The Influence of Time Scale on the Quantitative Study of Soil and Water Conservation Effect of Grassland

Xiaoxia WU, Zhujun GU *

School of Bio-Chemical and Environmental Engineering, Nanjing Xiaozhuang University, Nanjing 211171, China

Abstract Quantitative analysis of time scale effects is conducive to further understanding of vegetation water and soil conservation mechanism. Based on the observation data of the grass covered and bare soil (control) experimental plots located in Hetian Town, Changting County of Fujian Province from 2007 to 2010, the characteristics of 4 parameters (precipitation, vegetation, RE and SE) were analyzed at precipitation event, month, season, and annual scales, and then the linear regression models were established to describe the relationships between RE(SE) and its influencing factors of precipitation and vegetation. RE (SE) means the ratio of runoff depth (soil loss) of grass covered plot to that of the control plot. Results show that these 4 parameters presented different magnitude and variation on different time scales. RE and SE were relatively stable either within or among different time scales due to their ratios reducing the influence of other factors. The coupling of precipitation and vegetation led to better water conservation effect at lower RE (< 0.3) at precipitation event scale as well as at season scale, while the water conservation effect was dominated by precipitation at slightly higher (0.3 – 0.4) and higher (>0.7) REs at precipitation event scale as well as at annual scale ($R^2 > 0.78$). For the soil conservation effect, precipitation or/and vegetation was/were the dominated influence factor (s) at precipitation event and annual scales, and the grass LAI could basically describe the positive conservation effect (SE <1, $R^2 > 0.55$), while the maximum 30 min intensity (I_{30}) could describe the negative conservation effect more accurately (SE >1, $R^2 > 0.79$). More uncertainties ($R^2 \approx 0.4$) exist in the models of both RE and SE at two moderate time scales (month and season). Consequently, factors influencing water and soil conservation effect of grass present different variation and coupling characteristics on different time scales, indicating the importance of time scale at the study on water and soil conservation.

Key words Time scale, Leaf area index, Water conservation effect, Soil conservation effect

1 Introduction

China's soil erosion is serious[1], which has severely restricted the sustained and stable development of China's economy. Soil erosion is affected by climate, topography, vegetation, soil, land use and other factors, and there is heterogeneity in the spatial and temporal distribution of these factors, so there is a significant scale effect[2-3]. In the above-mentioned factors, vegetation is the key controlling factor[4-5]. In recent years, the study on the soil and water conservation effect of vegetation has been widely carried out. Peng Shaoyun *et al.* compare the soil and water conservation functions of five plants (*Pueraria lobata*; *Manglietia yuyuanensis* Law; *Lespedeza bicolor* Turcz; *Paspalum notatum Flugge*; *Paspalum wettsteinii* Hackel), and it is found that *Pueraria lobata and Manglietia yuyuanensis* Law are better than *Lespedeza bicolor* Turcz and *Paspalum notatum Flugge*, while *Paspalum wettsteinii* Hackel is poorest[6]. Chirino *et al.* perform four years of observation on five plant coverage plots in southeastern semi-arid region of Spain and find that the runoff and erosion of forest-grass and forest-shrub plots are slightly less than pure grass and shrub plots[7]. With further research, the quantification of vegetation indicators has become the widespread demand in the soil and water conservation study, and the vegetation coverage has been widely used[8]. Many scholars believe that the higher the vegetation cover, the more significant the soil and water conservation functions[9-11]. But some studies have pointed out that at the same level of coverage vegetation, natural forests are better than plantations in terms of soil and water conservation effect due to multi-layered structure[12-13]. It indicates that there are limitations in the vegetation coverage which reflect the soil and water conservation functions of vegetation only from the horizontal level, so the leaf area index (LAI) that can reflect the vertical distribution density of vegetation has attracted increasing attention. The studies of Sun Jiajia *et al.* show that it is more stable and reliable to use leaf area index to evaluate the vegetation soil and water conservation benefits compared with the vegetation coverage. Some scholars believe that in the universal soil loss equation (USLE), the value of vegetation cover and management factor *C* must take into account the value of the leaf area index[15]. In the recent studies on hydrological and ecological function of forest, LAI has become the key parameter of precipitation-vegetation coupling due to its hydrological sensitivity[16]. The development of measurement technology and remote sensing technology has provided conditions for the LAI measurement in a wide range and further broadened the LAI applications[17]. Currently, the soil and water conservation research has been launched at various spatial scales[18]. Li Rui *et al.* establish the runoff experimental plots in Guizhou's karst areas to study the relationship between precipitation and soil erosion[19]. Nie Xiaojun *et al.* use 137Cs tracer method to research the characteristics of soil erosion in the hilly areas in the central part of the Sichuan Basin, and find that

Received: January 26, 2015 Accepted: March 6, 2015

Supported by National Natural Science Foundation Project (41071281); Natural Science Foundation of Jiangsu Province (BK20131078); "Qing Lan Project" of Jiangsu Provincial Department of Education.

* Corresponding author. E-mail: zhujungu@163.com

tillage erosion is a major erosion process of short steep arable land, while water erosion is a major erosion process of gentle long arable land[20]. Lu Kexin *et al*. study the rainstorm runoff erosion power at the scales of slope and basin, and results show that the runoff erosion power is more suitable as a dynamic erosion factor[21]. There are also many studies on soil and water conservation at the regional, watershed and global scales, combined with remote sensing, geographic information systems and other technologies[22-23]. Meanwhile, the soil erosion study on different time scales is also often reported. Jiao Juying *et al*. perform the statistical analysis of 248 storm precipitation events of three different types as well as erosion characteristics in the Loess Plateau, and results show that small-scale short-term heavy rainstorm has the highest frequency in the Loess Plateau, and it is the main reason for soil erosion[24]. Liu Zhengjia *et al*. estimate the temporal and spatial variation of precipitation erosivity in the Yimeng Mountain based on the daily precipitation data during 1971 - 2008, and results show that the precipitation erosivity is mainly concentrated in June to September[25]. Andreu *et al*. compare the soil aggregate and soil-stone ratio between southern and northern slopes in four seasons, and find that the soil aggregate and erosion get better gradually from winter to fall[26]. Wu Mei *et al*. use the 11 a precipitation, runoff and sediment data to study the monthly and annual erosion of runoff and soil in the hilly areas of northern Sichuan, and find that the annual runoff is significantly correlated with the precipitation or precipitation erosivity (R^2 = 0.716/0.660)[27]. In summary, there have been many studies on the soil erosion at different spatial and temporal scales, but the studies on soil and water conservation effect on different time scales based on the quantitative indicators of vegetation structure is rarely reported.

2 Materials and methods

2.1 Establishment of experimental plots In February 2007, we built two soil erosion experimental plots (grass cover plot and bare soil control) in Luodicao Mountain, Hetian Town, Changting County, Fujian Province. Changting borders Liancheng County to the east, Wuping and Shanghang counties to the south (all in Longyan municipality), Sanming municipality's Ninghua County to the north, Ganzhou municipality's Ruijin City in Jiangxi province to the west. Located in the southern end of the Wuyi Mountains, Changting belongs to subtropical zone. The region enjoys abundant precipitation as the warm maritime air meets the cool air in the mountains, generating a large amount of precipitation. Changting County is a typical severe soil erosion area in southern China. The plot slope is 8° and the horizontal projection area is 5 m × 20 m. The concrete slab is used to surround the plots, and the concrete slab is 20 cm protruding above the soil and 20 cm deep in the soil. The downslope has runoff and sediment outlet and runoff pond. The soil within the plots is the red mountain soil developed from the granite parent material and the physical and chemical properties are similar. The annual *Paspalurn wettsteinii* Hackel was planted in the grass cover plot. From March 2007, the grass seeds were evenly sown on the slope during March to April annually, and the grass was in a natural growth state. The height was up to about 60cm in summer and fall, and the vegetation coverage was up to about 80%.

2.2 Observation of precipitation parameters The precipitation of individual precipitation event (P, mm), precipitation duration (T, min), and the maximum 30 min precipitation intensity (I_{30}, mm/h) are all read from the precipitation curve. The data are from the meteorological observatory located in the vicinity of experimental plots. According to the observation data, we calculate the precipitation kinetic energy and precipitation erosivity of individual precipitation event, respectively. The total kinetic energy of one individual precipitation event (E, MJ/ha) is to total the product of unit kinetic energy of precipitation and the corresponding precipitation in various time periods[28]. The erosivity of one individual precipitation event (R) is the product of total kinetic energy of one precipitation event (E) and the maximum 30 min precipitation intensity of this precipitation (I_{30}), namely $R = E \cdot I_{30}$. The cumulative precipitation of 11 previous days (AP_{11}, mm) is the sum of precipitation 11 days before the calculation period. The monthly, quarterly and annual precipitation parameters are calculated using the mean on the corresponding time scale except precipitation (P) and precipitation duration (T) calculated by accumulating. To ensure the comparability of data values, the precipitation characteristic parameters on the corresponding time scales need to be normalized by the following formula:

$$X_1 = (X_0 - X_{min})/(X_{max} - X_{min})$$

where X_1, X_0, X_{max} and X_{min} are the normalized value of precipitation characteristic indicator, original data, maximum and minimum values.

2.3 Leaf area index estimates From March 2007 to November 2010, the leaf area index in the plots was periodically measured on sunny days each week. The grass cover plot was divided into three sub-plots, and a fixed measuring point was set and marked in each sub-plot. LP80 AccuPAR Canopy Analyzer was used to automatic measure the solar radiation values of lower part of herbaceous vegetation in the area outside the plot and inside the plot, respectively. According to the active radiation of photosynthesis, the leaf area index in sub-plots was calculated, and the average of three sub-plots was taken as leaf area index of grass. After reaching a peak in the summer, the leaf area index of grassland would probably remain unchanged in theory in the next few months, but it gradually decreased in reality and the reduced part could be understood as the contribution of dead leaf. To analyze the impact of dead leaf, the difference between LAI peak of grass and the observed values is regarded as LAI of dead leaf ($LAI_{dead\ leaf}$). The monthly, quarterly and annual LAI values (including LAI_{grass} and $LAI_{dead\ leaf}$) employ the corresponding time scale average.

2.4 Soil and water conservation effect assessment The ratio between surface runoff depth of grass cover plot and surface runoff depth of control plot under different time scales was used to represent the RE (SE) values of water conservation (soil conservation) of herbaceous vegetation. This ratio reduces the impact of precipitation, topography, soil and other external factors. The lower the values of RE and SE, the better the soil and water conservation effect of vegetation. Under various time scales, with RE/SE as the dependent variable, LAI_{grass}, $LAI_{dead\ leaf}$ and precipitation as the independent variables, we used stepwise regression to establish multi-variable linear model to identify the dominant factors affecting the soil and water conservation of grassland. According to the clustering feature of RE/SE for the scatterplot data of 7 precipitation parameters and 2 vegetation parameters, the RE/SE was divided into several sections for modeling. The statistical and analytical work was completed using SPSS17.0 (SPSS Inc., USA) and Excel (Microsoft, USA).

3 Results and discussions

3.1 Precipitation characteristics During the observation period, there were 144 erosive precipitation events, and the average precipitation (P) was 28.4 mm. The average precipitation duration (T) was 491.5 min, and the average maximum 30 min precipitation intensity (I_{30}) was 11.6 mm/h. The average kinetic energy (E) of individual precipitation event was calculated at 6.75 MJ/hm^2, and the average erosivity (R) of individual precipitation event was 104.1 (MJ · mm)/(hm^2 · h). After normalization, it is found that the precipitation parameters show different characteristics on different time scales. From the average normalized value (Fig. 1 a), precipitation (P), maximum 30 min precipitation intensity (I_{30}), precipitation erosivity (R) and multiplication factor ($P \cdot I_{30}$) gradually increased from the scale of individual precipitation event to the annual scale; kinetic energy of precipitation (E) on the quarterly and annual scales was significantly greater than on the monthly and individual precipitation event scales; precipitation duration (T) on the individual precipitation event, quarterly and annual scales was slightly larger than on the monthly scale; the cumulative precipitation of the first 11 days (AP_{11}) on an annual scale was significantly greater than on the other three time scales. Similarly, as to the standard deviation of normalized values, P, I_{30}, R, $P \cdot I_{30}$ and AP_{11} on an annual scale were the largest, and E and T on quarterly and annual scales were slightly larger than on the monthly and individual precipitation event scales. As far as the dispersion coefficient is concerned (Fig. 1 b), R and $P \cdot I_{30}$ were the greatest on each time scale, followed by E and AP_{11}. There are also great differences in the dispersion coefficient of each precipitation parameter between different time scales.

3.2 Vegetation changes With the coarsening of time scales from individual precipitation event to annual scale, the mean LAI_{grass} first slowly declines and then rises (Fig. 2 a), while the standard deviation slowly rises and then declines; both the mean and standard deviation of $LAI_{dead\ leaf}$ first slowly rise and then decline. From the dispersion coefficient (Fig. 2 b), with the coarsening of time scales, the dispersion coefficient of LAI_{grass} first slowly rises and then declines, reaching a peak on the monthly scale, while it is the other way around for $LAI_{dead\ leaf}$, reaching a minimum value on the quarterly scale.

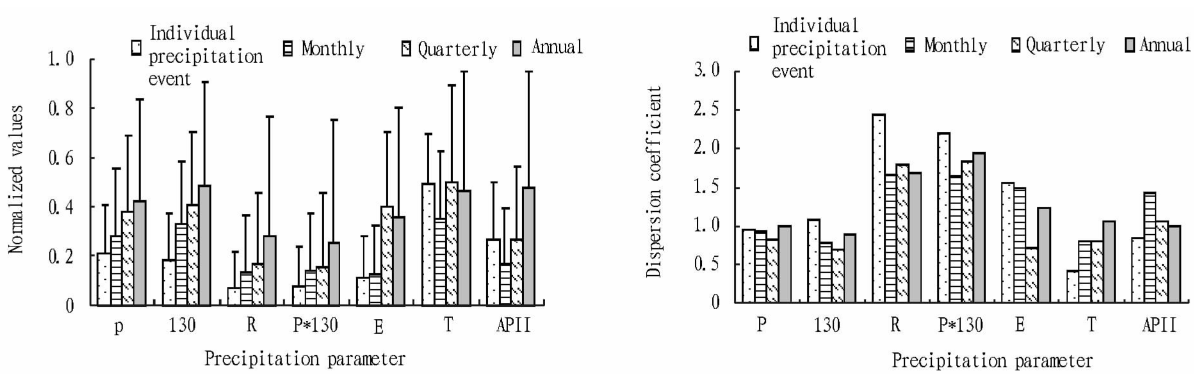

Fig. 1 The characteristics of precipitation parameters on different time scales

3.3 Water conservation effect With the coarsening of time scales from individual precipitation event to annual scale, RD (Runoff Depth) first slowly declines and then rises (Fig. 3 a), and the dispersion coefficient clearly indicates the variability of these two indicators (Fig. 3 b). The dispersion coefficient of RD is higher than that of RE on different time scales, and with the coarsening of time scales, the dispersion coefficient of RD shows a rising trend while the dispersion coefficient of RE is slightly higher on the quarterly scale and close on other scales. RD and RE show different characteristics with the change in time scales, and RD shows great fluctuation on different time scales due to the effect of various factors, while RE is relatively stable after eliminating the effect of the same factors. Therefore, this paper further analyzes the factors affecting the water conservation characteristics of herbaceous vegetation based on RE. On different time scales, this paper performs multivariate linear regression on RE and all precipitation and vegetation parameters, respectively, and for the individual precipitation event scale, the model is built based on segmented RE due to the cluster distribution of data. The optimal model is shown in Table 1. From the coefficient of determination (R^2), on the individual precipitation event scale (RE < 0.4 and RE > 0.7) and annual scale, the optimal model R^2 is higher than 0.78; on the individual precipitation event scale ($0.4 < RE < 0.7$) and monthly and quarterly scales, the optimal model R^2 is less than 0.4. On the individual precipitation event scale ($RE < 0.4$ and $RE > 0.7$) and annual scale, the role of precipitation and vegetation determines the water conservation effect; on the individual precipitation event scale ($0.4 < RE < 0.7$) and monthly and quarterly scales, the water conservation effect is also affected by topography, soil and other environmental factors. In terms of the independent variable of optimized model, on the individual precipitation event scale ($RE < 0.3$) and monthly scale, the independent variables of optimized model are precipitation and vegetation parameters, indicating that the coupling of precipitation and vegetation leads to better water conservation effect (normalized mean of RE is smallest on the monthly scale, Fig. 4a). On the individual precipitation event scale ($0.3 < RE < 0.4$ and $RE > 0.7$), quarterly and annual scales, the independent variables of the optimal model are all precipitation parameters (T, P, I_{30} and $P \cdot I_{30}$), indicating that when the time scale is large and RE is high, precipitation is the major factor for runoff generation, but there are differences in the key influencing factors on different time scales. At this point, the water conservation role of vegetation is very weak, so the water conservation effect is poor. The result indicates the importance of vegetation and precipitation to water conservation effect on different time scales, which can provide a reference for the study of factors influencing water conservation effect on different time scales.

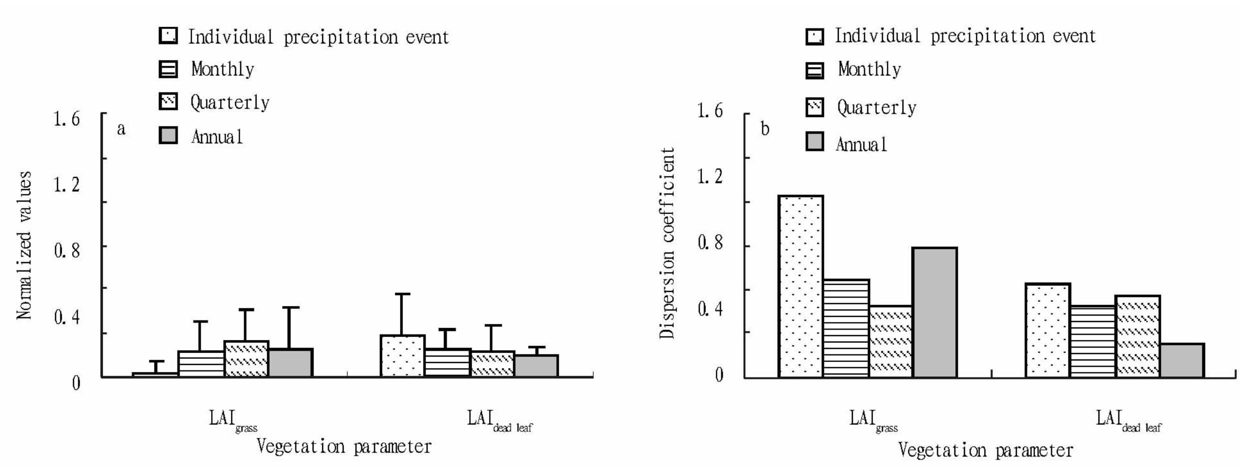

Fig. 2 The characteristics of vegetation parameters on different time scales

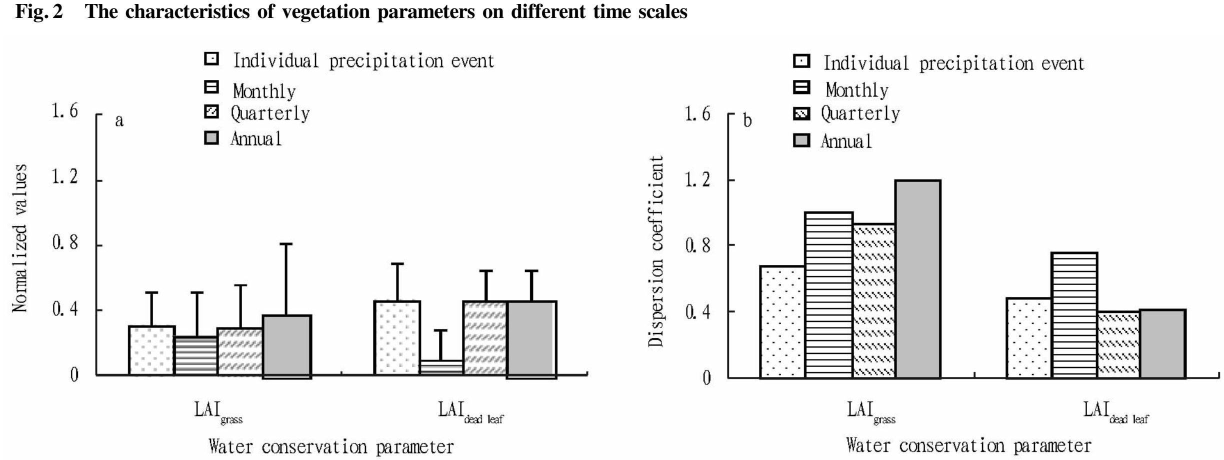

Fig. 3 The characteristics of water conservation parameters on different time scales

3.4 Soil conservation effect With the coarsening of time scales from individual precipitation event to annual scale, SL (Soil Loss) first slowly rises and then declines (Fig. 4a), reaching a peak on the quarterly scale, while SE (Soil Conservation Effect) is highest on the individual precipitation event scale, and small on other three time scales. In terms of the dispersion coefficient (Fig. 4b), except the quarterly scale, the dispersion coefficient of SL is higher than that of SE on other scales; both SL and SE are highest on the individual precipitation event scale, followed by monthly scale. The multivariate linear regression is also performed on SE and all precipitation and vegetation parameters on different time scales, respectively, and for the individual precipitation event scale, the model is built based on segmented SE. The optimal model is shown in Table 2. From the coefficient of determination (R^2), on the individual precipitation event scale and annual scale, the optimal model R^2 is higher than 0.55, and on monthly and quarterly scales, the optimal model R^2 is about 0.4. On the individual precipitation event scale and annual scale, the role of precipitation or vegetation determines the soil conservation effect; on the monthly and quarterly scales, the study on soil conservation effect of vegetation needs to consider the effect of other environmental factors. In terms of the independent variables of optimized model, the independent variable of optimized estimation model of soil conservation positive effect SE(<1) is LAI_{grass} on the individual precipitation event scale, indicating that the grass vegetation dominates the soil conservation positive effect. The independent variable of optimized estimation model of soil conservation negative effect SE(>1) is I_{30} on the individual precipitation event scale, showing that the soil conservation negative effect is mainly due to the impact of specific precipitation intensity ($I_{30}=11.3\pm8.7$ mm/h), and the soil conservation role of grassland vegetation is weak. On the annual scale, P can explain more than 60% of SE, once again showing that precipitation plays a key role in studying the soil conservation effect[29]. On the monthly and quarterly scales, the independent variables of optimized model are LAI_{grass} and I_{30}, and on the medium time scales, the soil conservation effect is mainly affected by grass vegetation and precipitation intensity.

Table 1 The estimation of optimized model based on RE segmentation on different time scales

Time scales	*RE* segmentation	Optimized model	R^2	Model No.
Individual precipitation event	$RE<0.3$	$RE=1.761T+0.174LAI_{dead\ leaf}-0.802$	0.988	(2)
	$0.3<RE<0.4$	$RE=-0.3494\ T+0.5107$	0.812	(3)
	$0.4<RE<0.7$	$RE=-0.3272\ LAI_{grass}+0.7795$	0.242	(4)
	$RE>0.7$	$RE=1.0357\ P+0.4988$	0.775	(5)
Monthly	Overall	$RE=-0.318I_{30}-0.381LAI_{grass}+0.238$	0.318	(6)
Quarterly	Overall	$RE=0.381P\times I_{30}+0.402$	0.364	(7)
Annual	Overall	$RE=0.433I_{30}+0.246$	0.927	(8)

Note: *RE* is water conservation effect; *P* is the precipitation (mm); *T* is the precipitation duration (min); I_{30} is the maximum 30 min precipitation intensity (mm/h); $LAI_{dead\ leaf}$ is the dead leaf area index; LAI_{grass} is the grass leaf area index.

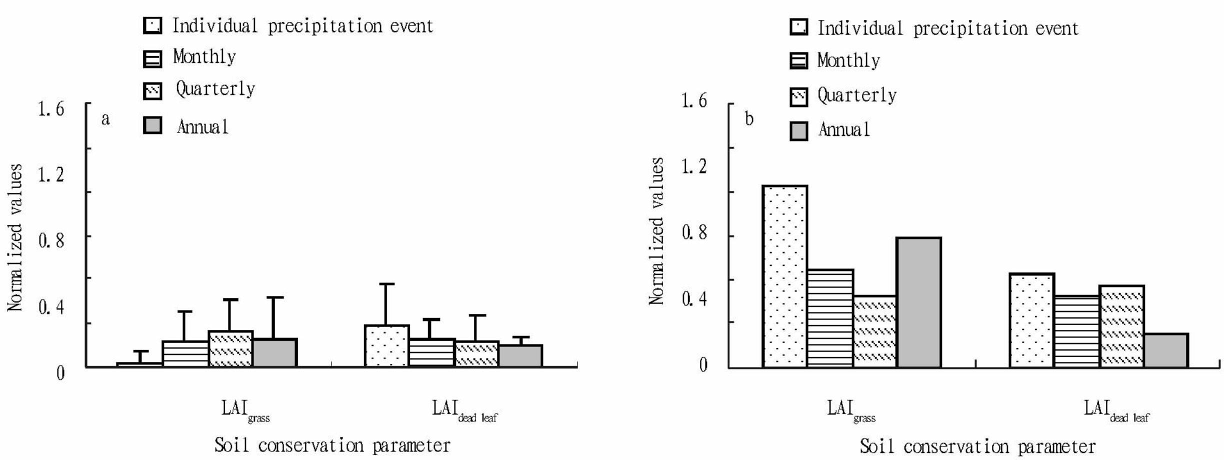

Fig. 4 The characteristics of soil conservation parameters on different time scales

Table 2 The estimation of RE optimized model on different time scales

Time scales	*SE* segmentation	Optimized model	R^2	Model No.
Individual precipitation event	$SE<0.5$	$SE=-0.778LAI_{grass}+0.866$	0.614	(8)
	$0.5<SE<1$	$SE=-0.1894\ LAI_{grass}+0.7363$	0.552	(9)
	$1<SE<1.4$	$SE=0.8447\ I_{30}+0.9613$	0.900	(10)
	$SE>1.4$	$SE=1.662I_{30}+1.311$	0.793	(11)
Monthly	Overall	$SE=-0.422I_{30}-0.271LAI_{grass}+0.368$	0.380	(12)
Quarterly	Overall	$SE=-0.696LAI_{grass}+0.848$	0.416	(13)
Annual	Overall	$SE=-0.1803\ P+0.3267$	0.640	(14)

Note: *SE* is soil conservation effect; *P* is the precipitation (mm); I_{30} is the maximum 30 min precipitation intensity (mm/h); LAI_{grass} is the grass leaf area index.

4 Conclusions

Based on the observation data about 144 erosive precipitation events in the experimental plots during 2007 – 2010, this paper analyzes the variation of four categories of parameters (precipitation, vegetation, water conservation and soil conservation) on the individual precipitation event scale, monthly, quarterly and annual scales, and establishes the relationship model between water and soil conservation effect value and all precipitation and vegetation indicators to analyze various elements. The results show that four types of parameters show different values and changes on different time scales, and RE and SE values are relatively stable between time scales or within the time scales by eliminating the impact of the same type of factors. On the individual precipitation event scale with low RE values (< 0.3) and monthly scale, the combined effect of precipitation and vegetation leads to better water conservation effect, while on the individual precipitation event scale with RE values in the interval of (0.3 - 0.4) or (>0.7) and annual scale, the precipitation characteristics dominate the water conservation effect of the study plot ($R^2 > 0.78$). In terms of the soil conservation effect, it is mainly affected by precipitation or vegetation on the individual precipitation event and annual scales, and grass leaf area index can better characterize the positive soil conservation effect of grassland in the study plot ($RE < 1, R^2 > 0.55$) while the maximum 30 min precipitation intensity can accurately characterize the negative soil conservation effect of grassland ($RE > 1$, $R^2 > 0.79$). For both water conservation or soil conservation effects, there are great uncertainties on the monthly and quarterly scales ($R^2 \approx 0.4$), so there is a need to consider more influencing factors. It indicates that on different time scales, the factors influencing soil and water conservation effect of vegetation show different changes and coupling characteristics, so there is a need to be concerned about time scale effect in the study on the soil and water conservation effect of vegetation.

References

[1] ZHENG FL, WANG ZL, YANG QK. The retrospection and prospect on soil erosion research in China [J]. Chinese Journal of Nature, 2008,30(1):12 -16. (in Chinese).

[2] Fekete B M, V r smarty C J, Lammers R B. Scaling gridded river networks for macroscale hydrology: Development, analysis, and control of error [J]. Water Resources Research,2001,37(7):1955 - 1967.

[3] QIU Y, FU BJ. Spatial variation and scale variation in soil and water loss in heterogeneous landscape:A review [J]. Acta Ecologica Sinica,2004,24(2): 330 -337. (in Chinese).

[4] LI P, LI ZB, ZHENG LY. Advances in researches of the effectiveness for vegetation conserving soil and water [J]. Research of Soil and Water Conservation, 2002,9(1):76 -80. (in Chinese).

[5] YU XX, ZHANG XM, WU SH, *et al*. The effect of vegetation and precipitation upon runoff and sediment production in sloping lands of Loess Area [J]. Journal of Mountain Research,2006,24(1):19 -26. (in Chinese).

[6] PENG SY, GU ZJ, XIU P. Multiple comparison of effect of tree, shrub and grass in the plot on soil and water conversation in the red soil area of Southern China [J]. Research of Soil and Water Conservation,2013,20(1):25 - 29. (in Chinese).

[7] Chirino E, Bonet A, Bellot J, *et al*. Effects of 30-year-old Aleppo pine plantations on runoff, soil erosion and plant diversity in a semi-arid landscape in south eastern Spain[J]. Catena,2006,65:19 -29.

[8] ZHANG QC, LIU BY, ZHAI G. Review on relationship between vegetation and soil and water loss [J]. Research of Soil and Water Conservation,2002, 9(4):96 -101. (in Chinese).

[9] Zhang B, Yang Y S, Zepp H. Effect of vegetation restoration on soil and water erosion and nutrient losses of a severely eroded clayey Plinthudult in southeastern China[J]. Catena,2004,57:77 -90.

[10] Zhou Z C, Shangguan Z P, Zhao D. Modeling vegetation coverage and soil erosion in the Loess Plateau Area of China[J]. Ecological Modelling,2006, 198 (1/2):263 -268.

[11] WANG S, WANG QJ, DONG WC, *et al*. Runoff and sediment generations and nutrient losses under different vegetation coverage in loess slope [J]. Journal of Soil and Water Conservation, 2012,26(4):23 - 27. (in Chinese).

[12] ZHANG X, YU X, WU S, *et al*. Effects of forest vegetation on runoff and sediment production on sloping lands of Loess area[J]. Chinese Journal of Applied Ecology,2005,16(9):1613 - 1617.

[13] ZHENG H, CHEN F, OUYANG Z, *et al*. Impacts of reforestation approaches on runoff control in the hilly red soil region of Southern China[J]. Journal of Hydrology,2008,356 (1/2):174 - 184.

[14] SUN JJ, YU DS, SHI XZ, *et al*. Comparison of between LAI and VFC in relationship with soil erosion in the red soil hilly region of South China [J]. Acta Pedologica Sinica,2010,47(6):1060 - 1066. (in Chinese).

[15] Panicker G K, Tiwari SC, Bunch J, *et al*. Research on biomass development and residue decomposition of horticultural crops for erosion prediction models: Philosophy and methodology of data collection[J]. Acta Horticulturae,2004,638:53 -58.

[16] WANG XQ, MA LY, JIA ZK, *et al*. Research and application advances in leaf area index (LAI) [J]. Chinese Journal of Ecology, 2005,24(5):537 -541. (in Chinese).

[17] GU ZJ, LIU YM, LU JY. Accuracy analysis of vegetation leaf area index (LAI) derivation from remote sensing data at different radiometric correction levels [J]. Acta Pedologica Sinica,2010,47(6):1067 - 1074. (in Chinese).

[18] WANG JQ, LU ZH. Study on impact of land use changes on the hydrological system [J]. Advance in Earth Sciences,2003,18(2):292 -298.

[19] LI R, LI Y, LIU YF, Study of rainfall and soil erosion on slope in Karst Region of Guizhou Province[J]. Research of Soil and Water Conservation, 2012,19(3):7 - 11. (in Chinese).

[20] NIE XJ, SU YY. Characteristics of soil erosion on sloping farmlands in a purple hilly region of the Sichuan Basin [J]. Ecology and Environment, 2012,21(4):682 -686. (in Chinese).

[21] LU KX, LI ZB, JU H, *et al*. Study on a comparison of runoff erosion power and rainfall erosivity for single rainstorm event under different spatial scales [J]. Journal of Northwest A & F University(Natural Science Edition) ,2009,37(10):204 - 209. (in Chinese).

[22] De Vente J, Poesen J, Verstraeten G, *et al*. Spatially distributed modeling of soil erosion and sediment yield at regional scales in Spain[J]. Global and Planetary Change,2008,60(3 -4):393 -415.

[23] FENG YL, LI YB, CHENG XL, *et al*. The spatial - temporal variation characteristics of the different geological conditions of soil erosion in the downtown area of Chongqing [J]. Journal of Soil and Water Conservation, 2011,25(5):30 -34. (in Chinese).

[24] JIAO JY, WANG WZ, HAO XP, *et al*. Precipitation and erosion characteristics of rain - storm in different pattern on Loess Plateau [J]. Journal of Arid Land Resources and Environment, 1999, 13 (1): 34 - 42. (in Chinese).

[25] LIU ZJ, LIU ZR, WANG SS, *et al*. Spatiotemporal variation of rainfall erosivity in Yimeng Mountainous area based on daily rainfall [J]. Research of Soil and Water Conservation, 2012, 19 (2): 34 - 38. (in Chinese).

[26] Andreu V, Imeson A C, Rubio J L. Temporal changes in soil aggregates and water erosion after a wildfire in a Mediterranean pine forest[J]. Catena, 2001,44(1):69 - 84.

[27] WU M, HE BH, WANG RL. Study on runoff and soil erosion in purple soil deep hilly region in northern Sichuan [J]. Research of Soil and Water Conservation, 2013,20(1):9 - 13. (in Chinese).

[28] Wischmeier WH, Smith DD. Rainfall energy and its relationship to soil loss[J]. Transmission. AGU, 1958,39:285 -291.

[29] YANG YT, WANG NH, WANG P. Conprehensive evaluation of environmental effects from land change in Hotan Oasis, Xinjiang[J]. Agricultural Science & Technology, 2014, 15(4):653 -658.