

The evolution analysis of seasonal drought in the upper and middle reaches of Huai River basin based on two different types of drought index

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Abstract. The Huai River Basin is in the transitional zone between the climates of northern and southern China, and is liable to seasonal drought. This study is based on two types of drought index, one is the traditional meteorological drought index including precipitation anomaly percentage (P_a) and Standardized Precipitation Index (SPI), and the other is the remote sensing drought index (water deficit index, WDI), analyzing the serious winter and spring drought development and evolution of the Huai River Basin. The results showed that: (1) the drought development was similar based on P_a and SPI, but the indicated drought intensity was different, SPI was closer to the actual drought degree. (2) WDI reflect drought and spatiotemporal characteristics well, and respond quickly to soil wet conditions caused by short-term rainfall. (3) WDI had significant correlation with P_a and SPI, and the correlation coefficients were 0.93 and 0.92, respectively, which means WDI can supplement meteorological drought index, but WDI is better than meteorological drought index on the whole, which is helpful to improve the ability of assessing regional drought.

1. Introduction

Drought is the first major meteorological disaster affecting agricultural production in China. The complex climatic condition, the uneven distribution of the intra-annual precipitation and the large change of inter-annual precipitation, resulted in frequent droughts in Huai River basin [1]. The causes of drought are complex and diverse, it's difficult to monitor drought than other natural disasters, especially its occurrence and conclusion. At present, there has been a lot of research on drought indicators. Drought is usually divided into four types including meteorological or climatologically, agricultural and hydrological droughts; meteorological drought is the basis of other types of drought research. From the standpoint of meteorological drought, precipitation anomaly percentage (P_a), standardized precipitation index (SPI) [2] and other indicators mainly supplemented by the meteorological observation data are widespread in drought monitoring. Remote sensing acquires the distribution of drought in space and time changes with advantages of large converge and long-term of dynamic monitoring, which makes up the deficiency of traditional drought monitoring. There are a series of drought indices based on remote sensing data, among them the TVDI index [3] is famous, but it has the shortcomings of small application range and neglecting meteorological factors. Wang et al [4] proposed a water deficit index (WDI) applied in a semi-arid region of United States using remote sensing and meteorological data, which was based on the trapezoidal relationship of surface



temperature and vegetation index. In this paper, the meteorological drought index of P_a and SPI (one-month time scale) and the remote-sensing index of WDI were used for analysing the temporal and spatial evolution of seasonal drought in the upper and middle reaches of the Huai River basin, which could provide basis for drought monitoring and utilization of water resources.

2. Study area

The Huai River Basin lies between the Yangtze and Yellow River basins with a catchment area of 270,000 km², is divided into three parts: the upper reaches, the middle reaches and the lower reaches. The upper and middle reaches of the Huai River were selected as the study area and it's located at 111°55'-119°E and 30°55'-34°55'N, with an area of 190,000 km². Annually, the average air temperature is 11 ~ 16 °C, increasing from north to south, from east to west; the average precipitation is 920mm, decreasing from south to north; the water surface evaporation is 900-1500mm, decreasing from north to south. The study area is shown in Figure 1.

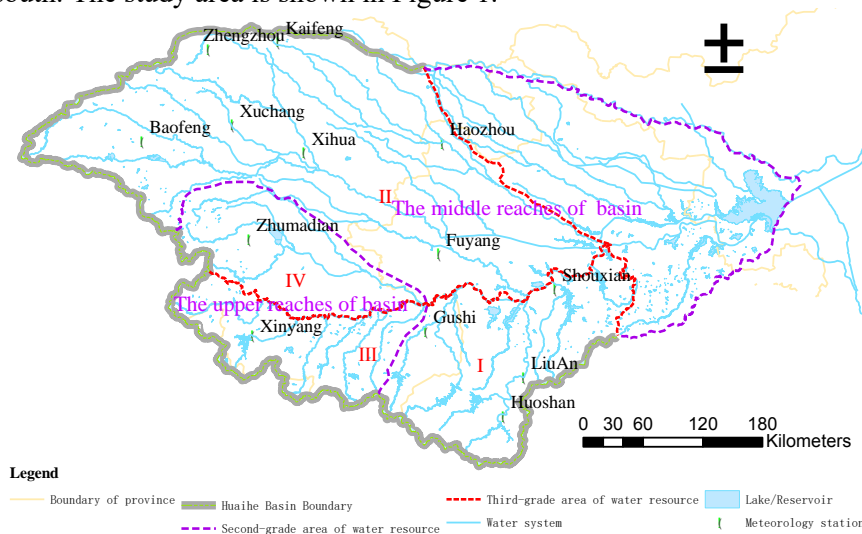


Figure 1. Overview of the upper and middle reaches of the Huai River Basin.

3. Data

3.1. Meteorology data

The meteorological data used in the paper include daily air temperature, wind speed, relative humidity, and rainfall provided by the National Meteorological Information Centre (NMIC) of China Meteorological Administration. There are 13 basic meteorological stations (Figure 1), data length was from 1958 to 2009 and the outliers and missing values were excluded.

3.2. Remote sensing data

Moderate Resolution Imaging Spectroradiometer (MODIS) has a high spectral resolution (36 channels) and a spatial resolution of 250-1000 m. NASA provides many kinds of free long time series surface products. The main remote sensing data are shown in Table 1. A series of operations include remote sensing data selection, re-projection, re-sampling to ensure data quality and space-time consistency.

Table 1. MODIS data used in the study.

Data type	Contents	Spatial resolution	Temporal resolution
MOD09A1	Surface Reflectance	500 m	8 days
MOD11A1	Surface Temperature and Emissivity	1 Km	daily
MOD13A1	Vegetation Indices	250 m	8 days
MOD15A2	Leaf Area Index	1 km	8 days

4. Methodology of Drought monitoring

4.1. Precipitation-based drought index

P_a indicates the rainfall is more or less than normal value at a certain period, which can directly reflect the drought caused by precipitation anomaly, is used to evaluate the monthly, seasonal and annual drought events. P_a (%) is calculated by dividing the difference between the precipitation of a certain period (P , mm) and the multi-year mean precipitation of the corresponding time period (\bar{p} , mm) by the latter.

SPI is a commonly used precipitation-based drought index recommended by the World Meteorological Organization (WMO) in 2009. It is a probability index proposed by McKee [2] indicates the scarcity of drought for any rainfall station with historical data at a given time scale. A long-term daily or monthly precipitation database with 30 years or more length is usually required. The classification of drought grade of monthly-scale P_a and SPI is seen in Table 2 according to China's first published national standard for monitoring drought disasters [5].

Table 2. Grade classifications of drought based on monthly-scale P_a and SPI.

Type	Normal	Light drought	Middle drought	Severe drought	Extreme drought
P_a	$(-40, +\infty)$	$(-60, -40]$	$(-80, -60]$	$(-95, -80]$	$[-95, -\infty)$
SPI	$(-0.5, +\infty)$	$(-1.0, -0.5]$	$(-1.5, -1.0]$	$(-2.0, -1.5]$	$[-2, -\infty)$

4.2. Remote sensing-based drought index

Water Deficit Index (WDI) for evaluating relative water shortage of both full-cover and partially vegetated sites, which was first proposed by Moran [6]. Wang et al [4] proposed the modified WDI based on the trapezoid relationship between land surface temperature (T_s) and enhanced vegetation index (EVI) using both remotely sensing and meteorological observation data. This method constructs a T_s -EVI trapezoidal space for each image pixel based on the principle of energy balance, and considers the influence of underlying surfaces and meteorological factors on the four theoretical extreme points of each trapezoid space.

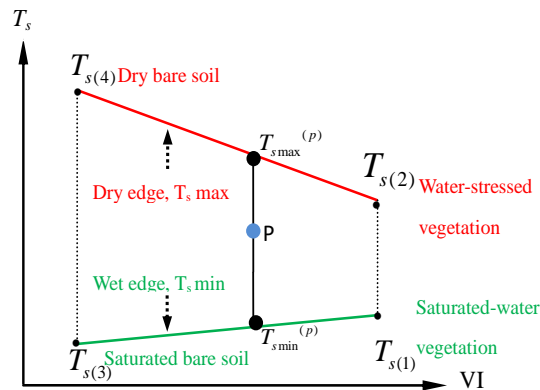


Figure 2. The hypothetical trapezoidal space of each pixel.

As shown in Figure 2, for each pixel $P(T_s^{(p)}, EVI^{(p)})$, a trapezoidal space with four extreme vertices $T_{s(i)}$ ($T_{s(1)}$, $T_{s(2)}$, $T_{s(3)}$, $T_{s(4)}$) is constructed. The four extreme vertexes indicate that the pixel P is theoretical covered by different land surface (bare soil, full coverage) and water supply conditions (extremely dry, extreme wetness). According to the location of the pixel P in the trapezoid space, the wet and dry state of the pixel P is calculated with the following equation:

$$WDI^{(p)} = \frac{T_s^{(p)} - T_{smin}^{(p)}}{T_{smax}^{(p)} - T_{smin}^{(p)}} \quad (1)$$

Where, $T_{s\max}^{(p)}$ 、 $T_{s\min}^{(p)}$ refer to minimum and maximum values, respectively are interpolated linearly on the dry edge ($T_{s(2)}$ 、 $T_{s(4)}$) and wet edge ($T_{s(1)}$ 、 $T_{s(3)}$) of the T_s ~EVI trapezoid. A WDI close to 1 indicate extreme dry, whereas 0 indicates soil moisture saturation. The method is mainly used in semi-arid areas, however the impact of the climatic conditions on the trapezoidal space is still need studied in the warm temperate-subtropical zone of Huai River basin.

A simplified method is proposed to calculate WDI by estimating the saturated bare soil and saturated-water vegetation point. We assume that the surface temperature of bare soil in the extreme wet condition is the same as the surface temperature of saturated-water vegetation. For each image, the minimum surface temperature of the regional water body (rivers, lakes and reservoirs) is selected as wet edge. The dry edge calculation is still performed by the existing iteration algorithm.

As an important component of energy balance, soil heat flux (G) is usually considered to be linearly related to net radiation (Rn), that is, G/R_n is a certain value. There are very different conclusions about G / R_n under different land cover and climate conditions. In this study, G/R_n to be 0.05 for both vegetated points and 0.2 for both bare soil points.

5. Results and discussion

According to the historical meteorological data and drought conditions, the study period is from November 2008 to April 2009, and winter is from Nov. to Jan. and spring is from Feb. to Apr.

5.1. Application of P_a and SPI

In accordance with WMO regulations, the latest 30-year (1973-2002) average is used as the climate baseline average for computing P_a . The P_a and SPI values of 13 meteorological stations and water resources zoning are calculated, as shown in Figure 3 and Figure 4. It indicates from November 2008 to January 2009 all sites suffered different degrees of drought except area I; Regions II and IV suffered drought in March and April 2009, respectively. The degree of drought indicated by the two indices is different: in December and January, P_a indicates that the areas II, III, and IV have suffered heavy drought ($P_a < -80$), while SPI indicates that the regions II, III and IV suffered middle drought ($-1.5 < SPI < -1$) in December.

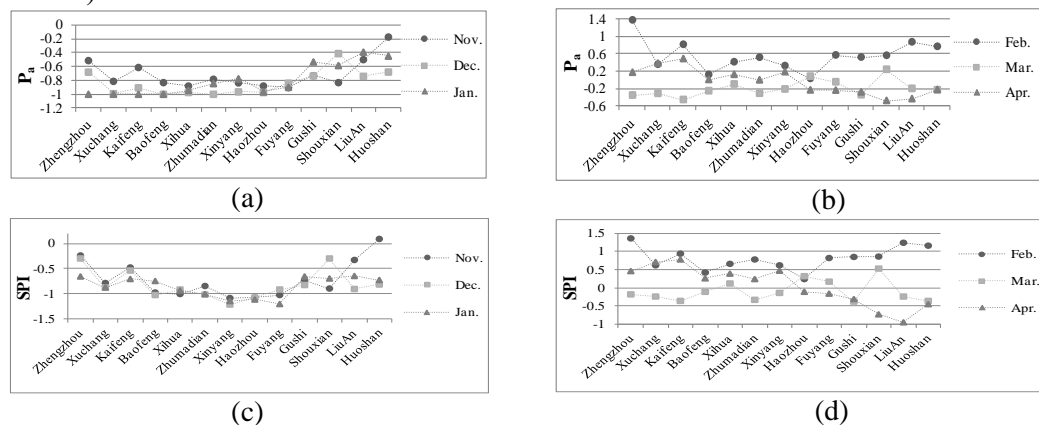


Figure 3. The P_a and SPI of each site in winter (left) and spring (right).

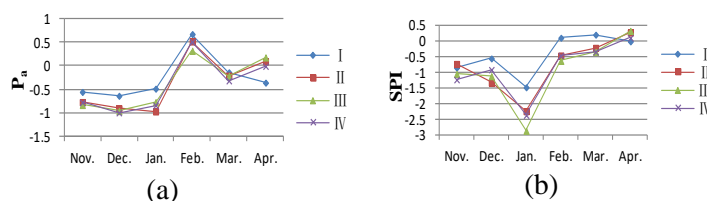


Figure 4. P_a and SPI of water resources zoning.

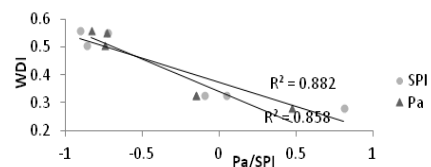


Figure 5. The correlation coefficient between WDI and SPI, P_a .

5.2. Application of WDI

WDI images of different time are obtained as shown in Figure 6. It showed the study area suffered different degrees of drought during the period. In terms of space, the degree of drought decreased from north to south, which is consistent with the spatial distribution of average annual precipitation; In terms of time, the most severe drought happened in December (WDI>0.5), and relieved in March 14 (WDI<0.3). The reason maybe there were different degrees of rainfall in the whole area for two consecutive days before March 14. The precipitation of Baofeng Station on March 12 was 14.7mm, which indicated that WDI respond quickly to soil wet and dry conditions of short-term rainfall.

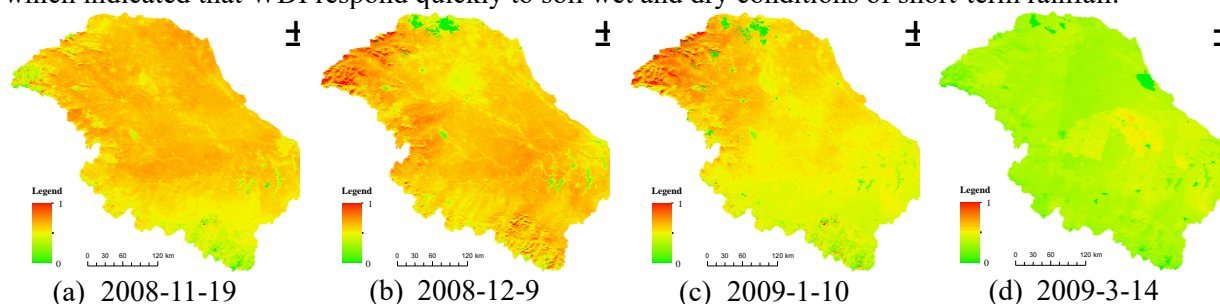


Figure 6. Some WDI maps during the period from November, 2008 to April, 2009.

5.3. Comparison of drought monitoring results with different index

The corresponding drought index of 13 sites in the whole area was extracted and compared, as shown in figure 5. The correlation coefficients of WDI and P_a , WDI and SPI were 0.93 and 0.92 respectively, which indicates WDI has obvious correlation with the precipitation index. WDI is obviously superior to P_a and SPI in terms of reflecting the spatial distribution and development of drought.

6. Conclusions

The seasonal drought evolution characteristics were analyzed using the traditional meteorological drought indexes (P_a and SPI) and remote sensing drought index (WDI). P_a and SPI showed the same drought development, while the drought intensity indicated by SPI was closer to the actual drought. WDI, which combines the meteorological and remote sensing data with obvious physical basis, reflect the temporal and spatial of drought during the study period well, is sensitive to short-term rainfall.

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