COMPARISON OF THE SPI AND SPEI ON PREDICTING DROUGHT CONDITIONS AND STREAMFLOW IN THE CANADIAN PRAIRIES

Sunil Gurrapu[1 2], Aston Chipanshi[2], David Sauchyn[1], Allan Howard[2]

[1] Prairie Adaptation Research Collaborative (PARC), University of Regina

[2] Science and Technology Branch, Agriculture and Agri-food Canada (AAFC), Regina

INTRODUCTION

Droughts are ranked among the highest natural disasters globally (Bryant, 2005) having the major impacts on various economic sectors. Drought is associated with various climatic and hydrologic processes such as precipitation, temperature, streamflow, etc. (Sheffield and Wood, 2011). Hence, the measured quantities of these processes are primary indicators of drought and one or more of these indicators are assimilated to compute a drought index (Zarger et al., 2011), which is generally used to express drought quantitatively (Hayes, 2006). Indices that are frequently used for forecasting, monitoring and planning operations include Precipitation Percentiles and Deciles, Standardised Precipitation Index (SPI), and Palmer Drought Severity Index (PDSI) among many others (Zarger et al., 2011). Drought is a multi-scalar phenomenon and the timescale over which the water deficits accumulate is extremely important to functionally separate the meteorological, agricultural, hydrological, and socio-economic forms of droughts. Therefore, the SPI is widely accepted as it can be computed at different time scales to monitor droughts with respect to specific water resources. The SPI is a precipitation based index and is computed from the non-exceedance probability of precipitation (P) over a region (McKee et al., 1993). A major assumption made in the SPI computation is that the precipitation and other meteorological factors are stationary with no temporal trends (Vicente-Serrano et al., 2010). However, temperature plays an important role in the moisture availability and various empirical studies have shown that an increase in temperature affects the severity and duration of droughts (Abramopoulos et al., 1988; Rebetez et al., 2006).

The Canadian prairie region is primarily dry and moisture deficient, i.e. the difference between annual precipitation and potential evapotranspiration (PET) is less than zero (Hogg, 1994). Therefore, a drought index based on precipitation data alone may not be sufficient to monitor droughts across the prairies. Moreover, various studies have reported increases in annual global mean temperatures (Trenberth et al., 2007; Rohde et al., 2013) and 21st century global climate models (GCMs) projections show significant increases in the annual mean temperatures (Meehl et al., 2007). Therefore, an index incorporating the effect of temperature is a useful addition for the assessment of droughts in the 21st century. Vicente-Serrano et al. (2010) developed the Standardised Precipitation Evapotranspiration Index (SPEI) similar to SPI but incorporating estimates of moisture losses to the atmosphere due to evapotranspiration. SPEI is computed at various temporal scales based on the non-exceedance probability of precipitation and potential evapotranspiration (P-PET) differences (Vecente-Serrano et al., 2010) and is capable of depicting the multi-temporal nature of drought.

In this study, we analysed and compared the Standardised Precipitation Index (SPI) and Standardised Precipitation Evapotranspiration Index (SPEI) in different climate zones of Canada with a focus on the Canadian prairies to understand which of the two indices best represents drought conditions and the associated hydrological impacts. The Canadian climatic zones ranged from arid to sub-humid. Response of hydrological systems to precipitation deficits vary with the temporal scale, longer temporal scales are considered as hydrological drought indicators (McKee et al., 1993; Hayes et al., 1999). O'Brien and Stroich (2005) found that the monthly mean streamflow in Canadian rivers is highly correlated to the 3-, 6- and 9-month SPI. Therefore, we evaluated the relationships between the SPEI and monthly mean streamflow in selected western Canadian rivers.

DATA AND METHODS

For the comparative analysis, the SPEI and SPI were computed for the meteorological stations located in five different climate zones of southern Canada, Table 1, in addition to eighteen other stations spread across the Canadian prairies. The precipitation and temperature data, at these stations is collected and archived by Environment Canada (EC). These data were corrected for the missing values by the Eastern Cereal and Oilseeds Research Center (ECORC), Ottawa and archived by the Science and Technology Branch, Agriculture and Agri-Food Canada (AAFC), Regina.

Table 1: List of regional climate stations used in the comparative analysis

SID	Name	Longitude	Latitude	Elevation (m)
1108447	Vancouver A	-123.17	49.18	3
3053600	Kananaskis	-115.03	51.03	1391
4016560	Regina A	-104.67	50.43	577
6127514	Sarnia A	-82.3	43	181
8202250	Halifax A	-63.52	44.88	145
8403506	St. Johns A	-52.75	47.62	140

SPI and SPEI were computed at various temporal scales using the SPEI package in R statistical software developed and provided by Beguería and Vicente-Serrano (2013). Computation of these indices involves fitting the P and P-PET series to a suitable probability distribution. The fitted series is then transformed into standardised values that define SPI (McKee et al., 1993) and SPEI (Vicente-Serrano et al., 2010). Precipitation regimes across Canada differ widely in terms of total accumulations, seasonal timing and variability (Qi, 2013; Wan et al., 2005) and hence the widely accepted gamma distribution (Thom, 1966) might be inadequate. Shoukri et al., (1988) showed that the precipitation data from various regions of Canada fits better the 2-parameter log-logistic distribution (LL2) and Vicente-Serrano et al. (2010) determined that the 3-parameter log-logistic distribution (LL3) adapted very well to the P-PET series. Therefore in the current analysis, SPI and SPEI were computed with the assumption that the P and the P-PET series follow the LL3 distribution.

Estimation of potential evapotranspiration (PET) is a critical step in the computation of SPEI, as it involves numerous parameters (Allen et al., 1998). The Food and Agricultural Organisation (FAO) of the United Nations adopted the Penman–Monteith method as the standard procedure to compute potential evapotranspiration. However this method requires extensive climate data sets that are seldom available and hence depending on the data availability, PET may be estimated either by using the temperature based Thornthwaite method (Thornthwaite, 1948), or the modified Penman's equation, Priestley-Taylor method (Priestley and Taylor, 1972), among many other empirical relationships. In the present analysis, the temperature-based Thornthwaite method (Thornthwaite, 1948) was used as it only requires monthly mean temperature data and the latitudinal coordinate of the location, that are readily available at most of the meteorological stations.

SPI and SPEI were compared using simple correlation analysis by computing the Pearson product-moment correlation coefficient (Pearson's r). To assess the degree to which temperature influences the intensity of drought, an artificial trend with a progressive increase up to 2° and 4° C was introduced into the temperature data series. SPEI was computed again leaving the precipitation as is.

To evaluate the relationships between streamflow in the rivers of western Canada and the SPEI, 8 streamflow gauging stations were chosen, Table 2. Stations with naturally flowing streams were used to avoid the anthropogenic influence on the streamflow. The gauging stations were spread across southern Alberta near the eastern foothills of the Rocky Mountains. These stations are operated and maintained by the Water Survey Canada (WSC). Monthly averaged streamflow at each gauging station were obtained from HYDAT database (HYDAT, 2010) and standardised for comparison with the SPEI which had different temporal scales. The climate within the watersheds was assumed to be represented by the climate grid developed by the Natural Resources Canada (NRCAN, McKenny et al., 2011). Climate data for each specific node within the watershed was obtained from the gridded dataset and the computed SPEI was than averaged over the drainage basin to obtain a unique value for the watershed. The relationships between standardised SPEI and streamflow at each gauging station were analysed using correlation analysis.

Table 2 List of the streamflow gauging stations on naturally flowing rivers in Alberta

ID	Name of the Station	Lat.	Long.	Drainage Area
05AA008	CROWSNEST RIVER AT FRANK	49.597	-114.411	402.7
05AA022	CASTLE RIVER NEAR BEAVER MINES	49.489	-114.144	820.7
05AA023	OLDMAN RIVER NEAR WALDRON'S CORNER	49.814	-114.183	1446.1
05AD003	WATERTON RIVER NEAR WATERTON PARK	49.114	-113.84	612.7
05AF010	MANYBERRIES CREEK AT BRODIN'S FARM	49.358	-110.725	338
05BB001	BOW RIVER AT BANFF	51.172	-115.572	2209.6
05BJ004	ELBOW RIVER AT BRAGG CREEK	50.949	-114.571	790.8

05BL019	HIGHWOOD RIVER AT DIEBEL'S RANCH	50.405	-114.501	773.6

RESULTS AND DISCUSSION

The results of the comparative analysis indicate that the SPI and SPEI were significantly correlated at all timescales with a correlation coefficient higher than 0.85. However the correlation was relatively weaker during spring/summer months at shorter timescales near the interior stations, Regina and Sarnia. Similar variability was also observed when comparing the indices from 18 prairie stations. The variability was probably caused by the moisture loss to evapotranspiration during spring/summer with the increasing temperatures that is accounted for by the SPEI. The indices were highly correlated at shorter timescales during winter as the effect of temperature did not exist in the SPEI computation with the assumption that the PET is zero for any month with negative mean temperature from Thornthwaite's method. SPI and SPEI from all the stations were in general highly correlated indicating that either of the indices is good for drought depiction based on the current climatic conditions. However, SPEI from the hypothetical climate with temperature increased up to 2° & 4° C indicate that the SPEI depicts severe and long duration droughts better than SPI. Therefore, it is advisable to use SPEI instead of SPI for drought depiction, considering the projected increases in the temperature during 21st century and hence SPEI was used in the further analysis.

Correlations between standardised streamflow and SPEI indicate seasonal differences at shorter timescales (1-, 2-, and 3-months). The correlations were weaker during winter months at shorter timescales but were positive and relatively stronger during spring/summer and fall months. The correlations during winter were weaker but positive, whereas the correlations in April were weaker and negative probably due to the increased streamflow from rapid snowmelt and lower SPEI computed from low precipitation and higher potential evapotranspiration. The correlations improved with the increasing temporal scales with stronger and statistically significant ($p < 0.001$) correlations at 6- and 9-months timescales. In general, the results indicate that the streamflow during late spring, summer and early fall seasons is highly influenced by the SPEI at 6- and 9-month timescales.

CONCLUSIONS

We conducted a comparative analysis between the Standardised Precipitation Index (SPI) and the Standardised Precipitation-Evapotranspiration Index (SPEI) because both SPI and SPEI are multi-scalar indices and have the advantage of identifying the multi-temporal nature of droughts. From the computation and analysis of these indices at meteorological stations spread across Canada and the prairie region, we observed that droughts of the 20th century were depicted by both of these indices based on the meteorological data. Results indicate that there is little difference between the droughts depicted by the precipitation based SPI and the temperature influenced SPEI primarily because of the low inter-annual variability of the temperature. However, SPEI captured the influence of temperature and depicted severe and longer duration droughts, when the temperature is hypothesized to increase up to 2˚ and 4˚ C. These results provide support for the notion that the SPEI is relatively a better index for evaluating droughts in the 21st century than SPI with projected increases in temperature, because it incorporates the influence of temperature on multi-temporal droughts. We also concluded that the SPEI is a reliable resource for examining the variability of streamflow in naturally flowing rivers of western Canada.

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