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Agricultural drought prediction using climate indices based on Support Vector Regression in Xiangjiang River basin

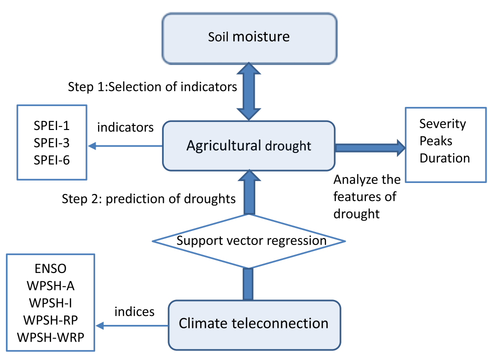
Ye Tian [a,b], Yue-Ping Xu [c,*], Guoqing Wang [d]

[a] College of Hydrometeorology, Nanjing University of Information Science & Technology, Nanjing 210044, China
[b] Key Laboratory of Meteorological Disaster (Nanjing University of Information Science and Technology), Ministry of Education, Nanjing 210044, China
[c] Institute of Hydrology and Water Resources, Department of Civil Engineering, Zhejiang University, Hangzhou 310058, China
[d] State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Nanjing Hydraulic Research Institute, Nanjing 210029, China

HIGHLIGHTS

- The SVR model is applied in agricultural drought prediction in Xiangjiang River basin.
- Drought index SPEI-6 is recommended to reflect the soil moisture condition.
- Ridge point of WPSH is the key factor affecting SPEI-6 mainly through temperature.
- Prediction of drought could be improved by incorporating climate indices in SVR model.

GRAPHICAL ABSTRACT



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ABSTRACT

Drought can have a substantial impact on the ecosystem and agriculture of the affected region and does harm to local economy. This study aims to analyze the relation between soil moisture and drought and predict agricultural drought in Xiangjiang River basin. The agriculture droughts are presented with the Precipitation-Evapotranspiration Index (SPEI). The Support Vector Regression (SVR) model incorporating climate indices is developed to predict the agricultural droughts. Analysis of climate forcing including El Niño Southern Oscillation and western Pacific subtropical high (WPSH) are carried out to select climate indices. The results show that SPEI of six months time scales (SPEI-6) represents the soil moisture better than that of three and one month time scale on drought duration, severity and peaks. The key factor that influences the agriculture drought is the Ridge Point of WPSH, which mainly controls regional temperature. The SVR model incorporating climate indices, especially ridge point of WPSH, could improve the prediction accuracy compared to that solely using drought index by 4.4% in training and 5.1% in testing measured by Nash Sutcliffe efficiency coefficient (NSE) for three month lead time. The improvement is more significant for the prediction with one month lead (15.8% in training and 27.0% in testing) than that with three months lead time. However, it needs to be cautious in selection of the input parameters, since adding redundant information could have a counter effect in attaining a better prediction.

1. Introduction

Drought is a common natural hazard that exerts severe effect on agriculture, ecology, economy and human daily life. Unlike floods, storms,

* Corresponding author at: Institute of Hydrology and Water Resources, Department of Civil Engineering, Zhejiang University, Hangzhou, Zhejiang 310058, China.
E-mail address: yuepingxu@zju.edu.cn (Y.-P. Xu).

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hurricanes and other natural hazards which often cause immediate and widespread devastation, drought usually develops slowly and can have long lasting impacts. The definition of drought varies according to the purpose of study, which not only takes the measurement of its physical features into account but also its impacts for environment and society. According to the previous studies, drought could be divided into four types, namely meteorological drought which is caused by lack of precipitation, agricultural drought which reflects the soil moisture deficiency, hydrological drought which is related to lack of surface and ground water supply, and socioeconomic drought which refers to lack of water supply to the society (Zargar et al., 2011; Hao and Singh, 2015). They are connected to each other and occur in a particular order.

Due to the complexity of the characteristics of drought, >100 drought indices have been developed to measure the level of drought, such as Normalized Difference Vegetation Index (NDVI), Palmer drought severity Index (PDSI), Standardized Precipitation Index (SPI) and Standardized Precipitation-Evapotranspiration Index (SPEI). NDVI is a remote sensing based index to measure vegetation conditions. PDSI and SPI are meteorological indices. PDSI requires precipitation and temperature as inputs, but compared to SPI it is more computationally expensive and varies through regions and time periods (Belayneh and Adamowski, 2013). SPI is precipitation based, measuring the anomalies in precipitation but does not account for other climate factors such as soil water, temperature and wind speed. To address this issue, SPEI was developed using precipitation and evapotranspiration as inputs to calculate the balance between precipitation and evapotranspiration taking on the inherent advantage of SPI while considering the effects of both precipitation and evapotranspiration.

The calculation of SPEI requires the observations like temperature, precipitation and radiation which are much easier to obtain than the measurement of soil moisture. Therefore, SPEI could provide more information on soil moisture, which is relatively short of ground observed data. SPEI index can reflect the soil moisture better than SPI in the months with increasing temperature (Li et al., 2015). The SPEI value shows better correlation with the yields of crop production which is strongly affected by soil moisture (Labudová et al., 2016). Such impacts are associated with SPEI of different time scales. Generally, surface soil moisture could be related to the SPEI with shorter time scales while deep-layer soil moisture could be more related to the SPEI with longer time scales considering the indicator at the same time steps (Wang et al., 2015).

Based on the hypothesis that the drought is expected to be propagated from one type to another, saying from meteorological drought to soil moisture deficit, there are usually time lags in between. Maity et al. (2016) utilized Standardized Precipitation Index (SPI), Standardized Soil Moisture Index (SSMI) and Standardized Stream Flow Index (SSFI) to analyze the temporal dependence between different types of drought and proved it to be effective for foreseeing the agricultural or hydrological droughts knowing the meteorological drought status. However, their study only considered drought indices with time scale of three-month. Due to soil texture, topography, land use and climate regime, such propagation varies depending on different regions and catchments. The temporal dependence between soil moisture and drought indices with different time scales considering features including severity, intensity and duration need to be explored to provide a wholesome perspective of the linkage between drought indices and soil moisture status.

Knowing the linkage between soil moisture and drought indices, prediction and forecasting of drought could target at a certain index with a certain time scale. Up to now, most commonly used methods to carry out the assessment and prediction of drought are hydrological models and data-driven methods. The former could provide an insight in understanding the physical progresses. Although the data-driven methods may not be adequate for long lead time forecast of the nonlinear dynamical system, the limitations on the availability of the spatial-temporal data in physical based models make the data-driven complementary to physical based models. Data-driven methods could aspire to extract relations that may further inform and augment the current physical understanding (Ganguly et al., 2014). Support Vector Machine (SVM) is one of the data-driven algorithms which has been successfully applied in classification, regression and forecasting in the field of hydrology (Bhagwat and Maity, 2012; Tabari et al., 2012; Ganguli and Reddy, 2014). It has been emphasized the need of combining an understanding of physics with data mining, not only to avoid generating misleading insight but also to produce new results. There are a number of studies using SVM in drought forecasting (D'Arrigo and Smerdon, 2008; Ganguly et al., 2014). Belayneh and Adamowski (2014) compared different algorithms, including artificial neural networks (ANN), wavelet neural networks (WNN) and support vector regression (SVR), in forecasting drought measured by SPI with three and twelve month time scales. The advantage of SVR is that it could transfer a non-linear problem to a linear problem using the kernel function, and be effective in solving a high dimension problem. Many drought events are influenced by atmospheric teleconnections like El Nino Southern Oscillation (ENSO) phenomenon (D'Arrigo and Smerdon, 2008). Therefore, the climate indices could be used as predictors to forecast the drought events. Ganguli and Reddy (2014) combined the SPI and climate indices including ENSO, Atlantic Multidecadal Oscillation (AMO) and Indian Ocean Dipole (IOD) to forecast the drought index SPI at 6-month time scale with up to three months lead-time for Western Rajasthan (India). The studies mentioned above only applied the SVM to forecast the SPI, which is regarded to be inadequate in assessment of drought. Moreover, the climate patterns and their teleconnections with drought vary with topography and geographical locations.

In the middle and lower catchments of Yangtze River, ENSO influenced the precipitation and temperature changes and drought events are closely related to La Niña (Jiang et al., 2006). Huang and Wu (1989) found that in the decaying stage of ENSO, a hot summer and drought could occur in Yangtze River due to the intensification of the convective activities around Philippines causing the western Pacific subtropical high (WPSH) shifting northward. On the contrary, when the western Pacific subtropical high is in the cold episode during El Niño phase, convections around Philippine Sea weakens (Zhang et al., 1996). This leads to WPSH shifting southward causing more floods. Therefore, weather in East Asian is also closely related to the variability of the western Pacific subtropical high system, which plays an important role in Asian monsoon system. WPSH regulates the transport of water vapor into East Asia and influences the mei-yu front with extratropical airflow (Zhou et al., 2009). The descending motion of WPSH causes the areas near the ridge line to be dominated by an anomalous sunny hot summer. For example, the severe drought which occurred in 2013 occurred in Hu'nan Province China where the study area is located, was closely related to the strong abnormal WPSH. The WPSH was shifted westward of the normal position, which led to strong descending airflow causing continuous high temperatures (Peng et al., 2015).

It is generally acknowledged that there are certain relationships between soil moisture, SPEI and climate indices. However, the time scales of the relationship between them is unknown, and it is also important to apply this relationship in prediction of the drought. This study aims to explore the relationship between the meteorological drought indices SPEI of different time scales and soil moisture for Xiangjiang River basin in China, by analyzing the effects of climatology factors including WPSH and ENSO on drought. Incorporating the climate impact on drought, the SVR model is built to predict the SPEI.

2. Materials and methods

2.1. Study areas and data

Xiangjiang River basin is located in Hu'nan Province of central China. It is the largest river basin in Hu'nan Province with 94,660 km^2 drainage