COMPARISON OF DROUGHT INDICES AND SC DROUGHT ALERT PHASES

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REFERENCE: *Proceedings of the 2012 South Carolina Water Resources Conference*, held October 10-11, 2012 at the Columbia Metropolitan Convention Center.

Abstract. Drought is a complex phenomenon with devastating effects on different sectors, especially water resources. It is hard to measure and evaluate drought due to its variations in temporal and spatial magnitude. South Carolina has a proactive drought management program to monitor and mitigate drought. The SC Drought Response Committee (DRC) evaluates climatic data and multiple drought indices to declare drought alert phases that trigger drought policy implementation. Previous research shows that different indicators are inconsistent in detecting drought and sometimes show opposite results.

This research takes a closer look at the work of the DRC in the complex decision-making process of evaluating drought indicators to determine drought alert phases. The purpose of this research is to investigate drought indicators and their resemblance with the DRC drought alert phases in detecting drought onset, duration, severity and recovery.

The research demonstrates a method to assess relationships among seven drought indicators and the DRC alert phases. The preliminary analysis is focused on Florence County and ability of indicators to detect the last two major droughts for a period of 2000-2008. The drought indices and the DRC alert phases were generally inconsistent with each other. However, there is a close resemblance between the DRC alert phases with the U.S. Drought Monitor (DM). These results can be explained with the fact that both the DRC and the DM use an integrated approach and rely on analyses of several key indices and ancillary indicators.

This research aims to benefit a decision-making process for drought and water managers, government officials, and stakeholders as it informs drought assessment through the use of major drought indicators.

INTRODUCTION

Recent drought management policy suggestions propose to avoid reactive (crisis management) and promote proactive (risk management) strategies in drought management. One of the essential elements of success in this area is an implementation of an effective drought monitoring and early warning system, an example of which is the drought response program in South Carolina.

For several decades, South Carolina has been using proactive drought monitoring and management strategies. The SC Drought Response Act of 1985 (DRA) established the SC Drought Response Committee (DRC) to address drought related problems and responses. The DRC evaluates drought conditions to determine if a need for action exists beyond the scope of local government.

The DRC drought alert phases initiate policy actions and promote drought management strategies through the distribution of water supplies. Drought alert phases trigger policy implementation such as a revision of local ordinances during the three drought levels and a mandatory water restriction during the extreme drought phase. Drought indices are often inconsistent with each other and this research aims to investigate the relationship between indicators and DRC drought alert phases in order to inform drought evaluation process.

BACKGROUND

South Carolina has a long history of proactive drought monitoring and management strategies. The state was among the first to formulate a drought management plan in 1982 and established the Drought Advisory Committee the same year. The DRA was originally enacted in 1985 and was amended in 2000. In the amendment, changes were made to determine specific numerical values for the indices that define each level of drought. It also established new Drought Management Areas (DMA) still basing the boundaries on geopolitical sectors, but switching from climate divisions to river basins.

The DRC, established by the act, meets regularly to evaluate monitored drought conditions and makes decision about the status of drought in the state. The

DRC declares drought alert phases (incipient, moderate, severe, extreme) based on the seven indices outlined in the regulations: the Palmer Drought Index (PDI), the Crop Moisture Index (CMI), the Standard Precipitation Index (SPI), the Keetch-Byram Drought Index (KBDI), the U.S. Drought Monitor (DM), the average daily streamflow and the static water level in an aquifer. The DRC uses several indices because drought can be characterized in many different ways (Wilhite and Glantz, 1985). South Carolina's has one of the largest numbers of indices suggested by drought management plans adopted on state levels throughout the United States.

Overview of drought indices

Drought indices assimilate thousands of bits of data on rainfall, snowpack, streamflow and other water supply indicators into a comprehensible big picture (Hayes, 1999). A drought index value is typically a single number and is more useful than raw data for decision-making. In order to understand the advantages and drawbacks of each indicator an overview of state drought indices used in the work of the DRC is presented below.

The regulations for the DRA establish Palmer Drought Index as a drought indictor and the DRC takes it into consideration when makeing alert phase decisions. The Palmer Drought Index collectively refers to three indices: PDSI, the PHDI, and the Z Index (Heim, 2002).

Palmer Drought Severity Index. In 1965 W.C Palmer developed the PDSI, one of the most widely used drought indicators. It is a soil moisture index and good indicator for meteorological and agricultural drought. It works well with large areas of uniform topography. The main advantages of this indicator as suggested by Alley (1984) are: it measures the abnormality of recent weather for a region; it places current conditions in historical perspective; and it provides spatial and temporal representations of historical droughts.

Alley (1984), Karl and Knight (1985) and McKee et al. (1995) discuss the limitations of the PDSI: it doesn't take into account streamflow, lake and reservoir levels, and other longer-term hydrologic impacts; it does not present accurate results in winter and spring due to the effects of frozen ground and snow; it tends to underestimate runoff conditions.

Palmer Hydrological Drought Index. The PHDI is very similar to the PDSI. The PHDI is a method to calculate hydrological droughts based on precipitation and evaporation. It quantifies the long-term cumulative impact from hydrological drought and wet conditions, which more accurately reflect groundwater conditions, reservoir levels, etc. (Heim, 2002). The PHDI has a slow response to drought and usually changes even more slowly than the PDSI.

Palmer Z-Index. This index shows short-term soil moisture droughts and wetness by detecting soil moisture anomaly on a monthly scale. The Z-index has the same advantages and disadvantages as the PDSI (Hayes, 1999). The Z-index responds faster to changes in soil moisture values. It declares drought more often with shorter duration of the drought spells.

Crop Moisture Index. In 1968 W.C. Palmer developed the CMI as a soil moisture drought indicator to monitor week-to-week crop conditions. It is not intended to assess long-term droughts. This index related to the Palmer Z-index, which is calculated similarly. It is based on the mean temperature and total precipitation for each week within a climate division, as well as the CMI value from the previous week (Hayes, 1999). The CMI responds rapidly to changing conditions. It is suited for summer drought prediction and can only be used in the growing season. It can detect drought sooner than the PHSI and the PDHI.

Standard Precipitation Index. The SPI Standard (or Standardized) Precipitation Index is a meteorological drought indicator that was developed by McKee et al. (1993) and designed to quantify precipitation deficits for multiple time scales. Soil moisture conditions respond to precipitation anomalies on a relatively short scale, while ground water, streamflow, and reservoir storage reflect the longer- term precipitation anomalies (Hayes, 1999). The SPI calculation for any location is based on the long-term (at least thirty years) precipitation record for a desired period. Its standardization allows the SPI to determine the rarity of a current drought, as well as the probability of the precipitation necessary to end the current drought (McKee et al. 1993).

The advantages of this indicator are that the longer timescale is sometimes used as an approximation of streamflow and groundwater droughts (Hayes, 1999). The disadvantages of the index are the need for a long time series of observed data and the possibility of trends in precipitation during this period (Hayes, 1999).

Keetch-Byram Drought Index: J. Keetch and G. Byram in 1968 developed the KBDI for use by fire control managers to determining forest fire potential. It reflects water gain or loss within soil layers and is specifically designed for fire potential assessment. The index analyzes precipitation and soil moisture in a water budget model. The index increases for each day without rain and decreases when it rains. Drought is not by itself a prerequisite for wildfires.

U.S. Drought Monitor: In 1999 US agencies within National Oceanic and Atmospheric Administration (NOAA) and the U.S. Department of Agricultural (USDA) with the NDMC developed the DM as a drought-monitoring tool that consolidates and centralizes drought-monitoring activities. The output produces weekly depiction of drought type, spatial extent and severity across the USA (Heim, 2002). The DM maps are based on many objective inputs, but the final maps are adjusted manually to reflect real-world conditions as reported by numerous experts throughout the country (Svoboda, 2000).

One of the main advantages of the DM is that it is a consensus product reflecting the collective best judgment of many experts based on several indicators. A limitation of the DM lies in its attempt to show drought at several temporal scales (from short-term drought to long-term drought) on one map product (Heim, 2002).

Recent studies point out the discrepancies among indicators and the inconsistencies between the occurrence frequency for most stages of drought (Mizzell, 2008). Mizzell (2008) illustrates the findings with an example of SC Florence County and shows that inconsistencies between most indicators are greatest from no drought to moderate and less for severe and extreme drought. While the indicators are inconsistent and sometimes show opposite results an expert judgment comes into play in the final decision to establish a degree of drought conditions.

The hypothesis is that the DRA implementation through the work of the DRC in drought alert phases declarations is not identical to any indicator as measured by correspondence with onset, duration, severity and recovery for the last major drought events.

METHODS

The research consists of an analysis of similarities and differences between the DRC drought alert phases and drought indices outlined in the regulations for the DRA. The project compares and evaluates drought detection capacity for drought indices and finds indicators that have the most resemblance to the DRC alert phases using Florence County indices in a period of 2000-2008 as an example.

The research follows three steps. Firstly, the raw data is collected and the advantages along with the limitations of the data sets are discussed. Secondly, the data is calibrated to a consistent unit of analysis (monthly values) and coded according to the regulations values into four drought alert phase categories. Finally, the coded data is compared and analyzed between DRC alert phases and drought indicators in terms of drought onset, duration, severity and recovery.

Data Collection and Data Limitations. The data for the research was collected from several online sources. The DRC alert phases are archived on the SCDNR website. The Dynamic Drought Index for Basins in North and South Carolina (DDIT) (Carbone et al., 2008) provided outputs for major drought indices. In addition, the DM data archive contributed drought intensity weekly data for each county.

The selected study period is January 2000 to December 2008. The time frame of the dataset is limited because of the data availability from the DM on one end and the DDIT on another. The DM is a relatively new tool and its data archive starts in 2000. The DDIT has longer historical records and the most recent data ends in the middle of the year 2009. The DRC Status Reports covers the study time frame. The nine-year data set is not too large, but is sufficient to make inference for general drought conditions since during that period South Carolina faced two major droughts: 1998-2002 and 2007-2008 which were different in their extent and properties.

Calibration and Coding. Different indices have different temporal scales: the PDSI, the PDHI, the Z-index and the SPI are calculated monthly, on the other hand, the CMI and the DM have weekly outputs and the KBDI is calculated daily.

Weekly data for the DM and the CMI converted into drought stages and then into monthly drought alert phases if three or more consecutive weeks experienced drought conditions. In the case of DM, monthly status was recorded if more than 75% of the county area entered any drought level for three or more consecutive weeks. The daily KBDI values were averaged and converted to drought status if the averaged monthly values reached or exceeded the 95th percentile of the trigger level established in the regulations.

Data Analysis. There are various statistical tools that suit a purpose of measuring the association between several variables. The project attempted to utilize rank correlation coefficients such as Kendall's T and Spearman's R. A sample test was performed for Florence County's DRC alert phases with two indicators. One of the most different and one of the most similar indicators were picked after a visual analysis of the data. The results were not statistically significant and showed low-sensitivity of these statistical tools for this research project because of the nature of the data set. Therefore, the research utilizes a visual analysis of the data.

The hypothesis will be rejected if any of the individual indicators have capacity to track state droughts of 1998-2002 and 2007-2008 with the same onset, duration, severity and recovery as declared by the DRC.

RESULTS AND DISCUSSION

Each of seven drought indictors has unique characteristics, specific purpose and use. As the data analysis showed, no single indicator is identical to the

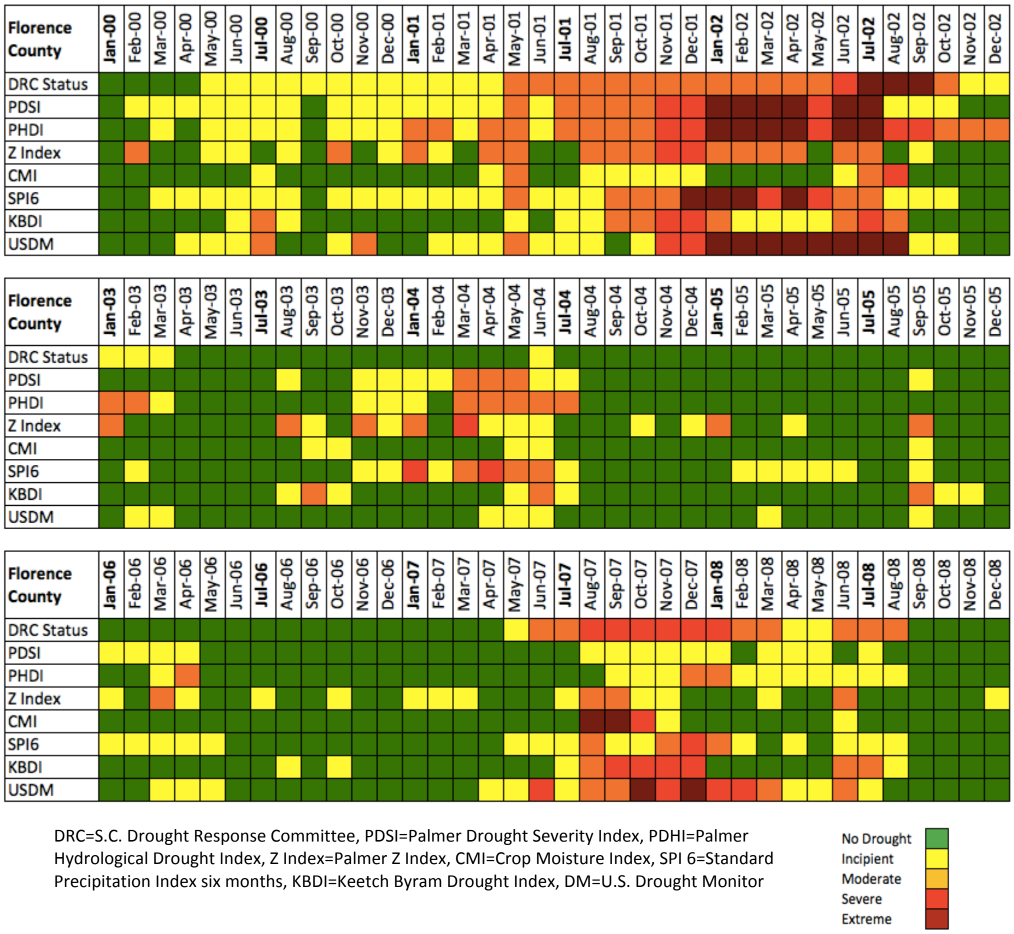

Figure 1. Florence County drought alert phases as measured by DRC and drought indicators.

status outputs of the DRC alert phases (Figure 1). The DM indicator has the most resemblance with the DRC statuses in the analysis of Florence County because it successfully defined two major droughts in the selected time period.

As the Florence County data analysis showed (Figure 1), no single indicator specifically corresponds to the onset, duration, severity and recovery of the DRC statuses and indicators have different sensitivity for different drought events.

The PDSI has mostly similar representation of the 1998-2002 drought in comparison to the DRC's declared drought alert phases. The elevated results for the second half of 2001 and 2002 show more intense drought status as severe and extreme while the DRC report suggest mostly moderate and extreme on a smaller temporal scale. These differences are due to the long-term parameters included in calculation of the PDSI. This index largely underrepresents the drought of 2007-2008 because of different nature of that drought and the fluctuations of the precipitation patterns. There is a similarity of the PDSI and the PDHI in the detecting of droughts for the selected location, however the PDHI has more extended timeframe and severity extent for the first drought and detects the second one in contrast to the PDSI. The long-term impacts of the PDHI extend far beyond the other compared indices. All three Palmer Drought Indices (the PDSI, the PHDI and the Z-index) show drought conditions similar to each other and indicate 2002 as a drought year and have difficulties to identify the drought of 2007-2008.

The CMI has a different output in a comparison to the previous indicators. In contrast to the PDSI, the PDHI and the Z-index, the CMI indicates the severity of the 2007-2008 drought, but has difficulties to detect the severity of the previous drought. Since this indicator is suitable only for a growing season and it resets during winter months, no drought is detected in the off-growing seasons.

The SPI has a good potential for detecting droughts and succeeded in both instances for detecting past drought, however the DRC alert phases lag behind several month in the case of the first drought period. The SPI provided significantly reliable results and has a close resemblance with the DRC alert phases. The spatial and temporal extents are different and somewhat underestimated in Florence County, especially for DRC drought alert phase of no drought in 2003-2005.

The KBDI elevated levels stated in the regulations for the DRA have an overlapping detection capacity of drought severity. The KBDI drought detection is widely present in the summer months when the evapotranspiration rates are higher than the rest of the year. This index showed both 1998-2002 and 2007-2008 droughts, which highlights the importance the KBDI in the decision-making process.

The DM is the only indicator that succeeded in detecting both 1998-2002 and 2007-2008 droughts with the onset and duration similar to the DRC alert phases. The onset, duration and recovery measured by the DRC generally correspond to the DM outputs, but the severity is stronger than the DRC alert phases. The explanation to it lays in the design of the criteria of the regulations for the DRA.

To summarize the results of the visual analysis of drought indices for Florence County the DRC drought alert phase are not identical to any state drought indicators. The DRC alert phases indicate different onset, duration, severity and recovery from drought events. Some indices (PDSI, PDHI, SPI and DM) have a larger resemblance with the DRC outputs, while others (Z-index, CMI and KBDI) did not succeed in identifying two droughts. The DM has the closest resemblance with DRC alert phases. The DM demonstrated better resemblance with the DRC alert phases than any other index. This can be explained by the fact that the DM relies on the analyses of several key indices and ancillary indicators from different agencies to create a comprehensive cumulative output.

CONCLUSION

The South Carolina Drought Management Program with the help of S.C. Drought Response Committee is an example of a comprehensive output effort of proactive approach to monitor and mitigate drought. Drought indicators and determinations of the DRC trigger the drought management responses that influence water management in the state. It is a difficult task to monitor and assess droughts due to variations in temporal and spatial extends of the complex events and their severity. There is no universal drought indicator and previous studies identified significant discrepancies between the state drought indices. In the recent years the integrated DM provides a collaborative outputs to better drought management.

South Carolina's drought management program utilizes a large number of drought indicators outlined by the regulation to the DRA and no single indicator is consistent with the DRC outputs. The majority of the state indices detected one or another but not both past droughts 1998-2002 and 2007-2008. However, the research shows that the DM data resemble most the DRC statuses because both use the integrated approach in the drought assessment.

Suggestions based on this research include a need for a closer attention to the integrated drought indicators in the monitoring of drought conditions for the DRC and the South Carolina water users. The state drought management program and the work of the DRC is a valuable example of assessment of drought indicators for policy purposes and makes suggestions for drought triggers in other regions of the country. The analysis of the drought indices provides a better understanding of the complexity of drought measurement and evaluation for water specialists, government officials, and stakeholders in the water resource management in the state of South Carolina and other states.

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