Methodology for development of severity-duration-frequency (SDF) curves and drought forecasting tool

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Abstract: Drought is a natural hazard that is often referred to as a creeping phenomenon. Drought monitoring and early warning is very essential in identifying climate and water supply trends and thus to detect the probability of occurrence and the anticipated severity of drought. This paper reviews the literature on developing a methodology to assess drought severity, monitor and prediction of droughts in the future. Thirty (30) meteorological stations across Victoria, Australia were selected. Drought Indices (DIs) have been commonly used to quantify drought conditions and meteorological drought indices were considered for further analysis based on literature for this study. Several regionalisation techniques such as Cluster Analysis, Discriminant Analysis and Andrews' curve will be applied in order to cluster each region with the similar drought characteristics. Catchment physiographical characteristics such as mean annual precipitation, mean seasonal precipitation, potential evapotranspiration and Standardised Precipitation Index values. Drought severity – duration - frequency curves for each region will be developed in order to provide information in a manner that is suitable for different drought affected groups. The best drought forecasting tool applicable to Victoria will be selected to forecast short and long term drought conditions. In addition, a method of parameter updating based on real time will be also developed.

Keywords: Meteorological drought indices; Regionalisation; Severity – duration - frequency curves

1. INTRODUCTION

Drought differs from other natural hazards such as cyclones and floods as it is a slow on setting creeping phenomenon (WMO, 2006). It has wiped out crops, decimated stock numbers, drained rivers and dams, driven murderous bushfires and affected hundreds of thousands of lives. It has also cost the Australian economy billions of dollars. In Victoria, several droughts have occurred in the past including 1963-1968, 1972-1973, 1982-1983, 1991-1995 and 2002-2007 (BoM, 2011). Tan and Rhodes (2008) reported 2006 annual inflow into four major harvesting reservoirs in Melbourne was the lowest on record resulting in adverse socio-economic and industry impacts due to the shortage of water and the imposition of restrictions. There were severe deficiency in water resources in terms of rainfall and storage reservoir volume, resulting in adverse socio-economic impacts due to the shortage of water (Barua *et al.*, 2011).

There are four (4) types of droughts commonly classified as meteorological, agricultural, hydrological and socio-economic droughts (Dracup *et al.*, 1980). Socio-economic drought is associated with failure of water resources systems to meet water demands and thus associating droughts with food security and supply of and demand for an economic good water (AMS, 2004; Mishra and Singh, 2010). In contrast with meteorological drought, the other three types of droughts occur less frequent because it usually takes weeks or months before precipitation deficiencies begin to produce soil moisture deficiencies, decline in streamflow, reduced reservoir and lake level and lowering groundwater levels. Thus, for drought monitoring and early warning, meteorological drought will be applied in this study. Meteorological drought is defined below average precipitation over a region covering an extensive period of time. Precipitation is commonly used for analysis (WMO, 2006; Mishra and Singh, 2010; Sene, 2010).

The overall aim of this study is to develop a methodology to assess drought risk and to monitor and predict droughts in the future. This study will i) select the most applicable meteorological drought index to Victoria; ii) identify homogeneous regions across Victoria with similar drought characteristics; iii) develop the drought severity – duration – frequency (SDF) curves of various return periods over the region and iv) forecast future drought conditions using drought forecasting tools across short and long term durations. 30 rainfall stations in Victoria, Australia (Figure 1) with 61 years (1949 - 2010) of monthly precipitation data sets to simulate were selected.

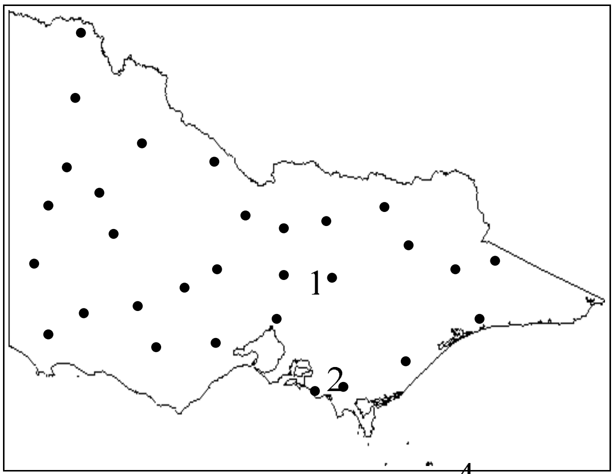

Figure 1 Location of the rainfall stations

2. Drought indices

Several methods have been used as drought assessment tools such as measurement of lack of rainfall, reduced levels of streamflow and water storage, and Drought Indices (DIs). DIs have been commonly used to quantify drought conditions and to assess drought severity around the world (Dracup *et al.*, 1980; Keyantash and Dracup, 2002; Morid *et al.*, 2006; Barua *et al.*, 2011; Mishra and Singh, 2011).

In the mid-twentieth century, Palmer (1965) first introduced a drought index (DI), the Palmer Drought Severity Index (PDSI), in the United States to define meteorological droughts by using a water balance model. Other DIs were developed around the world at different times including the widely used Percent of Normal (PN), Deciles (Gibbs and Maher, 1967), which is operational in Australia. Stochastic analysis including the Theory of Runs (ToR) has also been successfully applied for characterization of droughts (Yevjevich, 1967; Paulo and Pereira, 2006) and Standardized Precipitation Index (SPI) (McKee *et al.*, 1993), which has gained world popularity. Later, Tsakiris *et al.,* (2007) proposed new Reconnaissance Drought Index (RDI) which makes use of precipitation and potential evapotranspiration simultaneously. Recently, in Australia, Barua (2012) developed new drought index namely Nonlinear Aggregated Drought Index (NADI). The NADI has been developed using hydro-meteorological data of the Yarra River catchment and need to analyse for different catchments as variables varies from one catchment to other. These DIs were used to assess drought severity, quantify deficits in water resources and as drought monitoring tools (Morid *et al.*, 2006; Barua *et al.*, 2011).

In Australia, deciles are used for meteorological drought monitoring (BoM, 2007). Despite its advantages, deciles do not provide the characteristics of drought (e.g. severity and intensity). Recently, Barua (2012) developed new drought index namely Nonlinear Aggregated Drought Index (NADI). The NADI has been developed using hydro-meteorological data of the Yarra River catchment and need to analyse for different catchments as it is still not widely used and applied to other regions. Therefore, in addition to deciles and NADI, it is useful to consider the applicability of other existing DIs (SPI, ToR and RDI) in Victoria. Furthermore, frequent droughts are more common in Australia and Africa than anywhere in the world and have become more recurrent in the last 50 years (Keating, 1992; Tan and Rhodes, 2008).

To date, drought assessment which commonly classified as meteorological, agricultural, hydrological and socio-economic and eventually to find the most applicable meteorological drought index to Victoria has been reviewed. In addition, meteorological drought indices (SPI, RDI and Theory of Runs) were calculated to investigate how well SPI, RDI and TOR are capable of defining drought conditions. These three indices were applied to 3 – month, 6-month and 12 – month time scale to represent arbitrary but typical time scales for precipitation deficits to affect these two types of usable water sources. The results were then validated with the historical drought events. Based on these results, the SPI was shown to be a good indicator to characterize droughts and the best drought index applicable to Victoria. A poster entitled “Drought assessment using Standardised Precipitation Index (SPI) and Theory of Runs” were presented at the HDR Student Conference 2011. A draft of full paper related to drought monitoring, “Drought assessment using meteorological drought indices in Victoria, Australia” has been reviewed by my supervisor and ready for submission to a refereed journal.

3. Methods of regionalisation

Regionalization techniques will be applied in this study in order to cluster each region based on similar drought characteristics. This will be very useful in terms of water planning and management. Besides, by identifying other catchments that possess similar behaviour, the data that have been developed earlier can be used.

Application of multivariate classification methods to find patterns and relationships between several variables simultaneously has received much attention in the last few years and routinely used in many fields of application (Ragno *et al.*, 2007; Akbar *et al.*, 2011). The advantages of these methods are reduction in complexity of large-scale dataset, unbiasedness in methods which help in natural association between samples and parameters and information which cannot be observed from the dataset at first glance and related parameters can be identified by reducing and organizing a large dataset into groups with similar characteristics. There are several techniques widely used such as Principal Component Analysis (PCA), Cluster Analysis (CA), Discriminant Analysis (DA), Seasonality Indices (SI), Classification and Regression Trees (CRT), Residual Pattern Approach (RPA) and Weighted Cluster Analysis (WCA). Multivariate methods have been often used for the classification and comparison of different samples of waters (Ragno *et al.*, 2007; Varol and Şen, 2009; Zhang *et al.*, 2009; Zhao *et al.*, 2011) and regionalisation of streams (Christopher *et al.*, 2002; Vezza *et al.*, 2010), but for droughts characterisation it is still very rare.

At this stage, drought occurrence regionalization methods to separate catchments into homogeneous regions have been reviewed and the best method will be selected for further analysis.

4. Developing severity-duration–frequency (SDF) curves

The information delivered to give early warning of drought is often too technical and detailed. This study will provide information based on characterisation of the frequency, severity and duration of drought in a manner that is suitable for different drought affected groups (e.g. drought severity frequency analyses, determination of return periods and iso - drought severity maps). The severity values will be fitted with Log – Normal, Normal, Gumbel, etc. probability distributions. The best distribution will be selected to develop SDF curves.

By using the selected drought index, the SDF curves could be derived. To date, three SDF curves have been developed in order to get familiarised with the technique.

5. Drought Forecasting Tools

There are several modeling techniques that have been used to develop drought forecasting models including Autoregressive Integrated Moving Average (ARIMA) and Seasonal Autoregressive Integrated Moving Average (SARIMA) (Mishra and Desai, 2005), Markov Chain (Paulo and Pereira, 2007), Loglinear (Paulo *et al.*, 2005; Moreira *et al.*, 2008), Artificial Neural Network (ANN) (Mishra *et al.*, 2007; Barros and Bowden, 2008; Barua *et al.*, 2010) and Adaptive Neuro-Fuzzy Inference System (ANFIS) (Bacanli *et al.*, 2008). Barua (2012) concluded two types of ANNs namely - recursive multi-step neural network (RMSNN) and direct multi-step neural network (DMSNN) were the best method to be applied to the Yarra River Catchment, Victoria. Again, the applicability of existing drought forecasting tools should be examined if the whole Victoria is considered.

The probability based drought class transition model, Markov Chain will be used in order to forecast future drought for short and medium period. It is expected that forecasting model is capable of forecasting drought conditions up to 12 months ahead. By updating the parameters, drought can be monitored from time to time and this allows early drought detection. Vicente-Serrano et al. (2012) illustrated how the development of drought information systems based on geospatial technology, that combines static and real-time information, could improve the possibilities of drought mitigation in Africa.

Conclusions

This study aimed at developing a methodology to assess drought risk and to monitor and predict droughts in the future. Literature review on drought management studies was completed in order to identify the gaps and design the research objectives and the scope of the study. This study is very important in order to identify the drought behaviour in small or specific regions which might be useful for local use such as farmers. The SPI is selected for use in Victoria and further, will be analysed using the probability based drought class transition model, Markov Chain. This is to forecast future drought for short and medium period. By updating the parameters, drought can be monitored from time to time and this allows early drought detection. It is expected that forecasting model is capable of forecasting drought conditions up to 12 months ahead. In addition, the development of SDF curves for each region is useful for prediction of the probability of severity and drought occurrence.

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