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Study on estimating the evapotranspiration cover coefficient for stream flow simulation through remote sensing techniques

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ABSTRACT

This study focuses on using remote sensing techniques to estimate the evapotranspiration cover coefficient (CV) which is an important parameter for stream flow. The objective is to derive more accurate stream flow from the estimated CV. The study area is located in the Dan-Shuei watershed in northern Taiwan. The processes include the land-use classification using hybrid classification and four Landsat-5 TM images; the CV estimations based on remote sensing and traditional approaches; comparison of stream flow simulation according to the above two CV values. The result indicated that the study area was classified into seven land-use types with 88.3% classification accuracy. The simulated stream flow using remote sensing approach could represent more accurate hydrological characteristics than a traditional approach. Obviously integrating remote sensing technique and the SEBAL model is a useful approach to estimate the CV. The CV parameter estimated by remote sensing technique did improve the accuracy of the stream flow simulation. Therefore, the results can be extended to further studies such as forest water management.

1. Introduction

In recent years, the generalized watershed loading functions (GWLF) model has been widely applied to estimate human, natural, and climate effects on hydrology systems because parameters in the GWLF model can be adjusted according to the land-use types, soil characteristics and climate conditions of a watershed (Haith and Shoemaker, 1987; Haith et al., 1992). In previous studies, the amount of evapotranspiration (ET) of a watershed was calculated using evapotranspiration cover coefficient (CV) during the GWLF simulated procedures (Tung and Haith, 1995; Fan, 1998; Markel et al., 2006). However, the estimation of ET and CV under a large spatial scale is problematic for traditional hydrologic studies. Traditionally, CV can be determined from the published seasonal values based on crop types such as those given in the user's manual of the GWLF model (Haith et al., 1992). This approach often requires estimates of crop development (e.g., planting dates, time to maturity, etc.) which may not be available. Moreover, a single set of consistent values is seldom available for all of a watershed's land-use. A cursory setting of CV would influence the accuracy of stream flow simulations (Haith et al., 1992; Davis and Sorensen, 1969).

The increasing availability of remote sensing technology now produces satellite images that can easily and effectively provide large-scale spatial and temporal surface information. For hydrology studies, ET can be computed without quantifying other complex hydrological processes through remote sensing techniques (Morse et al., 2000). Thus, previous researches (Menenti and Choudhury, 1993; Laymon et al., 1998; Mauser and Schädlich, 1998; Morse et al., 2000; Chen et al., 2006) adopted remotely sensed data to calculate the energy balance parameters such as surface temperature, net radiance, sensible heat flux, soil heat flux, and then estimated the ET according to these parameters. However, few studies have calculated CV parameters using remote sensing-based ET for stream flow simulation.

This study proposes an approach to estimate CV value using remote sensing. Unlike the traditional approach, which calculated the CV according to the published reference, the overall and local CV values were determined through remote sensing data and did not require detail information on vegetation type, growth and land-use. The major objective of this study was to assess the effect of the CV estimated from satellite image on the stream flow simulation, which will allow a simpler and more accurate simulation of stream flow under a large spatial scale.

2. Study area and materials

The Dan-Shuei River is the largest catchment in the northern part of Taiwan. The drainage area covers 268.70 km^2. The Dan-

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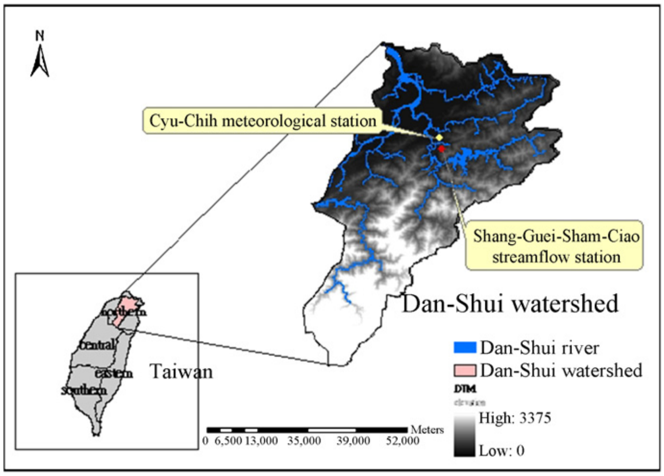

Fig. 1. Location of the study area with DTM.

Shuei watershed covers three counties (i.e., Taipei, Tao-Yuan, and Hsin-Chu). It is one of the principle water resource supplies for agricultural irrigation in the region.

Five types of data were used in this empirical study, including Landsat-5 TM images, digital terrain model (DTM), national land-use inventory data in 1995, weather, and stream flow observed records. Four Landsat-5 images (January 9, 1995; July 20, 1995; November 25, 1995; and March 16, 1996) were used for representing the seasonality. Each image contains seven spectral bands ranging from the visible blue to the reflected near infrared (reflected IR). The pixel resolution on bands 1–5 and band 7 is 30 m. Band 6 is the thermal IR with 120 m resolution. The DTM with 40 m resolution is provided by the Aerial Survey office of the Forestry Bureau. The first national land-use inventory data finished by the National Land Surveying and Mapping Center, Ministry of Interior in 1995 was regarded as ground truth and used to assess the classification accuracy of Landsat-5 images. It was based on photo interpretation to investigate the land-use status. If undefined land types occurred, then ground inventory was applied to further re-confirmation. As for the classification system of the national land-use inventory data, it is a hierarchical system including three levels. The category of the first level is divided into nine land types (i.e., agriculture, forest, transportation, water, built-up land, public land, recreation land, mining land, and others). Categories for the second and third level were further subdivided into 41 and 103 land types, respectively according to the upper level classification. In addition, historical daily temperature and precipitation records at the Cyu-Chih meteorological station, and stream flow observations at Shang-Guei-Shan-Ciao flow station were collected from 1995 to 2002. Fig. 1 shows the location of study area with DTM.

3. Methods

3.1. Land-use classification using hybrid method

The analytical procedures included two parts. The first part was to generate a land-use map using Landsat-5 TM image and hybrid classification method which combines supervised and unsupervised processes to improve the classification accuracy (Lillesand and Kiefer, 2000). There are four steps: (1) six blocks were selected from the study image according to ground land-use information; (2) the selected blocks were clustered into spectral subclasses by unsupervised classification and then merged or deleted subclass signatures as appropriate based on transformed divergence (TD) using Eq. (1). The TD ranged from 0 to 2000. If two classes can be separated completely, then the TD approaches 2000; (3) spectral signatures obtained from each block were then combined into a single spectral signature; and (4) supervised classification method with the single spectral signature and the maximum likelihood classifier was applied to generate the land-use map of the study area.

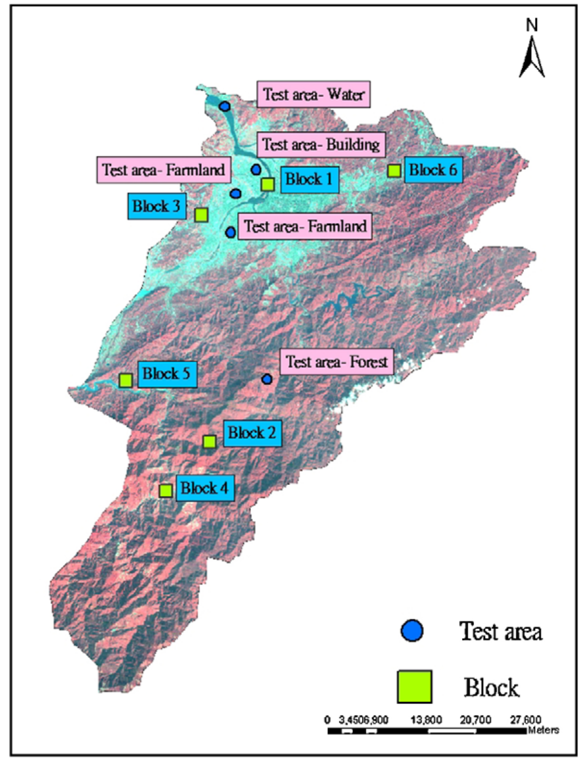

Fig. 2. Spatial distribution of the selected blocks and test areas covered with the Landsat image, November 25, 1995 (the size of each block is 100 ha, which was extracted from each landsat image. As for the test area, the size for forestland, building, water, farmland, and fallow farmland is 97.50 ha, 391.00 ha, 112.13 ha, 60.44 ha, and 151.81 ha, respectively.).

$$
\begin{aligned}
TD &= 2000\left[1 - \exp\left(\frac{-D}{8}\right)\right] \\
D &= \frac{1}{2}tr(Cov_iCov_j)Cov_i^{-1} - Cov_i^{-1} \\
&+\frac{1}{2}tr[Cov_i^{-1} - Cov_j^{-1}(m_{i-}m_j)(m_{i-}m_j)^T]
\end{aligned} \quad (1)
$$

where TD was transformed divergence; D was divergence; Cov_i was covariance matrix of class i; m was mean vector of class i; and $tr\,[A]$ was sum of the diagonal line of matrix A.

The second part was to evaluate the accuracy of land-use classification. Test areas for each cover type were selected from the generated map. All test areas were compared with national land-use inventory data, and the classification accuracy was then calculated. The above procedures were adopted to generate the land-use maps of the Dan-Shuei watershed in January 9, July 20, November 25, 1995, and March 16, 1996. Spatial distribution of the selected blocks and test areas are shown in Fig. 2.

3.2. Daily ET estimation based on the SEBAL model

SEBAL is an image processing model that calculates the ET and other energy exchanges at the earth's surface using digital image data collected by Landsat or other remote sensing satellites measuring visible, near infrared and thermal infrared radiation (Bastiaanssen et al., 1998). The major concept of this model is that ET flux is calculated as a residual of the surface energy budget equation and is expressed as the energy consumed by the evaporation