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Watershed discretization based on multiple factors and its application in the Chinese Loess Plateau

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Abstract

The spatial discretization of watersheds is an indispensable procedure for representing landscape variations in eco-hydrological research, representing the contrast between reality and data-supported models. When discretizing a watershed, it is important to construct a scheme of a moderate number of discretized factors while adequately considering the actual eco-hydrological processes, especially in regions with unique eco-hydrological features and intense human activities. Because of their special lithological and pedologic characteristics and widespread man-made vegetation, discretization of watersheds in the Loess Plateau in Northern China is a challenge. In order to simulate the rainfall-runoff process, a watershed in the Loess Plateau, referred as Ansai, was spatially discretized into new units called land type units. These land type units were delineated under a scheme of factors including land use, vegetation condition, soil type and slope. Instead of using units delineated by overlaying land use and soil maps, the land type units were used in the Soil and Water Assessment Tool (SWAT). Curve numbers were assigned and adjusted to simulate runoff, using the US Natural Resources Conservation Service (NRCS) curve number method. The results of the runoff simulation better matched actual observations. Compared to the results that used the original units, the coefficient of determination (R^2) and the Nash–Sutcliffe coefficient (E_{NS}) for monthly flow simulation increased from 0.710–0.721 and 0.581–0.656 to 0.726–0.731 and 0.692–0.703, respectively. This method of delineating into land type units is an easy operation and suitable approach for eco-hydrological studies in the Chinese Loess Plateau and other similar regions. It can be further applied in soil erosion simulation and the eco-hydrological assessment of re-vegetation.

1 Introduction

Watersheds are commonly spatially discretized in ecologic and hydrological studies. The purpose of spatial discretization is to objectively represent the differences in

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ecological or hydrological characteristics that exist within the watershed (Kumar et al., 2010; Hellebrand and van den Bos, 2008). By using spatial discretization, a watershed is divided into units, which are treated as statistical objects or calculated units for statistical analysis or simulation. Spatial discretization can be regarded as a tradeoff between reality and a model represented by supported data. The more discretized factors and more detailed discretization, the more reliably the discretization represents the true watershed (Das et al., 2008); however, at the same time, more physical mechanisms and data are needed. Over-parameterization and scaling problems also take effect (Doherty, 2003), so it is crucial to select a moderate number of discretized factors with major influences on the eco-hydrological processes, and have plenty of data and theory to support the discretization.

Spatial discretization most commonly divides a watershed into hydrological response units (HRUs). The crucial assumption for HRU discretization is that the hydrological characteristic variation within a HRU must be minute compared to the dynamics in different HRUs (Flügel, 1995). The parameters within each HRU should be uniform. HRUs are generated by overlaying maps of selected factors.

Based on existing theories and experimental data, researchers can construct a scheme of delineated factors and calculate or simulate the eco-hydrological processes within each HRU. A typical approach for HRU delineation is the combination of land use and soil types (Beldring et al., 2003; Das et al., 2008), which can be seen in a multitude of research and some hydrological models, including the Erosion Productivity Impact Calculator or EPIC (Williams, 1995), SWRRB (Williams et al., 1985; Arnold et al., 1990), Soil and Water Assessment Tools or SWAT (Arnold et al., 1998), etc. Other factor combinations that have been used to determine HRUs are the combinations of land use, topography and aquifers (Blöschl et al., 2008), the combinations of slope, aspect, elevation, soil particle size, soil water holding capacity and vegetation (Legesse et al., 2003), etc.

As far as runoff is concerned, to account for the lack of sub-daily meteorological data, physical soil properties and the physiological attributes of plants, the Soil Conservation

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Service (now the Natural Resources Conservation Service, NRCS) curve number method (NRCS, 1972) is the most common method for predicting runoff volume. It is an empirical method developed by the US Department of Agriculture based on measured precipitation and runoff. Accompany with this method, HRUs were delineated by the combination of land use and soil types, then the curve number of each HRU is determined according to land use, its hydrological condition (mostly represented by ground coverage), as well as the soil's hydrological group.

The hydrological condition of the vegetation is an important factor in determining the curve number for an HRU (NRCS, 1986). In existing studies, the HRU curve numbers with the same vegetation type and the same soil hydrological group are uniform, creating an assumption that the hydrological conditions for certain vegetation within the study area are the same. This assumption does not hold water in some studies, especially in some regions intensely influenced by human activities, exhibiting fractured vegetation patterns.

Hydrological processes are also dramatically affected by slope. The curve numbers obtained from the NRCS handbook (NRCS, 1986) are usually assumed to correspond to a slope of 5 %. Most studies do not account for the slope when determining the CN. Some hydrological models (e.g. SWAT) allow users to adjust CNs by slope. The adjustment, however, must be done prior to inputting the curve numbers, and according to the average slope in the study area. If the slope factor is excluded, there are many disadvantages using the CN method, especially in some regions with various landforms and steep slopes. Some attempts have modified curve numbers by slope (Williams, 1995; Huang et al., 2006). Using slope as a factor for HRU delineation and adjusting the curve numbers accordingly would be helpful for runoff simulation.

The Chinese Loess Plateau is a region with fractured vegetation pattern and steep slopes (Huang et al., 2006; Fu, 1989). In the plateau's Yanhe watershed, for example, the slopes range from 0° to 66.2°, with an average of 23.4°. Vegetation in the Chinese Loess Plateau is intensely influenced by human activities including reclamation, abandonment, afforestation, etc. (Fu et al., 2006, 2009; Li et al., 2009). Before the

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1970s, sloping cropland and natural grassland were the two dominant land use types. After the 1970s, several conservation projects were enforced in order to control soil erosion. Consequently, the landscape has been intensely adjusted by the redesigned land use patterns. Various vegetation types, including natural forest, planted forest, natural shrubland, planted shrubland, natural grassland, artificial grassland and cropland constitute a mosaic landscape pattern. The hydrological condition of the vegetation, using coverage as an indicator, is influenced by several environmental factors, such as climate, topography (slope, aspect, etc.), soil (soil organic matter, soil moisture, etc.) and so on. Nonnative vegetation coverage is also affected by age and some human factors, such as plant density and maintenance measures. Even within a watershed, the hydrological condition of the vegetation varies immensely.

Because of the lack of data of the aforementioned factors, especially plant age and human factors, quantification or simulation of the coverage of the vegetation in the Chinese Loess Plateau is difficult. Remote sensing data is relatively easy to access and time-efficient. The vegetation indices derived from remote sensing images, such as the normalized difference vegetation index (NDVI), are commonly used to retrieve vegetation coverage (Zribi et al., 2003; Leprieur et al., 1994). This is more reliable than simulation methods to determine the hydrological condition of the vegetation in the Loess Plateau.

A subwatershed in the upstream section of the Yanhe watershed in the Loess Plateau is the study area for this research. The area was spatially discretized into new units called "land type units" (units with relatively homogenous land use and environmental factors), a flexible concept employed by several researchers (Gustafson et al., 2004; Kupfer and Franklin, 2000; Rykken et al., 1997). The land use type, soil type, hydrological condition of vegetation and slope were all included as discretizing factors for delineating the land type units. The hydrological condition of the vegetation was determined by coverage retrieved from NDVI. The curve numbers of the land type units were determined by land use type, hydrological condition of vegetation and the soil's hydrological group, then further modified by slope. The monthly runoff processes were

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simulated by SWAT in periods near remote sensing image acquisition date. The results were compared with initial unit results. Also discussed is the advantages and further application of land type units.

2 Materials and methods

2.1 Study area

The Yanhe watershed (108°38′–110°29′ E, 36°21′–37°19′ N) lies in the middle of the Loess Plateau in the Northern Shaanxi Province and covers an area of 7725 km^2 (Fig. 1). The subwatershed in this study is located in the upstream section of the Yanhe, controlled by a hydrological station named "Ansai" (109°19′ E, 36°52′ N), and as a matter of convenience, it is referred to as the Ansai watershed. The area is 1334 km^2 with slopes that range from 0° to 66.2°, with an average 23.9°. It has a typical semiarid continental climate with an average temperature of 8.8° and an average annual precipitation of 505 mm. Rainfall shows high seasonal variability, with more than 60 % of the annual precipitation occurring between July and September. The landform is a typical loess hilly-gullied landscape with elevations ranging from 1057 m to 1743 m a.s.l., with an average of 1362 m). Covering 86.4 % of the watershed, loess soil, derived from loess parent material, is dominant.

Prior to conservation projects, sloping cropland and natural grassland were the two dominant land use types in the Yanhe watershed. After the 1970s, cropland abandonment and re-vegetation was implemented, dramatically changing the land use pattern. Croplands declined while forest shrubland and grassland expanded. Various land use types constitute a mosaic landscape pattern. Even along a slope surface, the landscape structure is often fragmentized. The major crop species are maize (*Zea mays* L.), potatoes (*Solanum tuberosum* L.), beans (*Phaseolus vulgaris* L.) and millet (*Panicum miliaceum* L.). The grassland is dominated by Gmelin Sagebrush (*Artemisia gmelinii* Web. ex Stechm.), Argy Sagebrush (*Artemisia. argyi* Levl. et Vant.) and Bunge

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Needlegrass (*Stipa bungeana* Trin.). The forests are mainly manmade and comprise of Black Locust (*Robinia pseudoacacia* L.). The shrubland is dominated by Intermediate Peashrub (*Caragana Intermedia* Kuang et H. C. Fu), Sandthorn (*Hippophae rhamnoides* L.) and Vetchleaf Pagodatree (*Sophora viciifolia* Lindl.).

2.2 Data sets

Land use type, soil type, topographical, meteorological, and hydrological data of the Ansai watershed, as well as satellite imagery, were collected for this research.

A year 2000 land use map (1:50 000 scale) was interpreted by the Institute Of Remote Sensing Applications, Chinese Academy of Sciences from remotely sensed Landsat TM images. Six land use types were identified: forest, shrubland, grassland, cropland, water bodies and residential areas.

A soil survey map (1:10 000 scale) was provided by the Institute of Soil and Water Conservation, Chinese Academy of Sciences. The soil types were divided into four categories: dark-purple loess soil, loess soil, red clay soil and alluvial soil.

A 25 m-resolution digital elevation model (DEM) for the watershed, derived from a 1:50 000 scale contour map, was supplied by the National Geomatics Center of China. The slope was calculated using the DEM.

Meteorological and hydrological data of 1995 to 2002 were collected. Daily precipitation data from five gauge stations in or near the Ansai watershed and the daily flow data of Ansai hydrological station were collected from the Hydrology and Water Resources Investigation Bureau in Yanan City. The daily precipitation data, maximum and minimum temperatures, average wind speeds and relative humidity of the Yanan (109°30′ E, 36°36′ N) and Wuqi (108°10′ E, 36°55′ N) meteorological stations was downloaded from China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/).

Landsat TM imagery of 17 October 1999 was downloaded from the International Scientific Data Service Platform of Chinese Academy of Sciences (http://datamirror.csdb.cn).

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2.3 Methods

Land type units for the Ansai watershed were delineated by a factor scheme including land use and soil type, the hydrological condition of vegetation and slope. These four factors were determined as follows:

According to the US National Engineering Handbook (NRCS, 1986), land use was reclassified into the following categories: woods, brush, grassland, contoured and terraced row crops, water and residential districts.

The hydrological groups of the four kinds of soil were determined according to the infiltration rate, texture and clay layer of the soil. Other properties of each soil were obtained from field sampling investments and supplemented by soil survey data, data from prior research and estimations of the empirical model Soil-Plant-Air-Water (SPAW) Soil Water Characteristics (Saxton, 2002).

The determination of the hydrological condition of vegetation included the following three steps:

1. Calculation of the normalized difference vegetation index (NDVI). NDVI is defined as the normalized ratio of the near infrared reflectance response to the red response of a surface. It was calculated as:

$$\mathrm{NDVI} = \frac{R_{\mathrm{nir}} - R_{\mathrm{red}}}{R_{\mathrm{nir}} + R_{\mathrm{red}}}$$

where R_{nir} is the reflectance at the near infrared band, and R_{red} is the reflectance at the red band. In this study, band 4 (infrared) and band 3 (red) of the Landsat-TM imagery were used for the NDVI derivation.

2. Vegetative coverage inversion using NDVI. Vegetation coverage of the watershed was inversed by NDVI using a dimidiated pixel model (Leprieur et al., 1994; Zribi

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et al., 2003). The main formula of this model is:

$$f_c = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}}$$

where f_c is vegetation coverage expressed as fraction; NDVI is the value of NDVI for the image cell; $NDVI_{soil}$ is the value of NDVI for bare soil; $NDVI_{veg}$ is the value of NDVI for full-covered vegetation. $NDVI_{soil}$ and $NDVI_{veg}$ was set to the value of NDVI at which the cumulative frequency was 5 % and 95 %, respectively.

3. Determination for hydrological condition using vegetation coverage. The relationship between the hydrological condition and vegetation coverage, based on the National Engineering Handbook (NRCS, 1986), is shown in Table 1. However, this relationship is only applicable for woods, brush and grassland. The hydrological condition of water and residential districts was not considered necessary. For crops, the hydrological condition is "based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good ≥ 20 %), and (e) degree of surface roughness" (NRCS, 1986). In the Ansai watershed, maize is the dominant crop, and there are no other plants in the corn fields. Little residue is left after harvest. These cropland factors impair infiltration and tend to increase runoff. As a result, all the cropland in Ansai watershed was considered to be in poor hydrological condition.

   The curve number modification using slope was completed using the method developed by Mingbin Huang (Huang et al., 2006). The slope-adjusted NRCS CN_2 (CN_{2slp}) was calculated as:

$$CN_{2slp} = CN_2 \frac{322.79 + 15.63slp}{slp + 323.52}$$

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where CN_2 is the initial curve numbers for an average soil moisture condition in the TR-55 manual, and slp is slope ($m\,m^{-1}$).

In this study, slope was divided into five classes: (1) 0°–8°, with an average of 4.2°; (2) 8°–15°, with an average of 11.8°; (3) 15°–25°, with an average of 20.2°; (4) 25°–35°, with an average of 29.7°; (5) 35°–66°, with an average of 39.4°. This classification was done with reference to the engineer classification standard (Ministry of Water Resources of the People's Republic of China, 1997) and of some ancient researches, as well as for the convenience of future application in soil erosion researches (see Sect. 4). The slope adjusted CN_{2slp} for the five classes of slope are expressed in Table 2.

Land type units were generated using ArcGIS 9.3, in which land use, hydrological condition, soil and slope classification maps were overlapped into a new shapefile. The corresponding CN_2s for each land type unit were added to the database of ArcSWAT2009 (Winchell et al., 2010).

The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) is a watershed scale model for simulating long-term runoff and nutrient losses from rural watersheds. In the hydrology module of SWAT, there are two methods for runoff simulation: the NCRS CN and the Green and Ampt infiltration method. The former was applied in this research. The method used rainfall P and a retention parameter S to predict runoff Q, all expressed in mm:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad \text{for} \quad P > 0.2S$$
$$Q = 0 \quad \text{for} \quad P \le 0.2S$$

The retention parameter S was calculated by:

$$S = \frac{25\,400}{\mathrm{CN}} - 254$$

where CN is the curve number. The CN values for average moisture condition or CN_2 are listed in the National Engineering Handbook (NRCS, 1986) for various land

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uses, managements, hydrological conditions and soil hydrological groups. SWAT adjusts the daily curve numbers with soil profile water content or accumulated plant evapotranspiration.

The agreement between the simulated and measured runoff was quantitatively evaluated using the coefficient of determination (R^2) and the Nash–Sutcliffe coefficient (E_{NS}) (Nash and Sutcliffe, 1970), calculated as:

$$R^2 = \frac{\left[\sum_i (Q_{m,i} - \overline{Q_m})(Q_{s,i} - \overline{Q_s})\right]^2}{\sum_i (Q_{m,i} - \overline{Q_m})^2 \sum_i (Q_{s,i} - \overline{Q_s})^2}$$

$$E_{NS} = 1 - \frac{\sum_i (Q_m - Q_s)_i^2}{\sum_i (Q_{m,i} - \overline{Q_m})^2}$$

where Q_m is the measured runoff, and Q_s is the simulated runoff.

3 Results

3.1 Land type units division

The delineation of the land type units was accomplished by combining the land use, soil, hydrological condition (as applicable for woods, brush, grassland and crops) and slope data, detailed in Table 3. There were at most 221 ($3 \times 3 \times 4 \times 5 + 1 \times 1 \times 4 \times 5 + 1 \times 1 \times 4 \times 5 + 1 \times 1 \times 1 \times 1$) possible land type unit combinations.

From the 221 combinations possible, the Ansai watershed was divided into 177 kinds of land type units. The four dominant combinations (listed as: land use – hydrological condition of vegetation – slope – soil), totaling 32.91 % of the watershed, were (1) crops – poor – $15^\circ \sim 25^\circ$ – loess soil, (2) crops – poor – $25^\circ \sim 35^\circ$ – loess soil, (3) grassland – poor – $25^\circ \sim 35^\circ$ – loess soil and (4) grassland – poor – $15^\circ \sim 25^\circ$ – loess soil. The dominant woodland type unit combination was woods – good – $25^\circ \sim 35^\circ$ – loess soil.

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The dominant brushland type unit combination was brush – good – 25° ~ 35° – loess soil. The main land type units and their distribution is shown in Fig. 2.

The Ansai watershed was divided into subbasins using "watershed delineation" in ArcSWAT. Because prior research has shown that the number of subbasins have little influence on runoff simulations (Jha et al., 2004; Tripathi et al., 2006), the watershed was divided into 21 subbasins, for when the number of subbasins was equal or greater than 21, the precipitation data of the five gauge stations would be read by the model, otherwise some gauge stations would be excluded.

In each subbasin, discretized units were delineated. When the initial method was applied, the subbasins were discretized into HRUs defined by land use and soil. There were thresholds of "land use area percentage over subbasin", "soil class percentage over land use area" and "slope class percentage over soil area". Slope classification was not applied in this study. In order to exclude the influence of the discretized unit amounts on the runoff simulation, land use and soil thresholds were set to three values: 0, 5 and 15. The HRU amounts based on these different thresholds are shown in Table 4.

When the land type unit discretization was applied, a land type map was used for land use definition instead of a land use map. The thresholds were set to 0, 5 and 15. The land type unit amounts are also shown in Table 4.

3.2 Rainfall-runoff process simulation

Runoff of the Ansai watershed from 1995 to 2002 were simulated using SWAT. The first three years were used as a warm up period. Discharges were observed daily at the Ansai monitoring center from April to October in 1998 to 2002, but observed on fixed dates in other months. These observations were evaluated against simulated ones by the coefficient of determination (R^2) and the Nash–Sutcliffe coefficient (E_{NS}). No calibration was performed for the model; that is, the influence of model parameters was excluded. The differences between the simulation results were caused only by

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spatial discretization, based on HRUs or land type units. The values of R^2 and E_{NS} for monthly flow, based on HRUs and land type unit discretization, are shown in Table 4.

When compared with the HRU simulation, the land type unit results were better. E_{NS} improved from 0.581–0.656 to 0.692–0.703; R^2 increased from 0.710–0.721 to 0.726–0.731. The observed and simulated monthly flow based on HRUs and land type units are shown in Fig. 3 (results for unit delineation thresholds equal to 15 were selected).

With the number of units increasing, the simulation coefficients increased slightly. The increasing trend of HRU-based simulation efficiency was more apparent than that based on land type units.

4 Discussion

As the results demonstrated above, land type unit discretization helped the hydrological model simulate runoff better than the initial HRU discretization. Land type units, delineated by multiple factors, contributed to the determination of CN values, reducing the uncertainty of the parameters.

After completion of the simulation based on land type units, further parameter calibration that included CN was run. The best CN value was $(1–0.03) \cdot CN_{initial}$, demonstrating that the CN values determined based on land type units were very close to the true values. In other words, the land type units accurately represented the actual spatial variation that existed within the watershed.

Altering CN values with the calibration of different parameters can also improve runoff simulation efficiency. In comparison, however, the determination of CN values based on land type units better represents the actual status. The eco-hydrological characteristic differences among land type units and subbasins can be indicated more accurately on the basis of land type unit discretization.

By means of remote sensing, the vegetation condition can be inversed and considered for an eco-hydrological simulation based on land type units. The hydrological

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process of vegetation on different slopes can also be better simulated, so the hydrological effect of land use changes can be more reliably reflected. This is helpful for assessing the re-vegetation projects (e.g. grain for green) in the Loess Plateau.

Land type units can also be applied to soil erosion simulation. Several types of erosion exists in the Loess Plateau, for instance, sheet erosion, rill erosion, gully erosion, gravitational erosion, etc. Lots of research has focused on the critical slope gradient and simulation of different erosion processes (Wu and Cheng, 2005; Valentin et al., 2005; Hessel and van Asch, 2003). Slope was taken into account in the land type unit delineation. Accompanied with the prior research, the land type units can be used to better simulate soil erosion.

The results showed that the amount of discretized units had a slight influence on runoff simulation. Fewer units would get better model performance. When the number of thresholds increased, smaller area units were excluded. In this study, units with the land use types such as forest, shrubland and residential areas were ignored when the number of units decreased. It can be deduced that the curve numbers of these units are not suitable for the watershed and have a negative effect on the simulation. Future studies will focus on this problem and try to reconfirm the curve numbers through experimentation and modeling.

Monthly discharges for April, May and October were commonly underestimated in the simulation of this study. Two probable reasons exist. Firstly, the base flow was not accurately simulated. Secondly, the curve numbers for these months were higher than the exact status. In the study area, April and May are the early period of growing season. Most crops are not planted until the end of May. As for October, it's a declining period for plant growth, as well as the harvest time for crops. Though the plant growth cycle and interception is simulated in SWAT, there may be some deviation in curve number adjustment and canopy storage simulation in initial and last growing season in this study. Assigning curve numbers for agricultural lands, especially cultivated lands separately for different growth period may solve this error.

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5 Conclusions

Land type units were delineated for the spatial discretization of a watershed in the Chinese Loess Plateau. The discretized factors were composed of land use and soil types, the hydrological condition of vegetation and slope.

The runoff curve number for each kind of land type unit was defined by land use type, soil type and the hydrological condition of vegetation (according to the National Engineering Handbook) and modified by slope.

The runoff processes of the studied watershed were simulated by Soil and Water Assessment Tools (SWAT), in which the NRCS curve number method was applied. When the initial HRUs were used for the spatial discretization of the watershed, the coefficient of determination (R^2) and the Nash–Sutcliffe coefficient (E_{NS}) for the monthly flow simulation were 0.710–0.721 and 0.581–0.656, respectively. When land type units were used for the spatial discretization of the watershed, the simulation efficiency was improved. R^2 and E_{NS} for the monthly flow simulations were 0.726–0.731 and 0.692–0.703, respectively.

Compared to the initial HRU discretization, the land type units help to determine the CN value and more accurately represent the actual status. This is a suitable approach for eco-hydrological studies in the Chinese Loess Plateau and similar regions. This method can be further applied to soil erosion simulations and the eco-hydrological evaluation of land use changes in the Chinese Loess Plateau.

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Table 1. The relationship between hydrological condition and vegetation coverage.

Hydrological condition	Vegetation coverage
Good	> 75 %
Fair	50 % to 75 %
Poor	< 50 %

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Table 2. The five classes of slope and the expressions of the slope-adjusted CN_2.

Slope classes	Average slope	Area percentage in watershed	Expression of the slope-adjusted CN_2
0°–8°	4.2°	7.31 %	$CN_{2slp} = CN_2$
8°–15°	11.8°	13.09 %	$CN_{2slp} = 1.007 \cdot CN_2$
15°–25°	20.2°	32.57 %	$CN_{2slp} = 1.014 \cdot CN_2$
25°–35°	29.7°	32.42 %	$CN_{2slp} = 1.023 \cdot CN_2$
35°–66°	39.4°	14.61 %	$CN_{2slp} = 1.035 \cdot CN_2$

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Table 3. Detail factors for land type unit delineation.

Land use	Hydrological condition	Soil	Slope
Woods Brush Grassland	Good, fair, poor	dark-purple loess soil, loess soil, red clay soil, alluvial soil	0°–8°, 8°–15°, 15°–25°, 25°–35°, 35°–60°
Crops	Poor		
Residential districts	Not applicable		
Water		Not applicable	Not applicable

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Table 4. Unit amounts and simulation results based on HRUs and land type units.

Discretized units	Threshold for units delineation	Amount of units	E_{NS} for monthly runoff	R^2 for monthly runoff
HRUs	0	256	0.581	0.710
	5	83	0.616	0.719
	15	54	0.656	0.721
Land type units	0	2472	0.692	0.726
	5	252	0.700	0.731
	15	33	0.703	0.726

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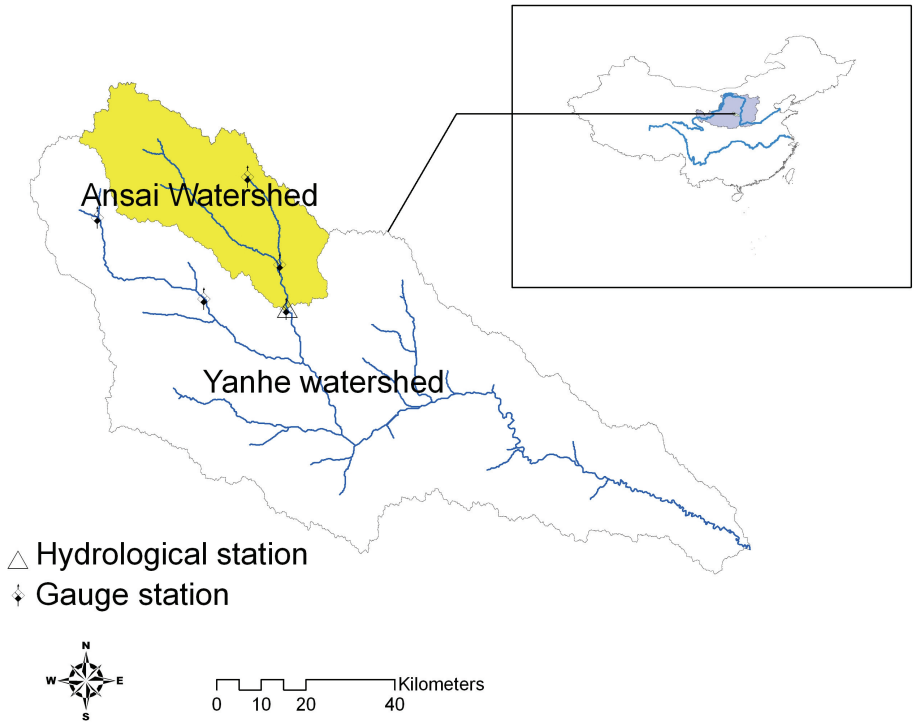

Fig. 1. Study area and the distribution of hydrological station and gauge stations.

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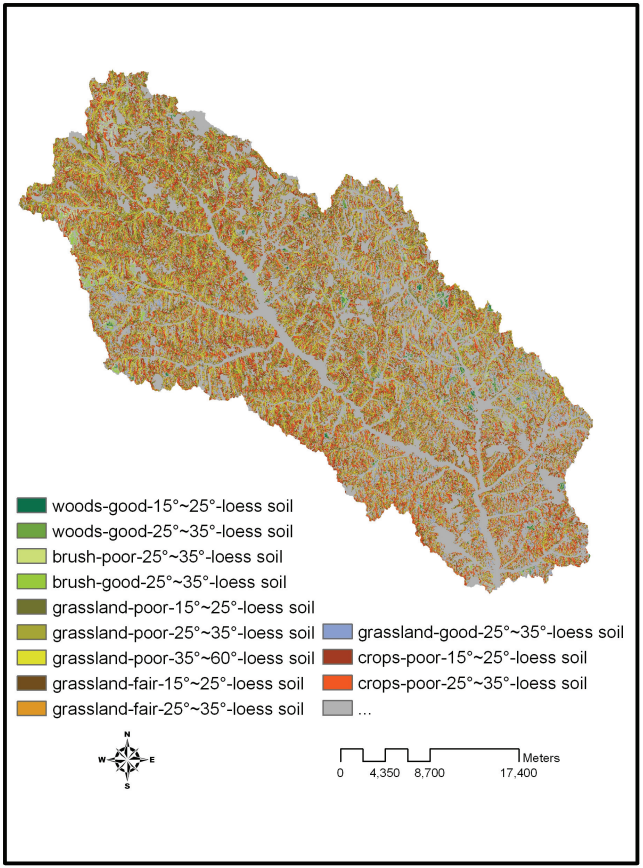

Fig. 2. Main land type unit distribution within the Ansai watershed.

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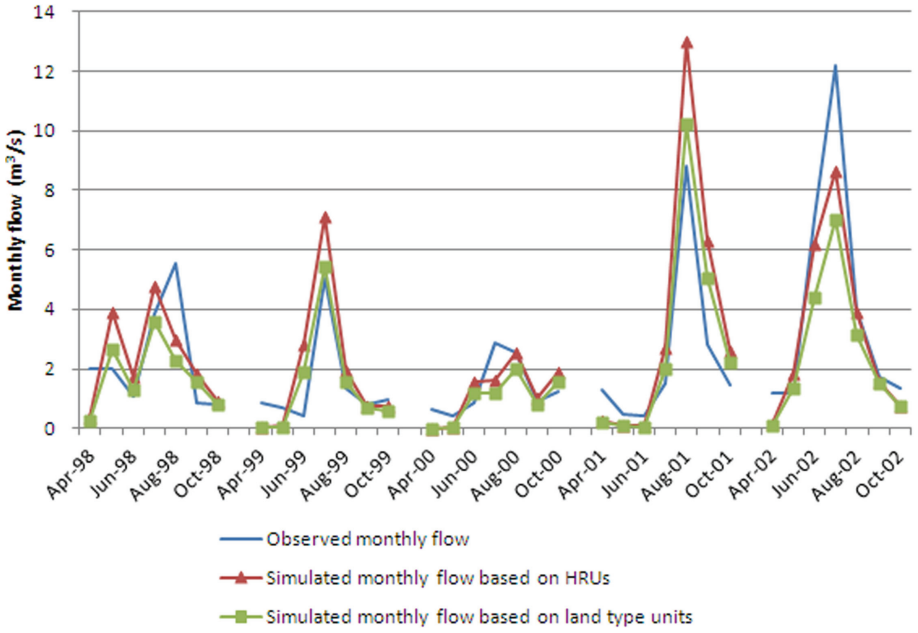

Fig. 3. Observed and simulated monthly flow.

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