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Probabilistic Assessment of Drought Characteristics using a Hidden Markov Model

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Abstract

Droughts are evaluated using drought indices that measure the departure of meteorological and hydrological variables such as precipitation and stream flow from their long-term averages. While there are many drought indices proposed in the literature, most of them use pre-defined thresholds for identifying drought classes ignoring the inherent uncertainties in characterizing droughts. In this study, a hidden Markov model (HMM) [1] is developed for probabilistic classification of drought states. The HMM captures space and time dependence in the data. The proposed model is applied to assess drought characteristics in Indiana using monthly precipitation and stream flow data. The comparison of HMM based drought index with standard precipitation index (SPI) [2] suggests that the HMM index provides more intuitive results.

Limitations of SPI

1. SPI cannot identify drought prone areas-the frequency of drought remains the same irrespective of the region.
2. For regions with small variability in rainfall, even small anomalies in precipitation can lead to large negative SPI values.
3. The independence assumption made in SPI computation may not hold true when estimating longer duration droughts.

Objective

The objective of this study is to develop a drought index using graphical modeling approach that captures the space and time dependence in the data. The proposed HMM-based drought index is then applied to assess drought characteristics in Indiana using monthly precipitation and stream flow data.

Hidden Markov Model (HMM)

where,

\[ X_t \rightarrow \text{Rainfall at time step } t, \quad X_t \in \mathbb{R} \]

\[ Z_t \rightarrow \text{Drought state at time step } t, \quad Z_t = [Z_{t1}, ..., Z_{tk}]^T, \quad Z_{tk} \in \{0,1\} \]

Results

At-site analysis

HMM and SPI (1-month window) drought states using precipitation data at location 1 – Alpine 2 NE, IN.

HMM and SPI (1-month window) drought states using stream flow data at location 1 – Whitewater River at Alpine, IN.

Conclusions

• HMM-based framework helps to overcome some of the inherent limitations of SPI
• HMM provides a probabilistic and intuitive classification of droughts
• Further work needs to be done to test the stability issues and estimation of parameters of the HMM model.
• Care must be exercised during regional drought analysis since averaging drought indices over a region and drought index computed using averaged precipitation are found to yield different results.

References


Acknowledgements

Authors acknowledge the support of the National Science Foundation under grants OCI-0753116 and AGS-1025430.