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Detecting water yield variability due to the small proportional land use and land cover changes in a watershed on the Loess Plateau, China

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Abstract:

Soil conservation practices have been widely implemented on the Loess Plateau to reduce severe soil erosion in north-central China over the past three decades. However, the hydrologic impacts of these practices are not well documented and understood. The objective of this study was to examine how water yield has changed after implementing soil conservation practices that resulted in changes in land use and land cover in a small agriculture-dominated watershed, the LuErGou Watershed in Tianshui City, Gansu Province, China. We collected 23 years of hydro-meteorological data along with three land use surveys of 1982, 1989, and 2000. The land use survey in 2000 suggested that the soil conservation efforts resulted in a 16·6%, 4%, and 16% increase in area of grassland, forested land, and terraces respectively over the two periods from 1982 to 1988 (baseline) and 1989 to 2003 (soil conservation measures implemented). Rainfall–runoff regression models developed for both time periods at the annual and monthly time steps were used to examine the significance of change in water yield in the second time period. The averaged annual run-off coefficient over 1989–2003 did not change significantly (at the $\alpha = 0{\cdot}05$ level) as compared to that in the period 1982–1988. However, we found that soil conservation practices that included re-vegetation and terracing reduced water yield during wet periods. This study highlights the importance of the precipitation regime in regulating hydrologic effects of soil conservation measures in a semi-arid environment. We concluded that adequately evaluating the effects of land use change and soil conservation measures on water yield must consider the climatic variability under an arid environment. Copyright © 2009 John Wiley & Sons, Ltd.

KEY WORDS small proportional land use and land cover change (SPLULCC); prediction interval; water yield; small watershed; the Loess Plateau

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INTRODUCTION

The Loess Plateau of the Yellow River Basin in north-central China is one of the world-known regions experiencing severe soil erosion and land degradation. The latest national survey indicated that over 71% of the plateau had an average soil erosion rate of over 1000 t km^{-2} year^{-1} (Li, 2003). Loose soil structure, steep slopes, low soil infiltration capacity, high rainfall intensity, and intensive human disturbances all contribute to the high soil erosion rate. To effectively improve ecological conditions of the Loess Plateau, integrated watershed measures that consisted of biological, structural, and institutional measures have been applied during the past decades.

However, recent studies have suggested that soil conservation measures have contributed significantly to the observed decrease in the stream flow of major tributaries of the Yellow River along with playing a significant role in reducing river sedimentation (e.g. Huang and Liu, 2002; Mu *et al.*, 2007; Zhang *et al.*, 2008a). Consequently, concerns exist regarding the implications of large-scale reforestation and soil conservation practices on aggravating the regional water shortage and frequent zero-flow in the lower reaches of the Yellow River (McVicar *et al.*, 2002, 2007a; Sun *et al.*, 2006).

Recent studies have focused on land use change impacts on the water yield in addition to evaluating the hydrologic effects of reforestation at slopes and watershed scales in the region; these have been summarized by McVicar *et al.* (2007b). Perhaps representing the first creditable literature that established the relationship between forest cover and stream flow for the Loess Plateau region, Liu and Zhong (1978) reported that the mean stream flow of the forested area was 27% lower than that of the non-forested area. Huang and Liu (2002) reported similar observations, but suggested that the reduction in flow occurred mostly during the flooding season (June to September) and forests' effects were marginal from October to May due to the sponge effect of forested land. Wang *et al.* (2004) reported that the accumulated total water yield of a reforested watershed reduced by 37% over a 44-year period

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(1956–2000) when compared to the water yield from an adjacent grassland watershed, and these reductions primarily occurred from June to September, which is the rainy season. Li *et al.* (2007) quantified the disparate effects of land use change and climate change on the stream flow of a 30 261 km^2 Wuding River located in the middle reaches of the Yellow River. They concluded that soil-conservation-induced land use change alone contributed over 87% of the stream flow reduction during 1972–1997. This study also found that the reduction in stream flow occurred mostly in the rainy months (i.e. July and August). Mu *et al.* (2007) report that three of the four catchments that were examined show significant changes in the daily stream flow over two 20-year periods due to soil conservation measures. Most recently, Zhang *et al.* (2008a) simulated the hydrological impacts of afforestation on the average annual stream flow in the Loess Plateau, showing that the stream flow of the region would decrease by 5·5% and 9·2% under two plantation scenarios, and that the rate of stream flow reduction tends to decrease from southeast to northwest due to the decreasing precipitation. Using long-term hydrologic monitoring data accumulated in major rivers in the Yellow River Basin, Zhang *et al.* (2008b) quantified the effects of land use change and climate change on river flow patterns and provided the best evidence that soil conservation was responsible for the observed decrease in stream flow on a rather large scale. To transform the scientific findings on the stream flow and vegetation changes into practical soil and water conservation planning, McVicar *et al.* (2007b) developed a decision-supporting tool for China's re-vegetation programme in the Loess Plateau.

While high temporal and spatial variability of hydrologic responses to land disturbances have been well recognized (Andreassian, 2004), nearly all the classical paired watershed studies were conducted in the catchments with uniform land uses (Lorup *et al.*, 1998; Costa *et al.*, 2003) and, with the changed area of more than 20%, the general assumed threshold value to detect yield change by hydrological measurements (Hibbert 1967; Bosch and Hewlett, 1982; Stednick, 1996). Deforestation/afforestation and the vegetation type conversion were usually the main land use change activities (Brown *et al.*, 2005). Few studies have been conducted in watersheds with mixed land uses (Lorup *et al.*, 1998) where various land management activities are present. The hydrological effects of human-induced land use changes were more complex and not well understood (Lorup *et al.*, 1998; Schreider *et al.*, 2002; Bruijnzeel, 2004). The inherent heterogeneity and spatial variability of a watershed and the distribution of different land uses is important in affecting catchment hydrology (Schulze, 2000), as compensating effects of water storage and release mechanism may occur within the same watershed (Fohrer *et al.*, 2001). This further complicates the hydrological response to small proportional land use and land cover changes of a watershed (i.e. less than 20% of the catchment area, SPLULCC). Evaluating the various impacts of land use (e.g. terracing, check dams, intercropping, and site preparation) and land cover (e.g. vegetation) on watershed hydrology is critically important for integrated land and water resource management (Calder, 2005).

Therefore, the overall goal of this study was to investigate whether, and how, the hydrological regime was affected by the SPLULCC as a result of vegetation-based soil conservation practices. In particular, our objectives were to (1) test the significance of the water yield change to the SPLULCC in the watershed by means of the prediction interval and (2) explore how the watershed hydrology might respond to the SPLULCC.

WATERSHED DESCRIPTION

The LuErGou watershed is located south of Tianshui City, Gansu Province in north-central China, with a total area of 12·0 km^2, and an elevation ranging from 1200 to 1720 m (Figure 1). The continental monsoon climate dominates this region. The average (1982–2003) annual potential evapotranspiration was around 836 mm $year^{-1}$, and the average (1982–2003) annual precipitation was 570 mm $year^{-1}$, among which over 80% occurred from May to October (Figure 2). The high rainfall intensity, the loose soil properties, and the sparse vegetation cover has meant that the average annual soil erosion rate of the watershed was over 2500 t km^{-2} $year^{-1}$ during the period of 1982–2000 (Zhang *et al.*, 2005). Although measures have been implemented recently to improve vegetation conditions in the watershed, over-grazing and droughts negatively affected the vegetation growth of young plantations. In addition to forested land and grass land, the watershed was dominated by agricultural land. Several residential villages were scattered across the watershed, and the total population was around 1825 in 2000.

METHODS

Data collection

Hydro-meteorological datasets for the period from 1982 to 2003 were acquired from the local soil and water conservation experimental station (N34°34′, E105°43′, elevation 1100 m). Rainfall records were collected from the upper, middle, and downstream of the watershed with elevations of 1555, 1455, and 1200 m respectively. As elevation was not found to be an important factor when spatially interpolating precipitation in the Loess Plateau (McVicar *et al.*, 2007a), the daily arithmetic average was used. The mean daily precipitation over the observation period was 5·3 ± 7·5 mm, and the maximum was 66·4 mm (1 June, 1992). Stream flow was estimated by measuring the water level and flow velocity using the floating method (Mosley and Mckerchar, 1993) at the watershed outlet with a varied time interval of 0·5 to 12 h. The daily stream flow was determined by integrating all the measurements on each day (Table I).

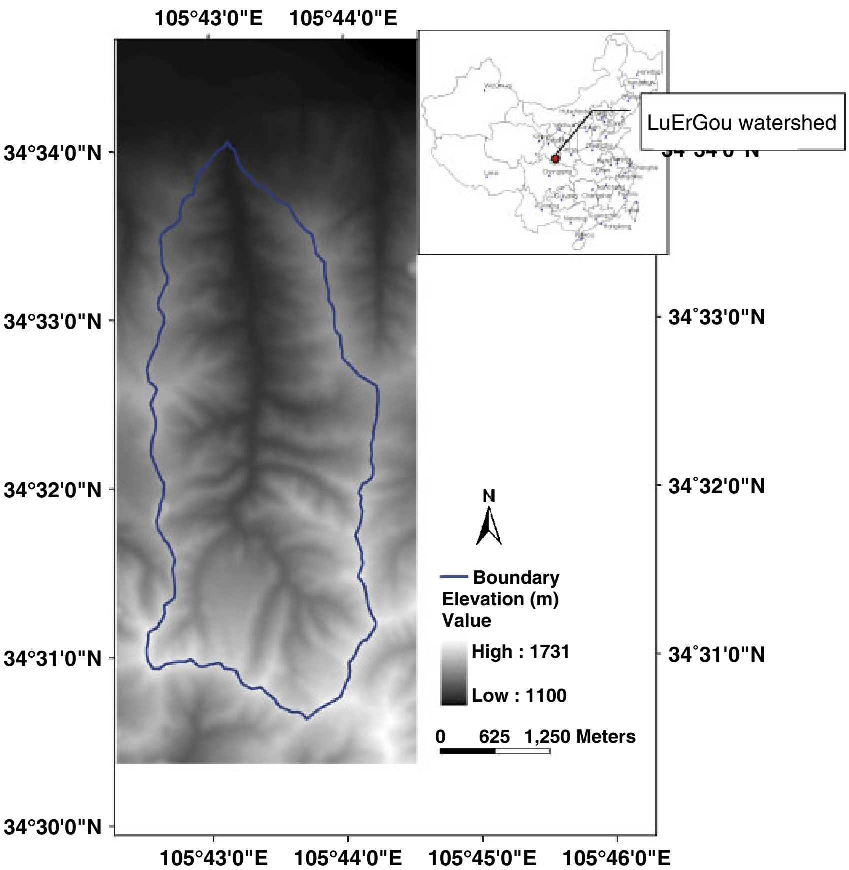

Figure 1. Location and topography of LuErGou watershed on the Loess Plateau of the Yellow River Basin in north-central China

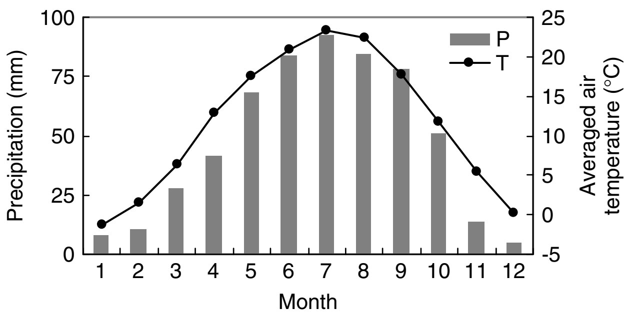

Figure 2. Distribution of average monthly precipitation and monthly air temperature over 1982–2003. *P* stands for precipitation and *T* for air temperature

Table I. Statistics of daily run-off $(m^{-3}\ s^{-1})$ from 1982 to 2003

Statistics	Value
Mean	0·012
SD (standard deviation)	0·060
Maximum	1·9
Minimum	0

In addition, the surface air temperature was acquired from a local meteorological station (N34°35′, E105°45′), approximately 1 km away from the study watershed.

Three land use surveys of 1982, 1989, and 2000 on a 1 : 10 000 scale were provided by Tianshui Soil and Water Conservation Experimental Station. Analysis indicated that the land use was quite different between 1982 and 1989, whilst few changes occurred from 1989 to 2000. Therefore, land use data of 1982 and 1989 were retained in the analysis to detect the impacts of land use change. Owing to the various land use classes presented in the two land use surveys, land uses for both periods were re-categorized without changing their land use nature. For instance, 'pasture' and 'natural meadow' were grouped into 'grassland', while 'village', 'factory', 'roads', and 'graveyard' were aggregated into 'residential'. The reclassified land uses, thus, included forested land (canopy coverage $\geq$30%), level terrace, sloping crop land (slope $>$15°, according to the original land use survey), sparse woodland (10% $\leq$ canopy coverage $<$30%), grassland, shrub, orchard, and residential.

Regression analysis

Regression analysis was used to eliminate the climate effect from that of the land use and land cover changes in the single watershed study (Trimble *et al.*, 1987). Once the rainfall–runoff relationship is established either before or after the treatments, the effects of land use change on water yield can be determined by comparing measured and predicted values (Trimble *et al.*, 1987; Lavabre *et al.*, 2000; Costa *et al.*, 2003).

As precipitation (P) is usually the dominating forcing for rainfall–runoff analysis for the Loess Plateau, the simple form of regression equation between annual or monthly water yield (Q) and P with an intercept of the fitting line was firstly used in this study (e.g. Lavabre *et al.*, 2000). To account for the effects of antecedent soil moisture on event run-off, potential evapotranspiration (*PET*) and antecedent precipitation (P'), both affecting the actual *ET* and antecedent soil moisture status, were introduced. Hamon's formulation (Hamon, 1963; Lu *et al.*, 2005) of potential *ET* was used primarily due to data limitation, and, while it did not consider all meteorological variables that were shown to change, including radiation (e.g. Stanhill and Cohen 2001; Wild *et al.*, 2004; Roderick 2006) and wind speed (e.g. Roderick *et al.*, 2007; McVicar *et al.*, 2008) that partly govern actual and potential evapotranspiration, such changes are considered to be negligible here due to the relatively short time-period involved. Previous studies suggest that Hamon's formulation of *PET* offers comparable results to that of Priestley–Taylor's equation and Turc's equation (Lu *et al.*, 2005; Sun *et al.*, 2006).

After aggregating the daily run-off observations to annual and monthly time-steps, respectively, both simple and multivariate linear regression equations (Table II) were established, respectively, on the basis of the pooled monthly and annual data for both land use periods (i.e. 1982 to 1988 and 1989 to 2003).

Prediction interval

To justify if the difference between the prediction and the measurement was due to the land use change rather than due to the estimation errors, the prediction interval was calculated for yearly and monthly water yield estimates, respectively (e.g. Hirsch *et al.*, 1993; Serengil *et al.*, 2007). If the measurement of run-off is outside the prediction interval, it is considered to be significantly affected by land use change and, if the measurement of run-off is in the band of the prediction interval, it cannot be considered to be significantly affected by land use change. It should be noted that the specification of α degree certainly determines the number of points contained in the prediction interval (i.e. around $\alpha/2 \times 100\%$ of the data beyond each side of intervals if the residuals are approximately normal).

Unlike confidence intervals, the prediction interval is usually computed to deal with individual data values as opposed to a summary statistic such as the mean (Hirsch *et al.*, 1993). It is a representation of the range of values that an individual y_0 might take on for a given x_0. It incorporates the parameter uncertainty as well as the unexplained variability of y, and is wider than the corresponding confidence interval (Hirsch *et al.*, 1993; Serengil *et al.*, 2007). For a simple linear regression model, prediction interval (*PI*) for the estimate of y_0 with a given input value of x_0 is calculated as follows:

$$PI = \hat{y}_0 \pm t \times s \left(1 + \frac{1}{n} + \frac{(x_0 - \overline{x})^2}{SS_x}\right)^{1/2} \quad (1)$$

where $\hat{y}_0$ is the best estimation of Y according to $X = x_0$, $\overline{x}$ is the mean of the observations, n is the sample size of observation, t is the quantile of the student's t-distribution having $n - 2$ degrees of freedom with probability in excess of $\alpha/2$ ($\alpha/2$ was taken as 0·05 in this study), s is the standard error of the regression, and SS_{x} is the sum of squares of x.

The prediction interval (*PI*) was estimated for multivariate linear regression as well. For a single response y_0, given a point x_0 in multi-dimensional space, the prediction interval is symmetric around the regression estimate

Table II. Linear regression equations established for both periods

	Period	Regression model	Number of points falling outside of the band
Annual	1982–1988	$Q = 0{\cdot}23P - 91{\cdot}8$ ($R^2 = 0{\cdot}58,\ p = 0{\cdot}03$) (3)	2 (28·6%*)
	($n = 7$)	$Q = 0{\cdot}171P + 0{\cdot}127P' - 0{\cdot}531PET + 288{\cdot}57$ ($R^2 = 0{\cdot}754,\ p = 0{\cdot}144$) (4)	2 (28·6%*)
	1989–2003	$Q = 0{\cdot}205P - 90{\cdot}599$ ($R^2 = 0{\cdot}85,\ p < 0{\cdot}001$) (5)	0
	($n = 15$)	$Q = 0{\cdot}198P - 0{\cdot}017P' - 0{\cdot}037PET - 46{\cdot}613$ ($R^2 = 0{\cdot}82,\ p < 0{\cdot}001$) (6)	0
Monthly	1982–1988	$Q = 0{\cdot}105P - 1{\cdot}431$ ($R^2 = 0{\cdot}49,\ p < 0{\cdot}001$) (7)	—
	($n = 84$)	$Q = 0{\cdot}103P + 0{\cdot}072P' - 0{\cdot}07PET - 0{\cdot}596$ ($R^2 = 0{\cdot}63,\ p < 0{\cdot}001$) (8)	—
	1989–2003	$Q = 0{\cdot}065P - 1{\cdot}262$ ($R^2 = 0{\cdot}33,\ p < 0{\cdot}001$) (9)	11 (6·1%*)
	($n = 180$)	$Q = 0{\cdot}086P + 0{\cdot}013P' - 0{\cdot}046PET + 0{\cdot}354$ ($R^2 = 0{\cdot}38,\ p < 0{\cdot}001$) (10)	11 (6·1%*)

In which, Q is water yield (mm); P is precipitation (mm); P' is the precipitation in the previous time period (mm); *PET* is the potential evapotranspiration (mm), estimated with Hamon's model (Lu *et al.*, 2005). All of regression models were with $\alpha = 0{\cdot}05$. "* " the percent of number of the points falling outside of the band.

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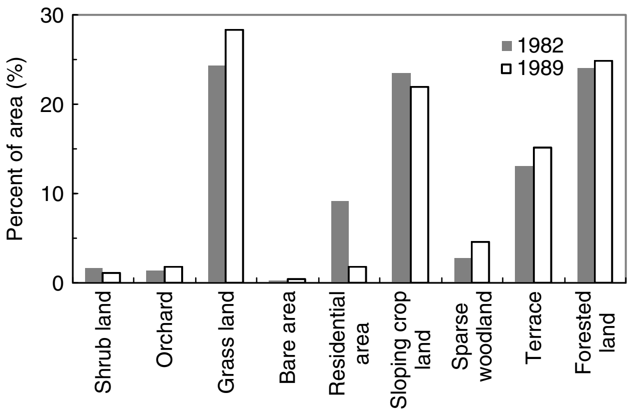

Figure 3. Land use surveyed in 1982 and 1989 representing two periods, 1982–1988 and 1989–2003, respectively

$\hat{y}_0$, and it is calculated as follows:

$$PI = \hat{y}_0 \pm t_{(\alpha/2,n-p)}\sqrt{s^2\left\langle\left(1 + x_0'\ (X'X)^{-1}x_0\right)\right\rangle} \quad (2)$$

where X is a matrix comprising values of p explanatory variables for each of the n observations, along with a vector for the intercept term; the other symbols are similar to those defined in Equation (1). We used the DPS 7·05 (http://www.chinadps.net) for the matrix operation and SPSS 13·0 for calculation of both s and SS_x.

RESULTS

Land use and land cover change

Comparing the dominant land uses for both periods between 1982 to1988 and 1989 to 2003, grassland and forested land areas increased by 16·6% and 4·0% respectively (Figure 3). Terraces, an influential land use in trapping run-off and sediment loads (Mu *et al*., 2007), increased by 16% as well. The sloping field, a major source of sediment yield, decreased by 6·5%. Owing to part of the residential area, which was originally used for roads and graveyard in the first period, being converted to either forested land or grass land in the second period, the residential area decreased by 80·6%. The other land uses such as the shrub, orchard, bare land, and sparse wood land displayed various small degrees of changes (<5%) (Figure 3).

Table III. Statistics of the annual run-off coefficient for both periods

Statistics	Period 1 (1982–1988)	Period 2 (1989–2003)
Mean (X)	0·07	0·03
SD	0·05	0·04
C_v	0·77	1·09
Maximum	0·168	0·114
Minimum	0·014	0·003

In which, *SD* is standard deviation, C_v is the coefficient of variation (*SD/X*, %). The period is defined by the calendar year.

Comparison of annual run-off coefficient

A statistical analysis has suggested that the mean annual run-off coefficient for the first period (i.e. 1982 to 1988) was higher than that of the second period (i.e. 1989 to 2003), being 0·07 and 0·03 respectively (Table III). Both periods present high variability with a C_V of 0·77 for the first period and 1·09 for the second, respectively. The confidence interval of the difference between mean annual run-off coefficients for the two periods ranged from −0·01 to 0·09. The inclusion of zero value in the range indicated that the difference of mean annual run-off coefficient was insignificant ($a = 0{\cdot}05$) between the two periods.

Detecting water yield changes by a simple linear regression model

Simple linear regression models were established for both periods (Table II). By running the model with the precipitation of the other period, the annual water yield of altered land use was estimated for that period. This ensured the same climate condition in comparison with the water yield measurement with the prediction of altered land use. Except for 1984 and 1985, the water yield measurements in the first period fell in the band of their prediction intervals (Figure 4a). This suggested that the land use and land cover change had no influence on the annual water yield except for 1984 and 1985, which both received high rainfall measuring 804 and 697 mm respectively (Figure 5). The reductions in the annual water yield for 1984 and 1985 were estimated to be 20·8 and 5·2 mm respectively. No significant changes were detected in the water yield (Figure 4b) with this method

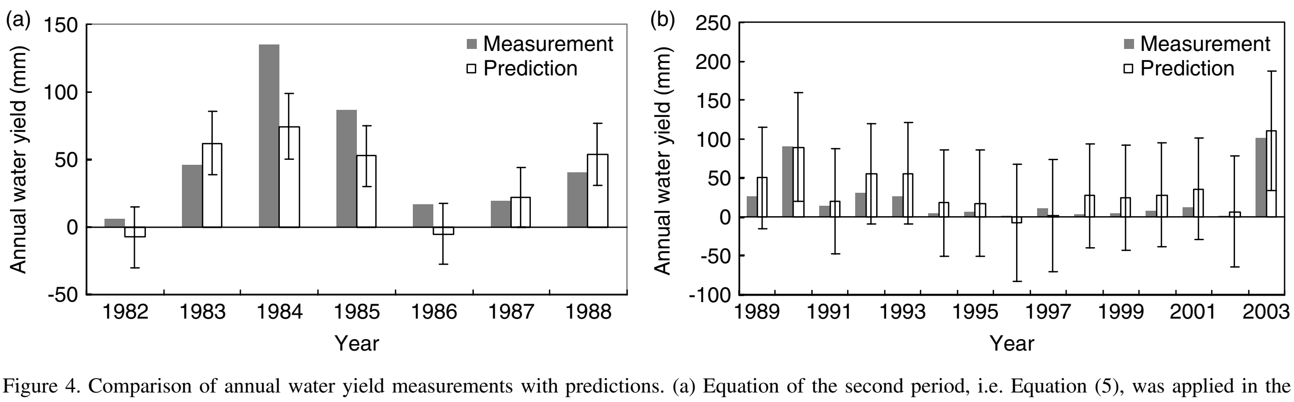

Figure 4. Comparison of annual water yield measurements with predictions. (a) Equation of the second period, i.e. Equation (5), was applied in the first period; (b) Equation of the first period, i.e. Equation (3), was applied in the second period. The error bars represent the prediction interval

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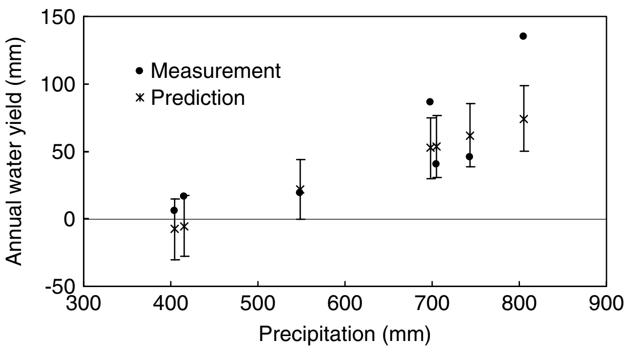

Figure 5. Scatter plot of annual water yield against precipitation. The prediction was estimated with the equation of the second period, i.e. Equation (5), and the error bars represent the prediction interval

for the second period that had a relatively wide range of prediction intervals. Most years of the second period were dry (except for 1990 and 2003) with an average precipitation of 509 mm. During the whole study period, the two years receiving high rainfall in 1983 and 1988 were also not identified with significant yield change; a detailed explanation for the above is given in the section on Discussion below.

The effects of SPLULCC on the monthly water yield were explored using the monthly regression equations in a similar manner to what was previously implemented at the annual time step. The derived equation of the first period (Equation 7) was used in the following analysis (Table II), whereas the equation derived from the second period (Equation 9) was not used due to its low determination coefficient (0·33). According to the method of the prediction interval, it was expected that 5% of data would fall beyond each side of intervals if a was specified as 0·1. Even though the number of points identified as having significant yield changes ($a = 0{\cdot}1$) was only 6·1% of the total (Table II), most of the identified points appeared when the measured monthly water yield was lower than their corresponding prediction (Figure 6). The statistically skewed distribution means that at least the effect of the SPLULCC on run-off reduction occurred on those months (Figure 6). The estimated reduction in the monthly water yield varied from 0·3 to 2·5 mm. Three points behaved in opposition to water yield reduction with an increased water yield of 1·7, 1·8, and 25 mm, respectively (Figure 6). A detailed explanation for this is given in the section on Discussion below. Similar to the annual basis, most of the points with detectable monthly yield reduction appeared when the monthly precipitation exceeded 100 mm (Figure 7); this usually occurred from June to October.

Detecting yield change by multivariate linear regression model

The annual multivariate model for the second period produced similar results to those derived from the simple linear regression (Figure 8), suggesting annual yield changes of 34 mm for 1984 and 8 mm for 1985, respectively. However, the significance test using the improved rainfall–runoff relationship on a monthly basis showed little difference. In addition to the number of points identified as significant yield changes remained as in the previous test, several points receiving relatively lower precipitation were identified in this test (Figure 9). The monthly change was estimated to be −5·2 to 14·5 mm. The detected changes were corresponding to the months with higher rainfall (Figure 10a) or with low PET/rainfall ratio (Figure 10b), respectively.

DISCUSSION

Our analysis showed that water yield changes in response to the SPLULCC occurred mostly in wet periods and the findings may explain our previously studied results that show no effects of land use and land cover change on an annual scale over a long-term period (Wang *et al.*, 2008). There was a notation that stream flow changes are not detectable without large changes in land cover, usually 20% (Bosch and Hewlett, 1982; Stednick, 1996). Apparently this may not hold true in the case of land use change scenarios that are more often associated with larger disturbances of soils in addition to land cover. In fact, a few of studies have reported detectable hydrological effects of land use changes of less than

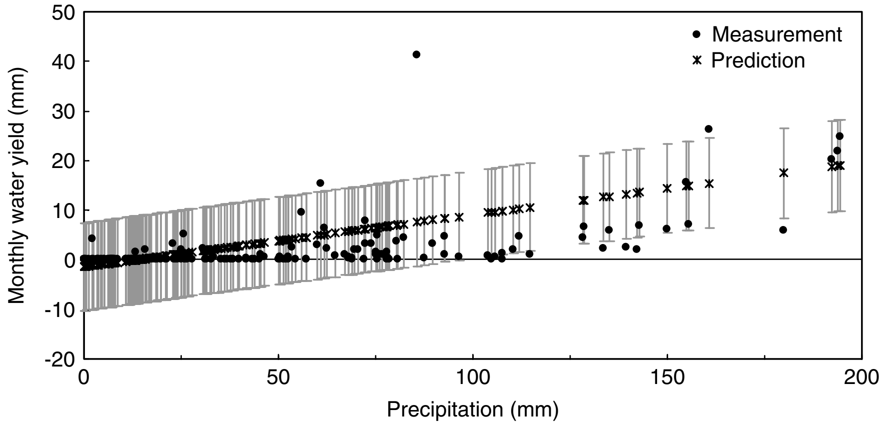

Figure 6. Scatter plot of monthly water yield against precipitation. The prediction was estimated with the equation of first period, i.e. Equation (7). The error bars represent the prediction interval

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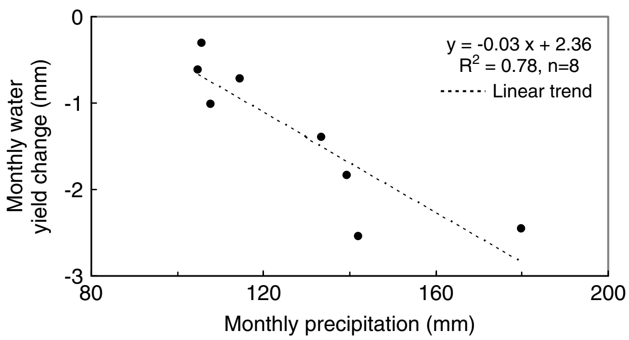

Figure 7. Scatter plot of the change in monthly water yield estimation (dQ) against monthly precipitation. d$Q = Q_{_measurement} - (Q_{_prediction} - PI)$. The prediction was estimated with the equation of the first period, i.e. Equation (7)

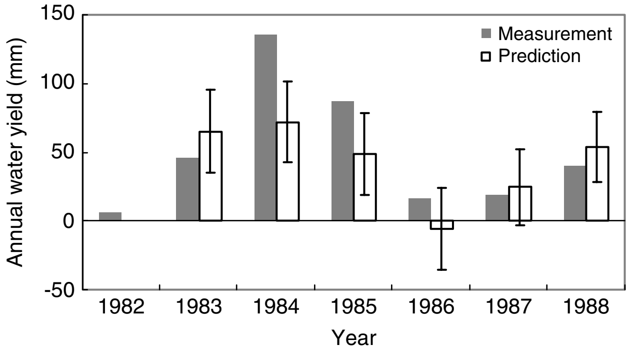

Figure 8. Comparison of annual water yield measurements with predictions together with their prediction intervals. The prediction was estimated with the equation of the second period, i.e. Equation (6), and the explanatory variables of the prediction include precipitation, potential evapotranspiration, and the antecedent precipitation. For 1982, there is no P data of previous year, hence there is no prediction for this year. The error bars represent the band of prediction interval

20% (e.g. Sahin and Hall, 1996; Serengil *et al*. 2007). Besides the land surface, various other causes of detecting significant hydrological impacts, including the magnitude and intensity of precipitation, soil properties (or soil disturbance), relief of watershed, and location of the treatment were all assumed to exert potential influence on hydrological effects of land use and land cover change.

Effects of terracing on hydrologic response

Apart from the characteristics of uniform land use in most previous studies, our research watershed was covered by various land uses and was highly fragmented. According to the minimum land use change reported by other related studies, it was hard to acknowledge that the sole change in land cover between the two periods was enough to induce a detectable yield change. Nevertheless, terracing, as one of major soil conservation practices in the Loess Plateau, has been proven to be effective in impounding water and trapping sediment (e.g. Tang *et al*., 1983), and the terrace in the watershed had a relative increase of 16%. Even though no measurement was made for the individual effects of each land use, it was reasonable to assume that the increase in terracing in the watershed facilitated, to a certain degree, the benefit of vegetation-based practices on water and soil conservation. Therefore, it was possible to observe a detectable yield change in response to the integrative effects of the SPLULCC.

Effects of rainfall magnitude on hydrologic response

The detected hydrological effect of land use and land cover change was observed to exhibit dependence on the magnitude of precipitation. As previously stated, the effects appeared only in two of the wet years with precipitations of 697 and 804 mm, and in a few specific months when precipitation was more than 100 mm (Figures 6 and 7). This generally agrees with the findings of Bosch and Hewlett (1982), where it was reported that the yield change was greatest in high-rainfall areas and the hydrological response depended on both mean annual precipitation and specific precipitation of the year under treatment. For a water-stressed region such as the study area, it was reckoned that, after a long-time period of drying, subsequent rainfall would usually firstly more or less replenish the soil moisture storage, which would mean the amount of water available for generating run-on and run-off would decline. In our research watershed, measurements of soil moisture were not made, yet the long

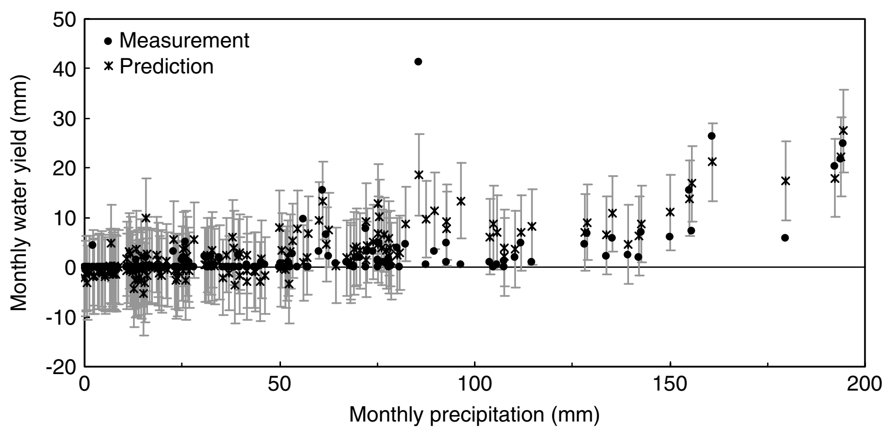

Figure 9. Scatter plot of monthly water yield against precipitation. The prediction was estimated with the equation of the first period, i.e. Equation (8), and the explanatory variables include precipitation (P), potential evapotranspiration (PET), and precipitation in the previous year (P'). The error bars represent the prediction interval

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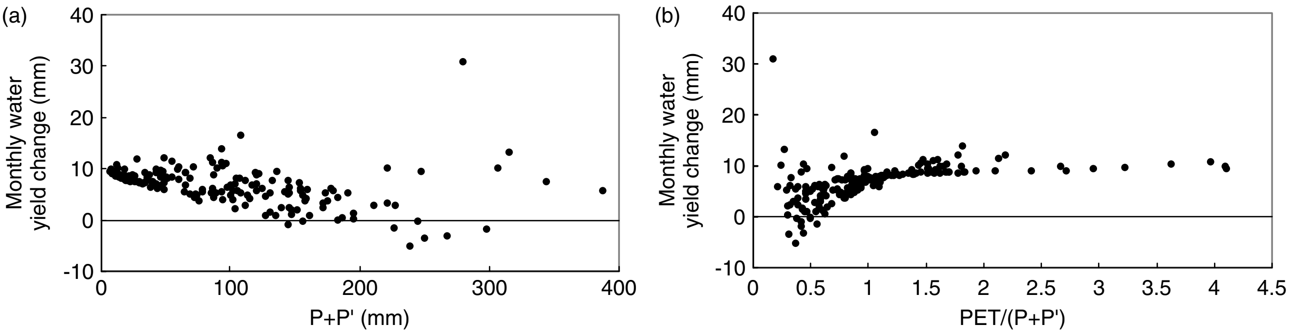

Figure 10. Scatter plot of the changes in monthly water yield dQ against (a) $(P + P')$ and (b) $PET/(P + P')$. $dQ = Q_{\_measurement} - (Q_{\_prediction} - PI)$, the negative value indicates where the change is significant ($\alpha = 0{\cdot}05$). The prediction was estimated with the equation of the first period, i.e. Equation (8), and the explanatory variables of the prediction include precipitation (P), potential evapotranspiration (PET), and the precipitation in previous year (P'). PI is the prediction interval

time period of climate drying with average annual precipitation of 570 mm was assumed to induce excessive consumption of soil moisture stores. The previous soil survey conducted by the experimental station indicated that the percentage of sand, silt, and clay of the upper layer soil (0–30 cm) in the watershed was generally 10·9%, 48·0%, and 41·2% respectively. This implies that more rainfall was required to increase the wetness of soil water before a detectable yield change would be observed.

Effects of antecedent precipitation on hydrologic response

The reliance of change detection on the magnitude of precipitation does not mean that a high rainfall amount was the only necessary explanatory variable in detecting yield change related to SPLULCC. In fact, we observed several identified points showing detected yield changes where only low rainfall was experienced in those months that had the opposite trend to that expected (Figures 6 and 9). Antecedent rainfall might account for much of this variability. Statistics suggested that, for most of the months from June to October, there were significant correlations ($a = 0{\cdot}05$) between monthly water yield and preceding precipitation in the previous month, with partial correlation coefficient of 0·47 to 0·68. In Figures 6 and 9, the points of lower rainfall amount, and those displaying opposite trend effects, occurred when high precipitation was received in the previous months, being around 155 to 194 mm. Conceptually, this should lead to an increase in the antecedent soil moisture content, with more subsequent rainfall producing run-on and run-off and hence the measurements for the months in question were likely much higher relative to the predictions, showing unexpected detectable yield changes.

The effects of antecedent precipitation have also partly explained the behaviour of a few points that were of higher precipitation, although they did not show any identified yield change in Figure 6. Owing to the replenishment of soil stores by the antecedent precipitation, the water yield increased with the increase in antecedent soil water content, which caused the measurement to become higher than expected when the effect of antecedent precipitation was not considered and, therefore, the measurement fell in the margin of the band of the prediction interval and no significant yield change was detected. On the contrary, the lack of soil store replenishment by antecedent precipitation usually resulted in lower measurement, which, therefore, reduced the ability to detect the effects of the SPLULCC on water yield reduction when comparing the measurements with the predictions that were estimated with relatively higher values. Consequently, the years 1983 and 1988 had high amounts of rainfall; but, because each experienced a dry preceding year, the expected yield changes were not present (Figure 5).

Uncertainty of regression models

Although the prediction interval has incorporated the parameter uncertainty as well as the unexplained variability of the dependent variable, uncertainty remained in the model structure, prediction, and its prediction interval. Water yields of several months with a higher magnitude of rainfall availability were not identified with significant yield change, and a few months were even predicted as being negatives. Besides measurement errors, the form of the simple linear regression equation might partially be accounted for that. The predicted monthly water yield was negative (Figure 6) when the precipitation was lower than 14 mm, the threshold value of Equation (7). Similarly, the estimated annual water yield was negative for 1982, 1986, and 1996 (Figure 4), which had precipitations lower than the required threshold values. Application of Equations (6) and (8) with more potential explaining variables did not get the negative predictions removed. It is obviously shown that there existed limitations in applying the linear regression equation to detect the effect of land use and land cover changes. However, the linear regression analysis combined with the interval prediction still provides a rough but simple methodology to detect the hydrological effects of SPLULCC when the data availability is poor for a given studied watershed. In fact, in our case study, when more variables were considered, R^2 increased from 0·49 to 0·63 (Table II; Equation 7 and 8) and prediction intervals reduced from around 8·8

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to 7·6 mm. This implies the importance of considering *P*, *PET*, and antecedent precipitation to detect effects of SPLULCC.

CONCLUSION

Land use/cover change effects on watershed hydrology are neither spatially nor temporally uniform because of its coupling with climate variability (e.g. Li *et al*., 2007; Ma *et al*., 2008; Zhang *et al*., 2008b). This is very important while making land and water management decisions to understand the seasonal and inter-annual water yield regime due to land use changes from a watershed given a specific climate condition. Our analysis indicated that the water yield changes due to SPLULCC in wet years and rainy months, by means of the prediction interval, could be significant. This confirmed previous large-scale studies that soil conservation practices reduced water yield during wet periods. We concluded that the effects of the SPLULCC induced by vegetation-based conservation practices cannot be neglected on the Loess Plateau and that evaluating the hydrologic effects of watershed management practices must consider the climatic variability at multiple temporal scales. There are large trade-offs between soil erosion control measures, ecosystem productivity, water yield from headwater streams, and downstream water availability. Effective tools and decision support systems are needed to optimize the benefits of soil conservation practices and to develop science-based comprehensive watershed management measures (McVicar *et al*., 2007b).

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