**Probabilistic Models for Droughts: Applications in Trigger Identification, Predictor Selection and Index Development.**

Meenu Ramadas
Ph.D. Student
Major Professor: Rao S. Govindaraju.
Purdue University

## ABSTRACT

The current practice of drought declaration (US Drought Monitor) provides a hard classification of droughts using various hydrologic variables. However, this method does not yield model uncertainty, and is very limited for forecasting upcoming droughts. The primary goal of this thesis is to develop and implement methods that incorporate uncertainty estimation into drought characterization, thereby enabling more informed and better decision making by water users and managers. Probabilistic models using hydrologic variables are developed, yielding new insights into drought characterization enabling fundamental applications in droughts.

Drought triggers are patterns in hydro-climatic variables that herald upcoming droughts and form the basis for mitigation plans. This thesis describes a new method for identification of triggers for hydrologic droughts by examining the association between the various hydro-climatic variables and streamflows over two study watersheds in Indiana, USA. The method combines the strengths of principal component analysis (PCA) for dimensionality reduction and copulas for building joint dependence. The expected values and ranges of predictor hydro-climatic variables for different streamflow quantiles are utilized to develop drought triggers for one-month lead time.

Accurate prediction of droughts requires a clear understanding of the dependence patterns among various influencing hydro-climatic variables and streamflows. A graphical modeling technique, employing conditional independence, is proposed to quantify the interrelationships between streamflows and a suite of available hydro-climatic variables, and to identify a reduced set of relevant variables for parsimonious model development. The graphical modeling approach is compared to the state-of-the-art method for predictor selection based on partial mutual information. For both a synthetic benchmark non-linear dataset and a watershed in southern Indiana, USA, this approach shows more discriminating results while being computationally efficient. The parsimonious models performed equally well as the models with the full set of original predictors.

In agricultural drought studies, soil moisture in the root zone of the soil is predominantly used to characterize agricultural droughts, but crop needs are rarely factored into the analysis. Accounting for crop responses to soil water deficits will provide a better representation of agricultural droughts, and is investigated in this thesis using crop stress functions available in the literature. A new probabilistic agricultural drought index is then developed within a graphical model (hidden Markov model) framework. This new index allows probabilistic classification of the drought states while taking into account the stress experienced by the crop due to soil moisture deficit. The method identified critical drought events and several drought occurrences that were not detected by popular indices such as standardized precipitation evapotranspiration index (SPEI) and self-calibrating Palmer drought severity index (SC-PDSI), and shows promise as a tool for agricultural drought studies.

An understanding of the role of hydrologic variables, either singly or in combination, is useful for assessment of overall drought status over a region. A multivariate cumulative density function (CDF)-based index is constructed using copulas, and probabilistic drought classification is performed using hidden Markov models. The resulting drought indices with various combinations of hydrologic variables are utilized to understand the roles of hydrologic variables for integrated drought assessment at watershed scales. In this thesis, the methodology is demonstrated using streamflow, precipitation and soil moisture variables to develop univariate and multivariate CDF-based indices at 1-, 3- and 6-month time scales. Drought characterization varied across the univariate, bivariate and trivariate drought models in the case study. Results are found to be watershed specific, and multivariate models tend to better capture the early onset of drought events and persistence of the drought states.