	-0.610159	0.3699499	1	1	2.4
Shrubland	Cropland	-1.775205	0.7507941	1	1	2.4
Shrubland	Cropland	-0.745975	0.5760022	1	1	1.6
Shrubland	Cropland	-0.848792	0.6291892	1	1	1.6
Shrubland	Cropland	-2.013837	1.0100334	1	1	1.6
Shrubland	Cropland	-0.724858	0.5570448	1	1	1.2
Shrubland	Cropland	-0.827675	0.6102319	1	1	1.2
Shrubland	Cropland	-1.992721	0.9910761	1	1	1.2
Shrubland	Cropland	-0.664107	0.5938705	1	1	0.96
Shrubland	Cropland	-0.766923	0.6470576	1	1	0.96
Shrubland	Cropland	-1.931969	1.0279018	1	1	0.96
Shrubland	Cropland	-0.220473	0.3180229	1	1	0.8
Shrubland	Cropland	-0.323289	0.37121	1	1	0.8
Shrubland	Cropland	-1.488335	0.7520542	1	1	0.8
Forest	Abandoned land	1.6899575	0.0967994	40	4	1.36
Forest	Abandoned land	-0.334424	0.0968857	40	4	1
Forest	Abandoned land	-5.884873	4.5418206	40	4	0.84
Forest	Abandoned land	-4.710753	0.1401103	40	4	0.92
Forest	Abandoned land	-5.709024	0.919013	40	4	1.42
Forest	Abandoned land	-7.112894	0.0749613	40	4	1.04
Forest	Abandoned land	-5.569414	0.7346276	40	4	0.88
Forest	Abandoned land	-5.57397	0.9670767	40	4	0.96
Forest	Abandoned land	-5.593789	0.0247343	40	4	1.48
Forest	Abandoned land	-5.720831	0.0258228	40	4	1.09
Forest	Abandoned land	-6.675125	6.5782964	40	4	0.91
Forest	Abandoned land	-5.335351	0.1199661	40	4	1
Forest	Abandoned land	-6.133372	0.2876035	40	4	1.36
Forest	Abandoned land	-6.189829	0.8032135	40	4	1
Forest	Abandoned land	-6.552655	0.181648	40	4	0.84
Forest	Abandoned land	-5.992262	0.0716021	40	4	0.92
Artificial grassland	Bareland	-2.256688	6.90E-07	1	1	1
Artificial grassland	Bareland	-1.068731	4.82E-08	2.07	2.7	9.5
Forest	Bareland	-0.498186	1.61E-08	1	1	1
Forest	Bareland	-1.776225	9.01E-08	1.62	2	9.5
Forest	Bareland	-0.960809	1.21E-08	2.07	2.7	9.5
Artificial grassland	Bareland	-2.471578	7.46E-08	1	1	1
Artificial grassland	Bareland	-1.283621	5.69E-09	2.07	2.7	9.5
Forest	Bareland	-0.713076	1.20E-08	1	1	1
Forest	Bareland	-1.991116	2.29E-07	1.62	2	9.5
Forest	Bareland	-1.1757	6.35E-08	2.07	2.7	9.5
Artificial grassland	Bareland	-1.471357	1.66E-07	0.48	0.37	0.11
Artificial grassland	Bareland	-0.283399	1.29E-08	1	1	1
Forest	Bareland	0.2871454	1.08E-08	0.48	0.37	0.11
Forest	Bareland	-0.990894	1.76E-08	0.78	0.74	1

Forest	Bareland	-0.175478	5.99E-08	1	1	1
Forest	Cropland	0.0621962	1.34E-05	1	1	1
Forest	Cropland	-0.227162	2.92E-06	1	1	1.17
Forest	Cropland	-0.282349	4.03E-05	1	1	1.17
Natural grassland	Cropland	0.3636028	9.17E-06	1	1	1
Shrubland	Cropland	0.329573	1.84E-05	1	1	1
Shrubland	Cropland	-1.072226	0.0002122	1	1	1.17
Artificial grassland	Cropland	-1.087885	1.59E-07	1	1	1
Artificial grassland	Cropland	-0.111859	7.12E-08	1	1	1
Forest	Cropland	-1.963763	0.0864447	1	1	1
Forest	Cropland	-0.673685	0.0864442	1	1	1
Natural grassland	Cropland	0.4223516	0.0864441	1	1	1
Shrubland	Cropland	-1.993575	0.0864456	1	1	1
Forest	Cropland	-1.674233	0.1223999	1	1	
Forest	Cropland	-1.102442	0.1223999	1	1	
Forest	Cropland	-0.820065	0.1224002	1	1	
Forest	Cropland	-6.648661	0.0285224	1	1	
Forest	Cropland	-6.977791	1.506993	1	1	
Forest	Cropland	-7.142907	0.4966	1	1	
Forest	Cropland	-6.678793	0.4222273	1	1	
Forest	Cropland	-6.703354	0.0353852	1	1	
Forest	Cropland	-6.63141	0.006179	1	1	
Natural grassland	Cropland	-6.749822	1.1140664	1	1	
Shrubland	Cropland	-6.88469	0.1292524	1	1	
Shrubland	Cropland	-8.072726	1.2654959	1	1	
Shrubland	Cropland	-7.056175	2.1360947	1	1	
Shrubland	Cropland	-6.80213	0.0882905	1	1	
Forest	Abandoned land	-8.690977	0.0171513	1	1	1
Forest	Abandoned land	-9.053804	0.097834	1	1	1
Shrubland	Abandoned land	-8.49341	0.0346451	1	1	1
Natural grassland	Cropland	-0.561087	4.35E-08	1	1	0.8
Shrubland	Cropland	-0.77909	7.43E-07	1	1	0.8
Natural grassland	Cropland	-0.629296	6.53E-08	1	1	0.71
Shrubland	Cropland	-0.847298	1.45E-06	1	1	0.71
Artificial grassland	Cropland	-1.310297	1.84E-07			
Forest	Cropland	-3.953117	1.25E-06			
Natural grassland	Cropland	-2.565288	6.58E-06			
Artificial grassland	Abandoned land	-0.314493	4.42E-07	1	1	1
Artificial grassland	Abandoned land	-0.847298	2.27E-06	1	1	1
Artificial grassland	Abandoned land	-0.965081	1.31E-06	1	1	1
Artificial grassland	Abandoned land	-0.405465	5.24E-07	1	1	1
Artificial grassland	Abandoned land	-0.904456	5.22E-07	1	1	1
Artificial grassland	Abandoned land	-1.225364	6.27E-06	1	1	1
Shrubland	Abandoned land	-0.676552	0.1784125	1	1	1

Shrubland	Bareland	-1.215596	0.0411253	1	1	1
Artificial grassland	Bareland	-0.129799	0.2752135	1	1	1
Forest	Bareland	-1.893636	0.2752136	1	1	1
Natural grassland	Bareland	0.4089494	0.2752134	1	1	1
Shrubland	Bareland	-2.105968	0.2752149	1	1	1
Shrubland	Bareland	-2.244119	0.2752145	1	1	1
Shrubland	Cropland	-2.044272	0.0801396	1	1	
Forest	Abandoned land	-2.018183	0.0510361	1	1	1
Shrubland	Abandoned land	-0.505447	0.0876701	1	1	1
Forest	Cropland	-2.498343	0.1079629	1	1	1
Shrubland	Cropland	-0.985607	0.0838981	1	1	1
Artificial grassland	Cropland	1.4387648	0.2229281			
Artificial grassland	Cropland	1.3029435	0.1806042			
Natural grassland	Cropland	1.1857613	0.1828801			
Forest	Bareland	-0.50481	0.0066904	1	1	0.81
Forest	Bareland	-0.83798	0.007383	1	1	1
Natural grassland	Bareland	-0.219722	0.0059779	1	1	1
Shrubland	Bareland	-0.873368	0.0221685	1	1	0.89
Shrubland	Bareland	-0.725751	0.0359013	1	1	1.04
Forest	Bareland	-1.283066	0.0054832			
Forest	Bareland	-1.526522	0.0054842			
Forest	Bareland	-2.026685	0.0054829			
Natural grassland	Bareland	-0.642287	0.0054844			
Shrubland	Bareland	-1.779588	0.0054832			
Shrubland	Bareland	-1.737111	0.0054877			

Note: ERT: ecological restoration types; LDT: land degradation types

Table 8. Event soil erosion rate (lnRR) ratio of plot characteristics between ERT and LDT for meta-analysis.

ERT	LDT	lnRR	VlnRR	Ratio of area	Ratio of slope length	Ratio of slope steepness
Artificial grassland	Cropland	-3.2153409	0.3101495	1	1	1
Natural grassland	Cropland	-3.5962433	0.52100589	1	1	1
Shrubland	Cropland	-4.8446014	0.63953667	1	1	1
Shrubland	Cropland	-5.3911451	0.7723778	1	1	1
Forest	Cropland	-1.6215239	0.77313976	1	1	1
Shrubland	Cropland	-11.010419	0.42477748	1	1	1
Shrubland	Bareland	-7.7160574	13949.9502	1	1	1
Shrubland	Bareland	-7.9451239	11770.0663	1	1	1
Forest	Bareland	-8.4770732	64266665.4	1	1	1
Shrubland	Bareland	-8.4548501	0.6715282	1	1	1
Shrubland	Cropland	-10.799052	591695.823	1	1	2.4
Shrubland	Cropland	-8.8410059	6289.85888	1	1	2.4
Forest	Cropland	-9.1234744	20850944.7	1	1	2.4
Shrubland	Cropland	-9.1234744	0.5948997	1	1	2.4
Shrubland	Cropland	-9.6382396	24670.0704	1	1	1.6
Shrubland	Cropland	-10.111389	33914.0539	1	1	1.6
Forest	Cropland	-9.2509728	11434071.1	1	1	1.6
Shrubland	Cropland	-9.3336849	0.62659388	1	1	1.6
Shrubland	Cropland	-9.667623	10226.2921	1	1	1.2
Shrubland	Cropland	-10.224434	16618.2815	1	1	1.2
Forest	Cropland	-1.0809876	1.02705812	1	1	1.2
Shrubland	Cropland	-11.54619	4.54387312	1	1	1.2
Shrubland	Cropland	-10.145654	22202.9646	1	1	0.96
Shrubland	Cropland	-11.697198	263809.424	1	1	0.96
Forest	Cropland	-9.8217968	11681882.6	1	1	0.96
Shrubland	Cropland	-10.542875	1.06147178	1	1	0.96
Shrubland	Cropland	-9.8068414	14438.7764	1	1	0.8
Shrubland	Cropland	-10.21498	17428.9157	1	1	0.8
Forest	Cropland	-11.083246	186463224	1	1	0.8
Shrubland	Cropland	-9.6945623	0.84760294	1	1	0.8
Shrubland	Abandoned land	-7.0854341	0.71235982	1	1	1
Natural grassland	Abandoned land	-5.811469	10203.7581	1	1	1
Artificial grassland	Abandoned land	-6.0829657	66192.3136	1	1	1
Forest	Abandoned land	-2.1517399	1.5911257	1	1	1
Shrubland	Abandoned land	-3.0680006	1.59103107	1	1	1
Forest	Abandoned land	-0.9279786	0.84372593	1	1	1
Shrubland	Abandoned land	-0.4653609	1.59113747	1	1	1
Forest	Abandoned land	0.6332514	0.8604502	1	1	1
Forest	Abandoned land	-5.2187734	0.72062712	1	1	1

Shrubland	Cropland	-9.2991232	0.94392225	1	1	1
Natural grassland	Cropland	-8.6626795	1967.77405	1	1	1
Artificial grassland	Cropland	-8.9918092	14322.021	1	1	1
Forest	Cropland	-9.1569254	782.543167	1	1	1
Shrubland	Cropland	-8.6928116	49.9738836	1	1	1
Forest	Cropland	-8.7173724	948.501589	1	1	1
Shrubland	Cropland	-8.6454289	8198.6468	1	1	1
Forest	Cropland	-8.7638409	25181.4542	1	1	1
Forest	Cropland	-8.8257404	0.53371799	1	1	1
Forest	Abandoned land	-8.3449513	57.69538	0.94	0.63	
Shrubland	Abandoned land	-9.3241235	291.370589	0.94	0.63	
Natural grassland	Abandoned land	-8.5198378	286.979844	0.94	0.63	
Natural grassland	Abandoned land	-9.6922163	439.361224	0.94	0.63	
Natural grassland	Abandoned land	-4.052251	0.35957775	0.94	0.63	
Natural grassland	Abandoned land	-3.9270902	0.34660916	0.94	0.63	
Forest	Bareland	-6.9728074	0.12028122	0.94	0.63	
Shrubland	Bareland	-6.8186584	0.11505675	0.94	0.63	
Natural grassland	Bareland	-6.3666737	0.12081173	0.94	0.63	
Natural grassland	Bareland	-7.0063745	0.11535632	0.94	0.63	
Natural grassland	Bareland	-6.9585797	0.12261143	0.94	0.63	
Natural grassland	Bareland	-6.8334189	0.10964285	0.94	0.63	
Forest	Cropland	-7.8878351	0.64063716	0.94	0.63	
Shrubland	Cropland	-7.733686	0.63541269	0.94	0.63	
Natural grassland	Cropland	-7.2817013	0.64116767	0.94	0.63	
Natural grassland	Cropland	-7.9214021	0.63571225	0.94	0.63	
Natural grassland	Cropland	-7.8736074	0.64296737	0.94	0.63	
Natural grassland	Cropland	-7.7484465	0.62999878	0.94	0.63	
Forest	Abandoned land	-2.4952181	0.18798327	0.94	0.63	
Shrubland	Abandoned land	-2.3410691	0.1827588	0.94	0.63	
Natural grassland	Abandoned land	-1.8890844	0.18851378	0.94	0.63	
Natural grassland	Abandoned land	-2.5287852	0.18305837	0.94	0.63	
Natural grassland	Abandoned land	-2.4809904	0.19031348	0.94	0.63	
Natural grassland	Abandoned land	-2.3558296	0.1773449	0.94	0.63	
Forest	Abandoned land	0.5110746	0.36411605	0.56	0.56	0.9
Shrubland	Abandoned land	0.8193191	0.35725412	0.56	0.56	0.9
Natural grassland	Abandoned land	0.9177266	0.35783284	0.56	0.56	0.9
Forest	Cropland	-3.3102818	0.64750567	0.56	0.56	0.9
Shrubland	Cropland	-3.0020372	0.64064374	0.56	0.56	0.9
Natural grassland	Cropland	-2.9036297	0.64122246	0.56	0.56	0.9
Forest	Abandoned land	2.0823351	0.19485179	0.56	0.56	0.9
Shrubland	Abandoned land	2.3905797	0.18798985	0.56	0.56	0.9
Natural grassland	Abandoned land	2.4889872	0.18856857	0.56	0.56	0.9
Forest	Bareland	-2.3952542	0.12714974	0.56	0.56	0.9
Shrubland	Bareland	-2.0870096	0.1202878	0.56	0.56	0.9

Natural grassland	Bareland	-1.9886021	0.12086652	0.56	0.56	0.9
Shrubland	Abandoned land	-0.8607975	0.50366105	1	1	1
Shrubland	Bareland	-3.7671263	0.26669474	1	1	1
Shrubland	Cropland	-4.9507842	1.01736962	1	1	1
Forest	Cropland	-5.6439314	0.75886485	1	1	1
Shrubland	Abandoned land	0.4418328	0.56471573	1	1	1
Forest	Abandoned land	-0.2513144	0.30621097	1	1	1
Forest	Cropland	-4.0699828	5.06E-09	0.2		1.55
Artificial grassland	Cropland	-1.245086	1.12E-10	0.1		1.5
Natural grassland	Cropland	-2.0301231	1.05E-09	0.39		1.85
Artificial grassland	Bareland	-2.5356292	0.3281973	1	1	1
Artificial grassland	Bareland	-2.0645269	0.34530288	1	1	1
Forest	Bareland	-0.3173913	1.04670441	1	1	1
Artificial grassland	Bareland	-1.3005193	0.81141653	1	1	1
Forest	Bareland	1.3425324	0.78410338	1.62	2	9.75
Artificial grassland	Bareland	2.643052	1.22034425	2.07	2.7	9.75
Forest	Bareland	2.489665	1.04233881	2.07	2.7	9.75
Forest	Bareland	-0.6434919	0.92395175	1	1	1
Artificial grassland	Bareland	-1.6266199	0.68866387	1	1	1
Forest	Bareland	1.0164319	0.66135071	1.62	2	9.75
Artificial grassland	Bareland	2.3169515	1.09759158	2.07	2.7	9.75
Forest	Bareland	2.1635645	0.91958614	2.07	2.7	9.75
Forest	Bareland	-3.0368525	1.29061774	0.48	0.37	0.1
Artificial grassland	Bareland	-4.0199805	1.05532986	0.48	0.37	0.1
Forest	Bareland	-1.3769288	1.0280167	0.78	0.74	1
Artificial grassland	Bareland	-0.0764092	1.46425757	1	1	1
Forest	Bareland	-0.2297962	1.28625213	1	1	1
Forest	Bareland	-3.0368525	1.29061774	0.48	0.37	0.1
Shrubland	Abandoned land	-1.1437327	4.11E-08	1	1	
Natural grassland	Abandoned land	0.0683799	6.18E-09	1	1	
Shrubland	Cropland	-7.3891634	1.36E-08	1	1	
Natural grassland	Cropland	-6.1770507	5.10E-09	1	1	
Shrubland	Cropland	-2.8024859	9.99E-09	1	1	
Natural grassland	Cropland	-1.5903732	7.23E-09	1	1	

Note: ERT: ecological restoration types; LDT: land degradation types

Table 9. Annual soil erosion rate (lnRR) ratio of plot characteristics between ERT and LDT for meta-analysis.

ERT	LDT	lnRR	VlnRR	Ratio of area	Ratio of slope length	Ratio of slope steepness
Artificial grassland	Bareland	-0.56132	7.83E-14	1	1	1
Artificial grassland	Bareland	-3.483967	1.25E-11	1	1	1
Artificial grassland	Bareland	-0.351479	1.41E-13	1	1	1
Artificial grassland	Bareland	-0.314616	1.95E-14	1	1	1
Artificial grassland	Bareland	-0.324167	9.10E-14	1	1	1
Artificial grassland	Bareland	-2.344414	1.20E-11	1	1	1
Artificial grassland	Bareland	-1.574848	1.00E-13	1	1	1
Artificial grassland	Cropland	-3.215909	5.43E-10	1	1	1
Natural grassland	Cropland	-2.596825	3.69E-10	1	1	1
Forest	Abandoned land	0.7595254	1.12E-09	1.8	1.8	0.76
Natural grassland	Abandoned land	1.2087262	1.06E-09	1.8	1.8	0.76
Shrubland	Abandoned land	1.1903665	2.69E-12	1.8	1.8	0.76
Forest	Abandoned land	1.5489517	1.69E-09	1.8	1.8	0.79
Natural grassland	Abandoned land	1.9981525	3.96E-10	1.8	1.8	0.79
Shrubland	Abandoned land	1.9797928	8.82E-10	1.8	1.8	0.79
Forest	Abandoned land	1.8950444	3.89E-11	1.8	1.8	0.83
Natural grassland	Abandoned land	2.3442451	1.14E-08	1.8	1.8	0.83
Shrubland	Abandoned land	2.3258854	2.85E-10	1.8	1.8	0.83
Forest	Abandoned land	2.4033663	1.12E-08	1.8	1.8	0.76
Natural grassland	Abandoned land	2.8525671	0.037812	1.8	1.8	0.76
Shrubland	Abandoned land	2.8342074	0.037812	1.8	1.8	0.76
Artificial grassland	Cropland	-0.865199	0.0665285	1	1	1
Forest	Cropland	-2.591463	0.0665285	1	1	1
Natural grassland	Cropland	-2.974455	0.0665285	1	1	1
Shrubland	Cropland	-1.453752	0.0665285	1	1	1
Forest	Cropland	-1.930974	0.1726457	1	1	1
Forest	Cropland	-1.94045	0.1726457	1	1	1
Shrubland	Bareland	-2.149311	0.9277359	1	1	1
Shrubland	Bareland	-2.695855	0.9277369	1	1	1
Shrubland	Bareland	-4.577782	0.9277935	1	1	1
Shrubland	Cropland	-7.476017	0.980223	1	1	1
Shrubland	Cropland	-7.258368	0.9802231	1	1	1
Shrubland	Cropland	-8.28208	0.9806724	1	1	1
Shrubland	Cropland	-6.665714	0.6925706	1	1	2.4
Shrubland	Cropland	-5.874509	0.6925336	1	1	2.4
Shrubland	Cropland	-6.110201	0.692627	1	1	2.4
Shrubland	Cropland	-8.242234	0.8686787	1	1	1.6
Shrubland	Cropland	-8.151131	0.8686548	1	1	1.6
Shrubland	Cropland	-7.196772	0.8686442	1	1	1.6

Shrubland	Cropland	-6.642609	0.9357582	1	1	1.2
Shrubland	Cropland	-6.7139	0.93576	1	1	1.2
Shrubland	Cropland	-7.649717	0.935835	1	1	1.2
Shrubland	Cropland	-7.409081	0.9538069	1	1	0.96
Shrubland	Cropland	-6.897239	0.9537997	1	1	0.96
Shrubland	Cropland	-7.84943	0.9537989	1	1	0.96
Shrubland	Cropland	-7.200605	0.8686879	1	1	0.8
Shrubland	Cropland	-6.547185	0.8686654	1	1	0.8
Shrubland	Cropland	-7.081528	0.8687784	1	1	0.8
Artificial grassland	Bareland	-8.590929	0.0001489	1	1	1
Artificial grassland	Bareland	-7.570384	1.56E-05	2.07	2.7	9.5
Forest	Bareland	-7.969248	2.00E-07	1	1	1
Forest	Bareland	-8.687949	2.20E-06	1.62	2	9.5
Forest	Bareland	-7.927541	7.39E-05	2.07	2.7	9.5
Artificial grassland	Bareland	-8.005592	3.42E-05	1	1	1
Artificial grassland	Bareland	-8.596713	6.20E-06	2.07	2.7	9.5
Forest	Bareland	-10.00681	0.0022607	1	1	1
Forest	Bareland	-7.946349	2.21E-05	1.62	2	9.5
Forest	Bareland	-8.015412	0.0001209	2.07	2.7	9.5
Artificial grassland	Bareland	-10.77242	0.0002582	0.48	0.37	0.11
Artificial grassland	Bareland	-11.64608	0.0005278	1	1	1
Forest	Bareland	-10.44653	5.73E-05	0.48	0.37	0.11
Forest	Bareland	-10.51059	5.79E-05	0.78	0.74	1
Forest	Bareland	-10.82023	0.000103	1	1	1
Forest	Abandoned land	-10.62486	0.0001471	0.87	0.87	1
Forest	Abandoned land	-10.0478	0.00035	0.36	0.41	2.17
Forest	Abandoned land	-10.22059	5.38E-06	1.23	1.37	1.28
Forest	Abandoned land	-9.464552	8.83E-06	1.03	1.08	1
Forest	Abandoned land	-9.898716	0.0001375	0.42	0.51	2.17
Forest	Abandoned land	-9.387918	3.61E-06	1.46	1.7	1.28
Forest	Abandoned land	-10.42442	0.0001439	4.08	2.1	0.46
Forest	Abandoned land	-10.51304	4.07E-05	1.67	1	1
Forest	Abandoned land	-10.2465	5.14E-05	5.78	3.32	0.59
Forest	Abandoned land	-11.32265	5.08E-05	3.93	2.26	0.46
Forest	Abandoned land	-10.21757	1.12E-06	1.6	1.07	1
Forest	Abandoned land	-10.06867	0.0001186	5.56	3.57	0.59
Forest	Abandoned land	-11.97829	0.007085	0.6	0.61	0.78
Forest	Abandoned land	-11.25112	0.0015054	0.24	0.29	1.7
Forest	Abandoned land	-11.01226	0.0013002	0.85	0.96	1
Forest	Cropland	-7.686742	2.55E-05	1	1	1
Forest	Cropland	-7.112123	1.40E-05	1	1	1.17
Forest	Cropland	-7.80199	0.0001536	1	1	1.17
Natural grassland	Cropland	-8.244545	0.0004044	1	1	1
Shrubland	Cropland	-7.415381	2.44E-06	1	1	1

Shrubland	Cropland	-7.37112	6.39E-05	1	1	1.17
Artificial grassland	Cropland	-8.660424	3.90E-11	1	1	1
Artificial grassland	Cropland	-8.787113	7.87E-05	1	1	1
Forest	Cropland	-9.090594	7.73E-06	1	1	1
Forest	Cropland	-8.137208	6.79E-08	1	1	1
Natural grassland	Cropland	-8.355333	5.33E-06	1	1	1
Shrubland	Cropland	-9.643734	8.43E-05	1	1	1
Forest	Cropland	-8.684158	0.1660635			
Forest	Cropland	-8.133491	0.1660218			
Forest	Cropland	-7.868563	0.1660216			
Forest	Cropland	-6.909631	3.33E-06			
Forest	Cropland	-9.871874	0.0335344			
Forest	Cropland	-8.38711	1.51E-05			
Forest	Cropland	-7.816815	1.57E-07			
Forest	Cropland	-7.49374	5.75E-05			
Forest	Cropland	-7.261567	1.11E-05			
Natural grassland	Cropland	-7.197746	1.26E-05			
Shrubland	Cropland	-9.233337	5.56E-05			
Shrubland	Cropland	-8.69069	9.84E-06			
Shrubland	Cropland	-7.54392	8.00E-05			
Shrubland	Cropland	-7.080023	8.87E-05			
Natural grassland	Cropland	-12.31022	8.11E-06	1	1	0.8
Shrubland	Cropland	-15.54097	0.0083735	1	1	0.8
Natural grassland	Cropland	-2.28352	7.56E-10	1	1	0.71
Shrubland	Cropland	-3.090168	6.62E-10	1	1	0.71
Artificial grassland	Cropland	-0.592178	3.01E-10			
Forest	Cropland	-3.645729	6.16E-07			
Natural grassland	Cropland	-2.9888	1.02E-07			
Artificial grassland	Abandoned land	-1.118613	4.82E-08	1	1	1
Artificial grassland	Abandoned land	-1.670682	3.64E-09	1	1	1
Artificial grassland	Abandoned land	-1.90707	3.57E-07	1	1	1
Artificial grassland	Abandoned land	-1.247825	3.80E-08	1	1	1
Artificial grassland	Abandoned land	-1.842532	1.27E-08	1	1	1
Artificial grassland	Abandoned land	-2.217225	6.67E-08	1	1	1
Shrubland	Abandoned land	2.9063314	2.29E-10	1	1	1
Shrubland	Bareland	3.7671325	2.19E-09	1	1	1
Artificial grassland	Bareland	0.362015	2.56E-10	1	1	1
Forest	Bareland	-3.008943	1.16E-07	1	1	1
Natural grassland	Bareland	0.9032223	3.21E-10	1	1	1
Shrubland	Bareland	-2.624984	1.57E-07	1	1	1
Shrubland	Bareland	-3.01606	6.20E-07	1	1	1
Shrubland	Cropland	-4.611318	1.93E-11	1	1	
Forest	Abandoned land	-1.504077	5.28E-08	1	1	1
Shrubland	Abandoned land	-0.649662	2.64E-09	1	1	1

Forest	Cropland	-4.808723	1.28E-12	1	1	1
Shrubland	Cropland	-3.954308	3.24E-09	1	1	1
Artificial grassland	Cropland	1.1332138	9.68E-10			
Artificial grassland	Cropland	0.7885825	1.68E-10			
Natural grassland	Cropland	0.5125991	4.44E-10			
Artificial grassland	Abandoned land	0.6455191	3.29E-06	1	1	1
Forest	Abandoned land	-2.151762	0.0003396	1	1	1
Forest	Abandoned land	-0.927987	7.84E-06	1	1	1
Forest	Abandoned land	0.633249	2.42E-06	1	1	1
Forest	Abandoned land	-7.762054	28.561139	1	1	1
Natural grassland	Abandoned land	-2.10526	5.82E-06	1	1	1
Shrubland	Abandoned land	-3.33639	0.0038386	1	1	1
Shrubland	Abandoned land	-2.724215	0.0002187	1	1	1
Shrubland	Abandoned land	-2.972425	9.80E-05	1	1	1
Artificial grassland	Cropland	-5.277844	5.35E-06	1	1	1
Forest	Cropland	-5.942939	0.0004418	1	1	1
Forest	Cropland	-5.786049	4.18E-07	1	1	1
Forest	Cropland	-5.889622	0.0003639	1	1	1
Forest	Cropland	-7.399588	0.0084892	1	1	1
Natural grassland	Cropland	-7.877049	0.000132	1	1	1
Shrubland	Cropland	-6.588154	1.29E-05	1	1	1
Shrubland	Cropland	-5.431299	0.0001145	1	1	1
Shrubland	Cropland	-6.996022	0.0002554	1	1	1

Note: ERT: ecological restoration types; LDT: land degradation types

Appendix 3. Spatial variability of effect size

Table 10. Regression analysis of annual and event runoff (lnRR) and soil erosion rate (lnRR) along longitude, latitude, MAT and MAP according to ecological restoration types.

Ecological resoration types	Response variables	Dependent variables		Estimate	Standard error	t value	p value	Sig.
Overall	Annual runoff depth (lnRR)	Longitude	Intercept	12.91297	9.78424	1.32	0.188	
			Slope	-0.1286	0.08948	-1.437	0.152	
		Latitude	Intercept	9.9388	5.0451	1.97	0.0503	.
			Slope	-0.302	0.1374	-2.199	0.0291	*
		MAT	Intercept	-0.38564	1.79393	-0.215	0.83	
			Slope	-0.08239	0.19912	-0.414	0.679	
		MAP	Intercept	0.48419	1.83786	0.263	0.792	
			Slope	-0.0032	0.00359	-0.892	0.374	
	Annual soil erosion rate (lnRR)	Longitude	Intercept	30.906	18.3815	1.681	0.0948	.
			Slope	-0.3298	0.1676	-1.968	0.051	.
		Latitude	Intercept	8.2671	9.7753	0.846	0.399	
			Slope	-0.3657	0.2642	-1.384	0.168	
		MAT	Intercept	-8.6028	3.2798	-2.623	0.00965	**
			Slope	0.3764	0.3735	1.008	0.31522	
		MAP	Intercept	-2.70667	3.17816	-0.852	0.396	
			Slope	-0.00504	0.00625	-0.807	0.421	
	Event runoff depth (lnRR)	Longitude	Intercept	-4.79133	10.07266	-0.476	0.635	
			Slope	0.03339	0.09146	0.365	0.716	
		Latitude	Intercept	-0.01025	3.79365	-0.003	0.998	
			Slope	-0.02985	0.10254	-0.291	0.771	
		MAT	Intercept	4.8552	1.9756	2.458	0.0151	*
			Slope	-0.6412	0.2118	-3.027	0.0029	**

		MAP	Intercept	0.52744	1.29787	0.406	0.685	
			Slope	-0.00324	0.00255	-1.27	0.206	
	Event soil erosion rate (lnRR)	Longitude	Intercept	-88.6679	31.9726	-2.773	0.00682	**
			Slope	0.7725	0.2895	2.669	0.00912	**
		Latitude	Intercept	-50.1103	11.2164	-4.468	2.42E-05	***
			Slope	1.2494	0.2995	4.171	7.28E-05	***
		MAT	Intercept	-17.7985	6.8092	-2.614	0.0106	*
			Slope	1.5396	0.7245	2.125	0.0365	*
		MAP	Intercept	3.24414	4.05361	0.8	0.426	
			Slope	-0.01327	0.00812	-1.634	0.106	
	Annual runoff depth (lnRR)	Longitude	Intercept	6.26347	5.48404	1.142	0.263	
			Slope	-0.06282	0.0501	-1.254	0.22	
		Latitude	Intercept	4.6185	3.632	1.272	0.214	
			Slope	-0.13959	0.09687	-1.441	0.161	
		MAT	Intercept	-0.59191	1.06151	-0.558	0.582	
			Slope	0.000632	0.12543	0.005	0.996	
		MAP	Intercept	-2.18164	1.70548	-1.279	0.211	
			Slope	0.00339	0.00366	0.925	0.363	
Artificial grassland	Annual soil erosion rate (lnRR)	Longitude	Intercept	4.98283	24.84942	0.201	0.843	
			Slope	-0.06824	0.22578	-0.302	0.766	
		Latitude	Intercept	-18.0669	17.3718	-1.04	0.312	
			Slope	0.4184	0.4675	0.895	0.383	
		MAT	Intercept	2.211	4.2224	0.524	0.607	
			Slope	-0.5651	0.4993	-1.132	0.273	
		MAP	Intercept	-0.000303	6.96711	0	1	
			Slope	-0.00522	0.01435	-0.364	0.72	

Forestland	Event runoff depth (lnRR)	Longitude	Intercept	109.6715	37.5569	2.92	0.00914	**
			Slope	-1.0097	0.3439	-2.936	0.00883	**
		Latitude	Intercept	25.3753	12.6314	2.009	0.0598	.
			Slope	-0.7085	0.3446	-2.056	0.0546	.
		MAT	Intercept	2.0317	5.0863	0.399	0.694	
			Slope	-0.2837	0.5493	-0.517	0.612	
		MAP	Intercept	-3.68811	5.7411	-0.642	0.529	
			Slope	0.00594	0.011	0.54	0.596	
	Event soil erosion rate (lnRR)	Longitude	Intercept	621.513	141.841	4.382	0.00137	**
			Slope	-5.685	1.292	-4.399	0.00134	**
		Latitude	Intercept	144.548	437.381	0.33	0.748	
			Slope	-4.007	11.92	-0.336	0.744	
		MAT	Intercept	-58.402	16.212	-3.602	0.00483	**
			Slope	5.884	1.704	3.453	0.0062	**
		MAP	Intercept	-51.19154	16.95633	-3.019	0.0129	*
			Slope	0.09158	0.03185	2.876	0.0165	*
	Annual runoff depth (lnRR)	Longitude	Intercept	26.0205	21.3445	1.219	0.227	
			Slope	-0.2551	0.1954	-1.305	0.196	
		Latitude	Intercept	15.2336	9.8264	1.55	0.1252	
			Slope	-0.4665	0.2684	-1.738	0.0862	.
		MAT	Intercept	2.5044	4.3935	0.57	0.57	
			Slope	-0.467	0.4741	-0.985	0.328	
		MAP	Intercept	0.09011	4.04416	0.022	0.982	
			Slope	-0.00366	0.00766	-0.478	0.634	
	Annual soil erosion rate (lnRR)	Longitude	Intercept	47.073	26.7432	1.76	0.083	.
			Slope	-0.4783	0.2441	-1.959	0.0543	.

		Latitude	Intercept	13.3732	13.4953	0.991	0.325	
			Slope	-0.5059	0.365	-1.386	0.17	
		MAT	Intercept	-9.8034	4.6835	-2.093	0.0404	*
			Slope	0.4998	0.534	0.936	0.3529	
		MAP	Intercept	-7.57522	4.88879	-1.55	0.126	
			Slope	0.00452	0.00972	0.465	0.643	
	Event runoff depth (lnRR)	Longitude	Intercept	-31.7922	18.9633	-1.677	0.0984	.
			Slope	0.2752	0.1721	1.599	0.1146	
		Latitude	Intercept	-8.2544	7.4451	-1.109	0.272	
			Slope	0.1838	0.2017	0.911	0.366	
		MAT	Intercept	5.6444	3.4679	1.628	0.1084	
			Slope	-0.768	0.3735	-2.056	0.0437	*
		MAP	Intercept	2.25431	2.33908	0.964	0.339	
			Slope	-0.00733	0.00458	-1.6	0.114	
	Event soil erosion rate (lnRR)	Longitude	Intercept	-151.4454	44.2031	-3.426	0.00197	**
			Slope	1.3413	0.3996	3.356	0.00236	**
		Latitude	Intercept	-61.3422	16.3608	-3.749	8.56E-04	***
			Slope	1.5468	0.4342	3.562	0.00139	**
		MAT	Intercept	-18.482	12.587	-1.468	0.154	
			Slope	1.639	1.338	1.224	0.231	
		MAP	Intercept	12.7951	6.21155	2.06	0.0492	*
			Slope	-0.03252	0.01265	-2.571	0.016	*
Natural grassland	Annual runoff depth (lnRR)	Longitude	Intercept	-6.59983	26.34747	-0.25	0.804	
			Slope	0.06271	0.24235	0.259	0.798	
		Latitude	Intercept	6.2491	11.4672	0.545	0.591	
			Slope	-0.1662	0.3157	-0.526	0.603	

	MAT	Intercept	-6.3433	4.0336	-1.573	0.129	
		Slope	0.7393	0.445	1.662	0.11	
	MAP	Intercept	-2.1549	4.80311	-0.449	0.658	
		Slope	0.00452	0.00911	0.496	0.625	
Annual soil erosion rate (lnRR)	Longitude	Intercept	82.1005	61.9098	1.326	0.203	
		Slope	-0.7901	0.5625	-1.405	0.179	
	Latitude	Intercept	15.4878	29.8888	0.518	0.611	
		Slope	-0.5484	0.8054	-0.681	0.506	
	MAT	Intercept	-20.424	11.165	-1.829	0.0861	.
		Slope	1.743	1.243	1.403	0.1799	
	MAP	Intercept	-20.82733	11.41619	-1.824	0.0868	.
		Slope	0.03241	0.02303	1.407	0.1786	
Event runoff depth (lnRR)	Longitude	Intercept	-5.26249	32.6057	-0.161	0.874	
		Slope	0.03845	0.29634	0.13	0.898	
	Latitude	Intercept	-3.0617	11.3565	-0.27	0.791	
		Slope	0.0551	0.3082	0.179	0.86	
	MAT	Intercept	10.1252	4.1316	2.451	0.0254	*
		Slope	-1.2197	0.4509	-2.705	0.015	*
	MAP	Intercept	4.58319	3.32076	1.38	0.185	
		Slope	-0.01123	0.00662	-1.697	0.108	
Event soil erosion rate (lnRR)	Longitude	Intercept	-124.8552	47.0829	-2.652	0.019	*
		Slope	1.1094	0.4256	2.607	0.0207	*
	Latitude	Intercept	-53.4483	16.6717	-3.206	0.00635	**
		Slope	1.359	0.4412	3.08	0.00815	**
	MAT	Intercept	-7.1224	12.461	-0.572	0.577	
		Slope	0.5343	1.3305	0.402	0.694	

		MAP	Intercept	12.6505	6.54138	1.934	0.0736	.
			Slope	-0.03045	0.01342	-2.269	0.0396	*
	Annual runoff depth (lnRR)	Longitude	Intercept	6.72346	17.64236	0.381	0.704	
			Slope	-0.07132	0.16082	-0.443	0.659	
		Latitude	Intercept	12.8984	9.5346	1.353	0.181	
			Slope	-0.3819	0.26	-1.469	0.147	
		MAT	Intercept	-4.2511	3.0463	-1.395	0.168	
			Slope	0.3555	0.3421	1.039	0.303	
		MAP	Intercept	0.10452	2.9235	0.036	0.972	
			Slope	-0.00238	0.00576	-0.414	0.68	
	Annual soil erosion rate (lnRR)	Longitude	Intercept	17.7187	41.0303	0.432	0.668	
			Slope	-0.2218	0.3746	-0.592	0.557	
		Latitude	Intercept	15.7201	21.2035	0.741	0.463	
Shrubland			Slope	-0.604	0.5741	-1.052	0.299	
		MAT	Intercept	-21.1393	8.0838	-2.615	0.0123	*
			Slope	1.6473	0.9125	1.805	0.0782	.
		MAP	Intercept	0.29581	5.39913	0.055	0.957	
			Slope	-0.01296	0.01013	-1.28	0.208	
	Event runoff depth (lnRR)	Longitude	Intercept	1.63947	12.75421	0.129	0.898	
			Slope	-0.02257	0.11544	-0.196	0.846	
		Latitude	Intercept	4.4392	4.5494	0.976	0.334	
			Slope	-0.142	0.1219	-1.165	0.25	
		MAT	Intercept	4.6024	3.0394	1.514	0.1368	
			Slope	-0.5769	0.3207	-1.799	0.0787	
		MAP	Intercept	-1.27206	1.63238	-0.779	0.44	

		Slope	0.0008316	0.00323	0.258	0.798	
Event soil erosion rate (lnRR)	Longitude	Intercept	-54.3258	60.7169	-0.895	0.379	
		Slope	0.4502	0.5496	0.819	0.42	
	Latitude	Intercept	-40.7148	21.374	-1.905	0.0671	.
		Slope	0.968	0.5726	1.691	0.102	
	MAT	Intercept	-7.1976	11.3521	-0.634	0.531	
		Slope	0.2787	1.2124	0.23	0.82	
	MAP	Intercept	-2.984	7.23123	-0.413	0.683	
		Slope	-0.00323	0.01449	-0.223	0.825	

Note: Significant level as follows: 0.001-‘***’, 0.01-‘**’, 0.05-‘*’, 0.1-‘.’, 1-‘ ’. MAT: mean annual temperature. MAP: mean annual precipitation.

Appendix 4. Fit statistic of the optimal model and model reliability in meta-analysis

1. Fit statistics and model choice

The fit statistic variables of the optimal model as follows.

Table 11. Fit statistic variable of optimal mixed-effect model regarding of the topological context and ecological restoration types.

Statistic variable	Annual runoff		Annual soil erosion rate		Event runoff		Event soil erosion rate	
	Overall	Individual	Overall	Individual	Overall	Individual	Overall	Individual
LogLik:	-335.556	-334.316	-352.643	-342.285	-149.296	-143.412	-134.986	-126.696
Deviance:	2001.909	1999.429	705.285	684.5703	298.5911	286.8237	269.971	253.3911
AIC:	681.1117	684.6315	715.285	700.5703	308.5911	302.8237	279.971	269.3911
BIC:	696.7612	709.6707	729.5452	723.1968	322.2281	324.4275	290.7654	286.2781
AICc:	681.4798	685.5315	715.7768	701.8117	309.1519	304.2494	281.0055	272.1604

Note: LogLik, BIC, AIC and AICc refer to Log-likelihood, Bayesian information criterion, Akaike information criterion and the sample-size corrected Akaike Information Criterion, respectively.

2. Model reliability

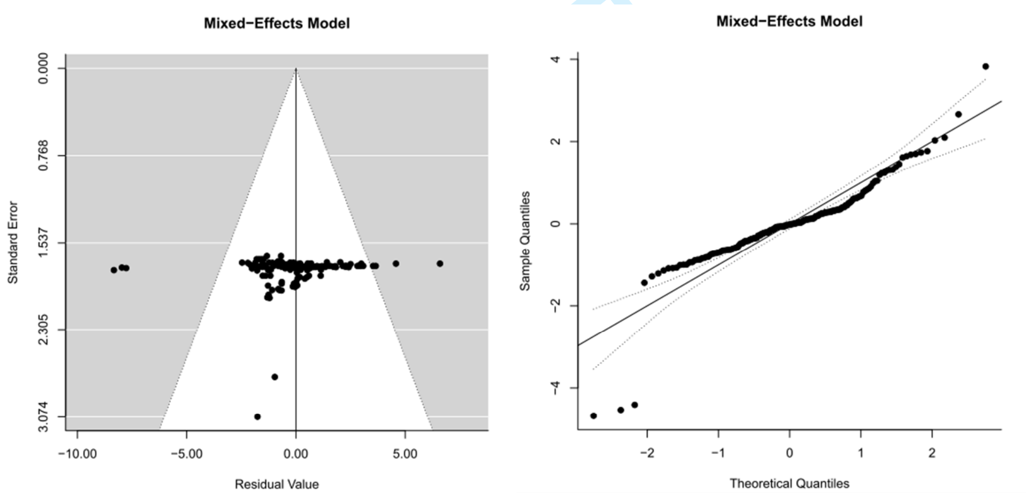

Figure 7. The funnel and Q-Q plot between standard error and overall effect model residual in the annual runoff. A pseudo confidence interval region is drawn around this value with bounds equal to ± 1.96 SE, where SE is the standard error value from the y-axis (assuming level=95%).

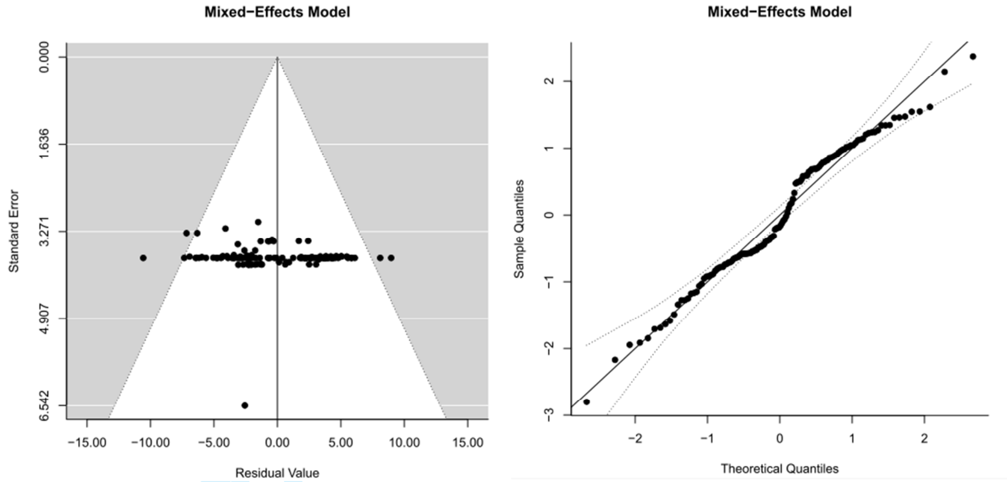

Figure 8. The funnel and Q-Q plot between standard error and overall effect model residual in the annual soil erosion rate. A pseudo confidence interval region is drawn around this value with bounds equal to ± 1.96 SE, where SE is the standard error value from the y-axis (assuming level=95%).

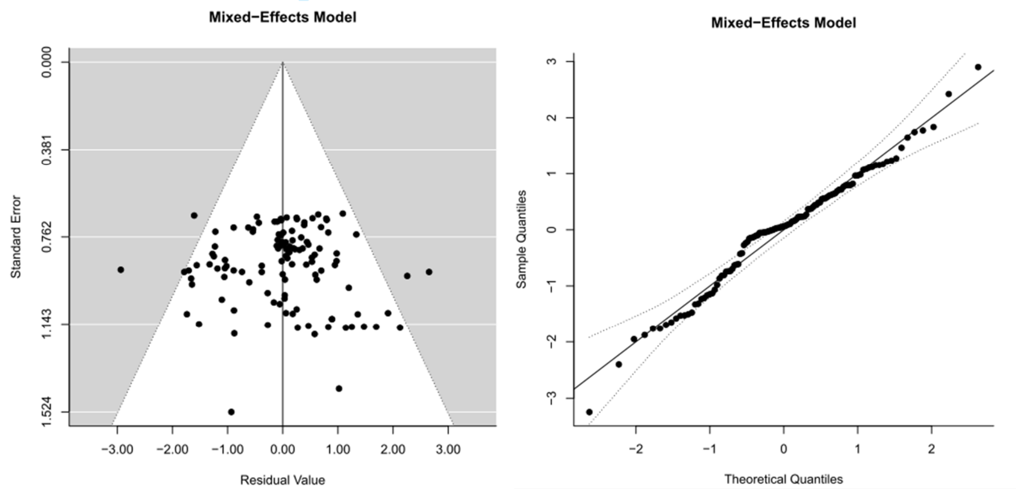

Figure 9. The funnel and Q-Q plot between standard error and overall effect model residual in the event runoff. A pseudo confidence interval region is drawn around this value with bounds equal to ± 1.96 SE, where SE is the standard error value from the y-axis (assuming level=95%).

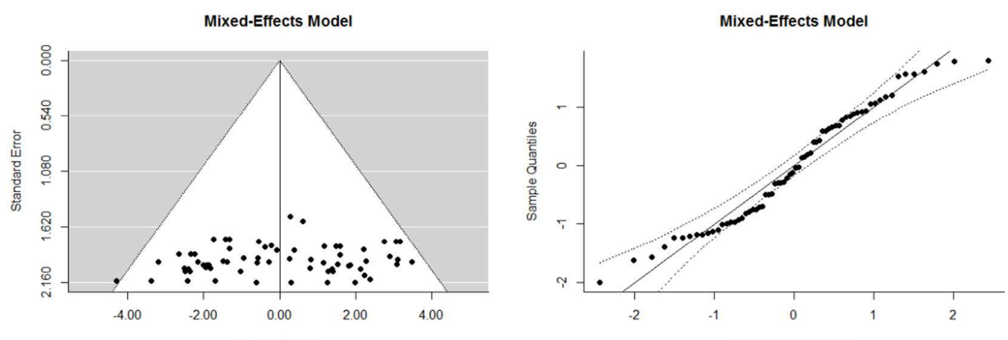

Figure 10. The funnel and Q-Q plot between standard error and overall effect model residual in the event soil erosion rate. A pseudo confidence interval region is drawn around this value with bounds

equal to ± 1.96 SE, where SE is the standard error value from the y-axis (assuming level=95%).

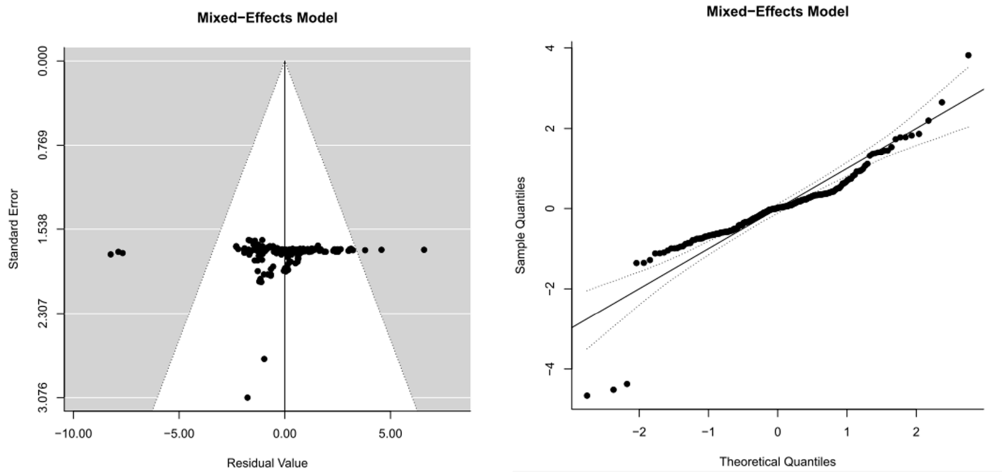

Figure 11. The funnel and Q-Q plot between standard error and Individual effect optimal model residual in the annual runoff. A pseudo confidence interval region is drawn around this value with bounds equal to ± 1.96 SE, where SE is the standard error value from the y-axis (assuming level=95%).

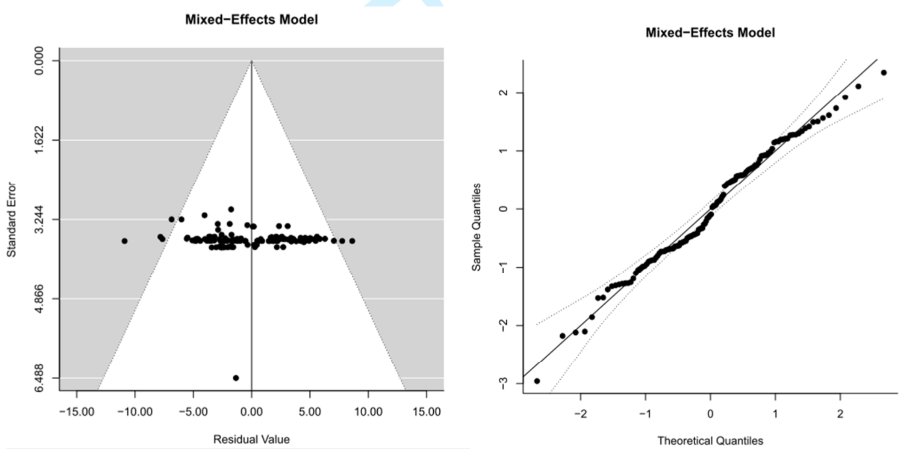

Figure 12. The funnel and Q-Q plot between standard error and Individual effect model residual in the annual soil erosion rate. A pseudo confidence interval region is drawn around this value with bounds equal to ± 1.96 SE, where SE is the standard error value from the y-axis (assuming level=95%).

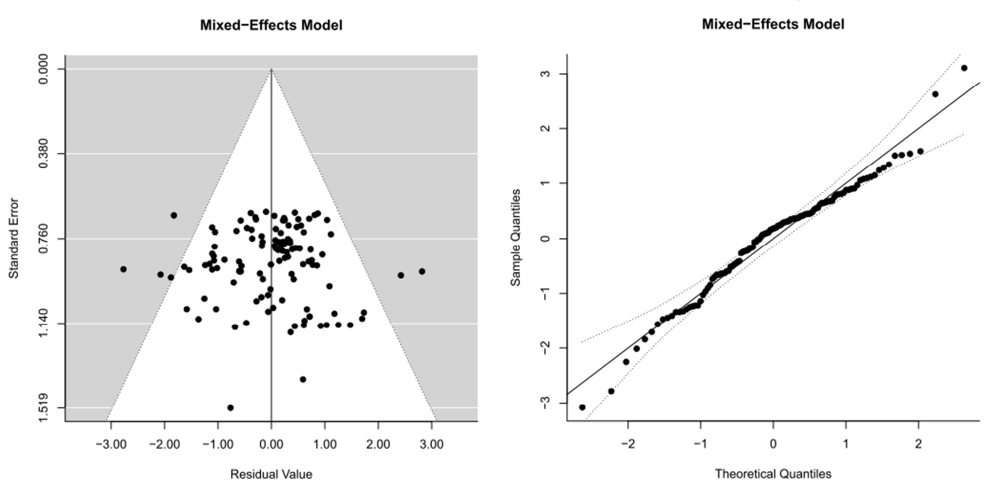

Figure 13. The funnel and Q-Q plot between standard error and Individual effect model residual in the event runoff. A pseudo confidence interval region is drawn around this value with bounds equal to ± 1.96 SE, where SE is the standard error value from the y-axis (assuming level=95%).

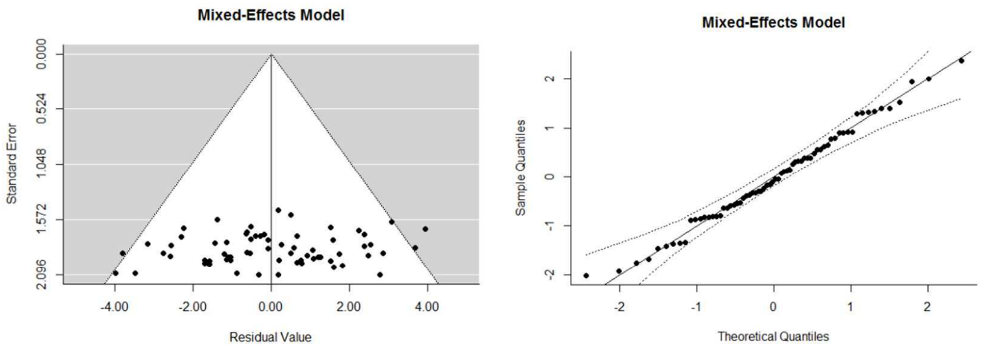

Figure 14. The funnel and Q-Q plot between standard error and Individual effect model residual in the event soil erosion rate. A pseudo confidence interval region is drawn around this value with bounds equal to ± 1.96 SE, where SE is the standard error value from the y-axis (assuming level=95%).