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# Hydrological drought forecasting and assessment based on the standardized stream index in the Southwest China

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**Abstract**

Southwest China is abundant of rainfall and water resources, however, severe and extremely droughts hits it more frequently in recent years, caused huge loss of human lives and financial damages. To investigate the feasibility of the standardized stream index in Southwest China, the Nanpanjiang River basin above the Xiaolongtan hydrological station was selected as the case study site. Based on long-term daily hydrological and meteorological data series, the generated runoff was simulated by the daily Xinanjiang model, then the standardized stream index was calculated and its feasibility was explored by comparing it with other two hydrological drought index. The result revealed that the standardized stream index performed well in detecting the onset, severity and duration in 2009/2010 extremely drought. The output of the paper could provide valuable references for the regional and national drought monitoring and forecasting systems.



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*Keywords:* standardized stream index; humid region; Southwest China; hydrological drought

## 1. Introduction

Special geographical location determines China being the country of droughts and floods prone areas over the world, particularly in recent decades (Li et al., 2014; Yu et al., 2014 and 2015), the drought in China becomes more

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severe and more frequently and tends to occur in semi-humid and humid region from arid and semi-arid regions. Locating in humid regions, the Southwest region is of abundant rainfall and water resources, however, severe and extremely droughts hits it more frequently in recent years, caused huge loss of human lives and financial damages. The standardized streamflow index (SSI) was developed by Vicent-Serrano et al. (2012), it was widely used in Europe but limited applications in China. To investigate the feasibility of the SSI in Southwest China, the Nanpanjiang River basin above the Xiaolongtan hydrological station was selected as the case study site. The Xiaolongtan subbasin, located between 102.0°-105.0° E and 23.5°-26.0° N, the mean annual precipitation and evaporation were about 988mm and 1100mm respectively with the catchment area of 15 410 km2 (Yu et al., 2014). Based on long-term daily hydrological and meteorological data series, the generated runoff was simulated by the daily Xinanjiang model which was applied widely in humid regions (Zhao, 1992; Bao and Zhao 2014). Then the SSI was calculated based on the generated runoff thereafter. The output of the paper could provide valuable references for developing the drought monitoring and forecasting systems of Southwest regions and the whole country.

## 2. The XAJ model

The XAJ model is a rainfall-runoff, distributed, basin model for use in humid and semi-humid regions. The evapotranspiration component is represented by a model of three soil layers. Runoff production occurs on repletion of storage to capacity values which are assumed to be distributed throughout the basin. Prior to 1980, runoff was separated into surface and groundwater components using Horton's concept of infiltration. Subsequently, the concept of hillslope hydrology was introduced with an additional component, interflow, being identified. Runoff concentration to the outflow of each sub-basin is represented by a unit hydrograph or by a lag and route technique. The damping or routing effects of the channel system connecting the sub-basins are represented by Muskingum routing. There are fifteen parameters in all, of which the model is particularly sensitive to six. Optimization of the parameters is achieved with different objective functions according to the nature of each parameter. The model has been widely used in China since 1980, mainly for flood forecasting, though more recently it is also being used for other purposes. In this paper, distributed dual-source evapotranspiration model was adopted to calculate the basin evapotranspiration (Yuan, 2006).

## 3. Data collection and processing

### *3.1. Topography and land-use data*

The topography of the Xiaolongtan basin is described by a Digital Elevation Model (DEM), which was downloaded from the Global Land One kilometer Base Elevation database with a spatial resolution of 1 km × 1 km. The river network and basin boundary was automatically extracted from the DEM itself by performing the ARCSWAT software. Land-use maps of 1990s and 2000s for Xixian basin were collected from the Chinese Academy of Science.

### *3.2. Hydrological data*

The daily rainfall at 21 stations and daily flow discharge at Xiaolongtan hydrological station during 1991-2010 were collected from the Pear River Water Resources Commission for the water-balance simulation. Before simulation, the spatial distribution of rainfall events was determined based on the inverse distance squared method.

### *3.3. Meteorological data*

The meteorological data, including daily temperature, solar net radiation, relative humidity, wind speed at eight weather stations in or neighboring the Xiaolongtan basin during 1991-2010 were collected from the China Meteorological Administration (CMA). The homogeneity and reliability of the meteorological data have been checked and firmly controlled by CMA before their release.

## 4. Applications of the Xinanjiang models

The daily Xinanjiang model was calibrated and validated by the use of observed daily flow, precipitation, and meteorological data in the Nanpanjiang River basin above the Xiaolongtan hydrological gauge station. Table 2 illustrated the parameter values for daily simulation of the Xinanjiang model in the study basin. The simulation result showed that the daily Xinanjiang model performed well with relatively satisfactory accuracy, i.e. the RE for calibration and validation periods were generally less than 10%. The long-term series of SSI was calculated based on the simulated daily discharge thereafter.

Table 1 Calibrated parameters for the daily Xinanjiang model in the Nanpanjiang River basin above the Xiaolongtan station

| Parameters | Meaning | Values |
|---|---|---|
| UM | areal mean tension water capacity in the upper layer (mm) | 20 |
| LM | areal mean tension water capacity in the lower layer (mm) | 80 |
| c | coefficient of deep evapotranspiration | 0.15 |
| WM | areal mean tension water capacity (mm) | 150 |
| b | exponent of the tension water capacity curve | 0.3 |
| IM | ratio of the impervious to the total area of the basin | 0.001 |
| SM | areal mean of the free water capacity of the surface soil layer (mm) | 15 |
| EX | exponent of the freewater capacity curve | 1.2 |
| KG | outflow coefficient of the freewater storage to groundwater relationship | 0.4 |
| CS | recession constant of surface water storage | 0.90 |
| CI | recession constant of interflow water storage | 0.92 |
| CG | recession constant of groundwater storage | 0.977 |
| L | lag time（d） | 1 |
| KE | parameter of the Muskingum method | 24 |
| XE | parameter of the Muskingum method | 0.49 |

Table 2 Calibration and validation results of the daily XAJ model in the Nanpanjiang River basin

| Year | | P (mm) | Ro (mm) | Rc (mm) | RE (%) |
|---|---|---|---|---|---|
| Calibration | 1991 | 1328.9 | 266.5 | 245.7 | -7.8 |
| | 1992 | 725.9 | 106.4 | 97.4 | -8.5 |
| | 1993 | 928.9 | 137.0 | 151.9 | 10.5 |
| | 1994 | 1144.9 | 288.2 | 262.3 | -9.0 |
| | 1995 | 1148.3 | 243.9 | 225.4 | -7.6 |
| | 1996 | 909.3 | 185.4 | 170.4 | -8.1 |
| | 1997 | 1238.2 | 331.0 | 337.6 | 2.0 |
| Validation | 1998 | 946.4 | 243.5 | 227.7 | -6.5 |
| | 1999 | 1203.1 | 337.7 | 352.9 | 4.6 |
| | 2000 | 943.0 | 261.3 | 240.7 | -7.9 |
| | 2001 | 974.2 | 293.8 | 273.5 | -6.9 |

Note: P is for precipitation, Ro for observed runoff, Rc for calculated runoff, RE for relative error

## 5. Drought assessment based on the SSI in the Nanpanjiang River basin

The long-term variation comparison between the SSI and the 6-mon SPEI, the SSI and the scPHDI time series in the Nanpanjiang River basin above Xiaolongtan station during 1991-2010 was presented in Figure 1. It has been found that the three drought index identified mostly dry spells of the Nanpanjiang River basin, the drier the conditions, the lower the drought index values. Generally, the Nanpanjiang River basin was in relatively drier conditions during late 2000s. Rank correlations between the SSI and the scPHDI, the SSI and 6-mon SPEI time series were also carried out by the Spearman correlation coefficient, with its range falling within [-1,1]. Spearman correlation is a robust measure which is not sensitive to the underlying data distributions and it is often recognized as a skilled tool in determining the best aggregate correlation (Wilks, 1995). Correlation analysis illustrated that the SSI was highly correlated with the 6-mon SPEI which was verified with the correlation coefficient being of 0.690, while the SSI and the scPHDI was correlated in comparison with the correlation between the SSI and the 6-mon SPEI with the correlation coefficient being of 0.631. The above analysis indicated that the variation patterns of the SSI, the 6-mon SPEI and the scPHDI in identifying the dry conditions were similar.

However, the 6-mon SPEI and the scPHDI showed differences in synchronization in detecting the severest month for drought events with the SSI, i.e. the 6-mon SPEI being one to eight months lag in judging the dry spells in comparison with the SSI, while the scPHDI being two to ten months lag in judging the dry spells in comparison with the SSI. Differences were also found in drought severity, onset, termination detected by the SSI, the 6-mon SPEI and the scPHDI for a given drought event. The drought occurred in 2009/2010 was the famous one-in-one-hundred extremely Southwest China drought, which began in 2009 Autumn and evolved to extremely drought in 2010 Spring. Yunnan province, which is in the subtropics, was hit the hardest and resembled a desert during the drought among the Yunnan, Guizhou, Guangxi, Sichuan, and Chongqing five provinces. The dried up lakes revealed desiccated aquatic animals. It was reported by the Yunnan Province Information Office that the drought continued till 26 March in 2010 and caused water shortages for 8.2 million people and 3.1 million hectares of crops (Lu et al., 2011a, 2011b). From Figure 1, it can be found severe drought was identified by the SSI in June 2009, extremely drought was detected in October 2009, drought ended in April 2010, while the 6-mon SPEI detected severe drought in October 2009, extremely drought in December 2009, drought ended in December 2010, and the scPHDI identified mild drought in September 2009, severe drought from July 2010 to November 2010. It revealed that the onset, duration, termination, and drought severity of 2009/2010 drought detected by the SSI was consistent with the historical records, while only the onset and drought severity detected by the 6-mon SPEI was consistent with the historical records, and the scPHDI could not identify and judge the onset, duration, termination, and drought severity of 2009/2010 drought accurately.

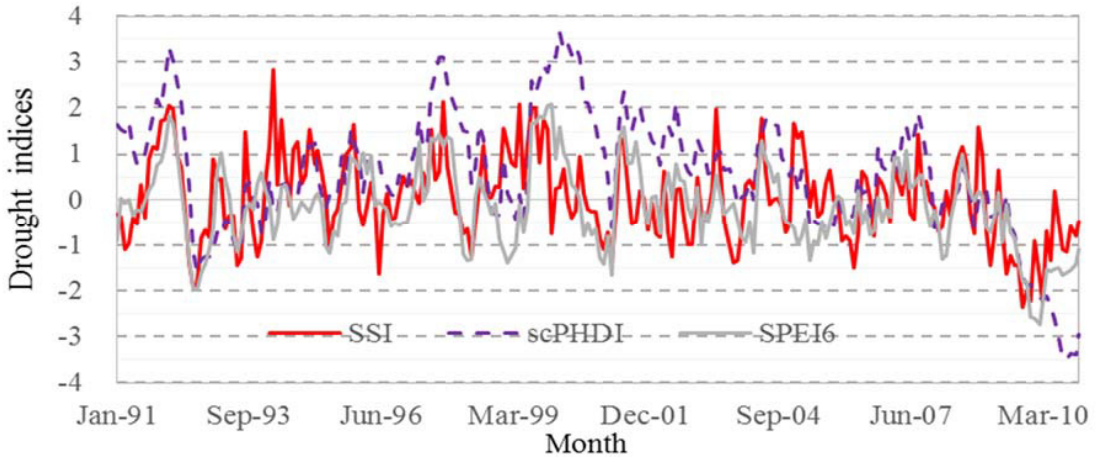


Fig. 1. Temporal variations of the SSI, 6-mon SPEI and scPHDI in the Nanpanjiang River basin above the Xiaolongtan station

## 6. Conclusion

This paper investigated the feasibility of the SSI in Southwest China based on the long term series of hydrological and meteorological data with the Nanpanjiang River basin above the Xiaolongtan hydrological station as the case study site. The SSI is of certain forecasting period since the input of the SSI was simulated by the Xinanjiang model coupled with the dual source evapotranspiration model based on rainfall and meteorological data. The result indicated that the modified Xinanjiang model achieved good accuracy of simulation in Southwest China; the SSI behaved well in identifying and judging the onset, severity and duration of drought events.

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