Drought Indices

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Introduction

Drought indices assimilate thousands of bits of data on rainfall, snowpack, streamflow and other water supply indicators into a comprehensible big picture. A drought index value is typically a single number, far more useful than raw data for decision making.

There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms. Although none of the major indices is inherently superior to the rest in all circumstances, some indices are better suited than others for certain uses. For example, the Palmer Drought Severity Index has been widely used by the U.S. Department of Agriculture to determine when to grant emergency drought assistance, but the Palmer is better when working with large areas of uniform topography. Western states, with mountainous terrain and the resulting complex regional microclimates, find it useful to supplement Palmer values with other indices such as the Surface Water Supply Index, which takes snowpack and other unique conditions into account.

The National Drought Mitigation Center is using a newer index, the Standardized Precipitation Index, to monitor moisture supply conditions. Distinguishing traits of this index are that it identifies emerging droughts months sooner than the Palmer Index and that it is computed on various time scales.

Most water supply planners find it useful to consult one or more indices before making a decision. What follows is an introduction to each of the major drought indices in use in the United States and in Australia.

Percent of Normal

Who uses it: a simple calculation well-suited to the needs of TV weather people and general audiences
Pros: quite effective for comparing a single region or season
Cons: easily misunderstood — "normal" is not what should always be expected

The percent of normal precipitation is one of the simplest measurements of rainfall for a location. Analyses using the percent of normal are very effective when used for a single region or a single season. Percent of normal is also easily misunderstood and gives different indications of conditions, depending on the location and season. It is calculated by dividing actual precipitation by normal precipitation -- typically considered to be a 30-year mean -- and multiplying by 100%. This can be calculated for a variety of time scales. Usually these time scales range from a single month to a group of months representing a particular season, to an annual or water year. Normal precipitation for a specific location is considered to be 100%.

One of the disadvantages of using the percent of normal precipitation is that the mean, or average, precipitation is often not the same as the median precipitation, which is the value exceeded by 50% of the precipitation occurrences in a long-term climate record. The reason for this is that precipitation on monthly or seasonal scales does not have a normal distribution. Use of the percent of normal comparison implies a normal distribution where the mean and median are considered to be the same. An example of the confusion this could create can be illustrated by the long-term precipitation record in Melbourne, Australia, for the month of January. The median January precipitation is 36.0 mm (1.4 in.), meaning that in half the years less than 36.0 mm is recorded, and in half the years more than 36.0 mm is recorded. However, a monthly January total of 36.0 mm would be only 75% of normal when compared to the mean, which is often considered to be quite dry. Because of the variety in the precipitation records over time and location, there is no way to determine the frequency of the departures from normal or compare different locations. This makes it difficult to link a value of a departure with a specific impact occurring as a result of the departure, inhibiting attempts to mitigate the risks of drought based on the departures from normal and form a plan of response (Willeke et al. 1994).

Standardized Precipitation Index (SPI)

Description: an index based on the probability of precipitation for any time scale
Who uses it: many drought planners appreciate the SPI's versatility
Pros: the SPI can be computed for different time scales, can provide early warning of drought and help assess drought severity, and is less complex than the Palmer
Cons: values based on preliminary data may change
Developed by: Tom McKee, et al., Colorado State University, 1993
Monthly maps:
http://enso.unl.edu/ndmc/watch/watch.htm
and
http://www.wrcc.sage.dir.edu/spi/spi.html

The understanding that a deficit of precipitation has different impacts on the ground water, reservoir storage, soil moisture, snowpack, and streamflow led McKee et al. (1993) to develop the Standardized Precipitation Index (SPI). The SPI was designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of the different water resources. 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. For these reasons, McKee et al. (1993) originally calculated the SPI for 3-, 6-,12-, 24-, and 48-month time scales.

The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee 1997). Positive SPI values indicate greater than median precipitation, while negative values indicate less than median precipitation. Because the SPI is normalized, wetter and drier climates can be represented in the same way, and wet periods can also be monitored using the SPI.

McKee et al. (1993) used the classification system shown in the SPI Values table to define drought intensities resulting from the SPI. McKee et al. (1993) also defined the criteria for a "drought event" for any of the time scales. A drought event occurs any time the SPI is continuously negative and reaches an intensity where the SPI is -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and an intensity for each month that the event continues. The accumulated magnitude of drought can also be drought magnitude, and it is the positive sum of the SPI for all the months within a drought event.

SPI Values	
2.0 and above	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2.0 and less	extremely dry

Based on an analysis of stations across Colorado, McKee determined that the SPI is in mild drought 24 percent of the time; in moderate drought 9.2 percent of the time; in severe drought 4.4 percent of the time; and in extreme drought 2.3 percent of the time (McKee et al. 1993). Because the SPI is standardized, these percentages are expected from a normal distribution of the SPI. The 2.3% of SPI values within the “Extreme Drought” category is a percentage that is typically expected for an “extreme” event (Wilhite 1995). In contrast, the Palmer Index reaches its “extreme” category more than 10% of the time across portions of the central Great Plains. This 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 SPI has been used operationally to monitor conditions across Colorado since 1994 (McKee et al. 1995). Monthly maps of the SPI for Colorado can be found on the Colorado State University home page (http://ulysses.atmos.colostate.edu/SPI.html). It is also being monitored at the Climate Division level for the contiguous United States by the National Drought Mitigation Center and the Western Regional Climate Center (WRCC). Current monthly SPI maps are found on the NDMC web site (http://enso.unl.edu/ndmc/watch/watch.htm) and as part of a matrix tool on the WRCC web site (http://www.wrcc.sage.dri.edu/spi/spi.html).

Palmer Drought Severity Index (PDSI)

In 1965, Palmer developed an index to measure the departure of the moisture supply (Palmer 1965). Palmer based his index on the supply-and-demand concept of the water balance equation, taking into account more than just the precipitation deficit at specific locations. The objective of the Palmer Drought Severity Index (PDSI), as this index is now called, was to provide measurements of moisture conditions that were standardized so that comparisons using the index could be made between locations and between months (Palmer 1965).

Description: a soil moisture algorithm calibrated for relatively homogeneous regions
Who uses it: many U.S. government agencies and states rely on the Palmer to trigger drought relief programs
Pros: the first comprehensive drought index developed in the United States
Cons: Palmer values may lag emerging droughts by several months; less well-suited for mountainous land or areas of frequent climatic extremes; complex, has an unspecified, built-in time scale that can be misleading
Developed by: W.C. Palmer, 1965
Weekly maps: http://nic.fb4.noaa.gov/products/analysis_monitoring/

The PDSI is a meteorological drought index and responds to weather conditions that have been abnormally dry or abnormally wet. When conditions change from dry to normal or wet, for example, the drought measured by the PDSI ends without taking into account streamflow, lake and reservoir levels, and other longer-term hydrologic impacts (Karl and Knight 1985). The PDSI is calculated based on precipitation and temperature data, as well as the local Available Water Content (AWC) of the soil. From the inputs, all the basic terms of the water balance equation can be determined, including evapotranspiration, soil recharge, runoff, and moisture loss from the surface layer. Human impacts on the water balance, such as irrigation, are not considered. Complete descriptions of the equations can be found in the original study by Palmer (1965) and in the more recent analysis by Alley (1984).

Palmer developed the PDSI to include the duration of a drought (or wet spell). His motivation was as follows: an abnormally wet month in the middle of a long-term drought should not have a major impact on the index, or a series of months with near-normal precipitation following a serious drought does not mean that the drought is over. Therefore, Palmer developed criteria for determining when a drought or a wet spell begins and ends, which adjust the PDSI accordingly. Palmer (1965) described this effort and gave examples, and it is also described in detail by Alley (1984). In near-real time, Palmer's index is no longer a meteorological index but becomes a hydrological index referred to as the Palmer Hydrological Drought Index (PHDI) because it is based on moisture inflow (precipitation), outflow, and storage, and does not take into account the long-term trend (Karl and Knight 1985).

PDSI Classifications for Dry and Wet Periods	
4.00 or more	Extremely wet
3.00 to 3.99	Very wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Slightly wet
0.50 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.50 to -0.99	Incipient dry spell
-1.00 to -1.99	Mild drought
-2.00 to -2.99	Moderate drought
-3.00 to -3.99	Severe drought
-4.00 or less	Extreme drought

In 1989, a modified method to compute the PDSI was begun operationally (Heddinghaus and Sabol 1991). This modified PDSI differs from the PDSI during transition periods between dry and wet spells. Because of the similarities between these Palmer indices, the terms "Palmer Index" and "Palmer Drought Index" have been used to describe general characteristics of the indices.

The Palmer Index varies roughly between -6.0 and +6.0. Palmer arbitrarily selected the classification scale of moisture conditions based on his original study areas in central Iowa and western Kansas (Palmer 1965). Ideally, the Palmer Index is designed so that a -4.0 in South Carolina has the same meaning in terms of the moisture departure from a climatological normal as a -4.0 in Idaho (Alley 1984). The Palmer Index has typically been calculated on a monthly basis, and a long-term archive of the monthly PDSI values for every Climate Division in the United States exists with the National Climatic Data Center from 1895 through the present. In addition, weekly Palmer Index values (actually modified PDSI values) are calculated for the Climate Divisions during every growing season and are available in the Weekly Weather and Crop Bulletin. These weekly Palmer Index maps are also available on the World Wide Web from the Climate Prediction Center at http://nic.fb4.noaa.gov/products/analysis_monitoring/regional_monitoring/palmer.gif.

The Palmer Index is popular and has been widely used for a variety of applications across the United States. It is most effective measuring impacts sensitive to soil moisture conditions, such as agriculture (Willeke et al. 1994). It has also been useful as a drought monitoring tool and has been used to trigger actions associated with drought contingency plans (Willeke et al. 1994). Alley (1984) identified three positive characteristics of the Palmer Index that contribute to its popularity: (1) it provides decision makers with a measurement of the abnormality of recent weather for a region; (2) it provides an opportunity to place current conditions in historical perspective; and (3) it provides spatial and temporal representations of historical droughts. Several states, including New York, Colorado, Idaho, and Utah, use the Palmer Index as one part of drought monitoring systems.

There are considerable limitations when using the Palmer Index, and these are described in detail by Alley (1984) and Karl and Knight (1985). Drawbacks of the Palmer Index include:

- The values quantifying the intensity of drought and signaling the beginning and end of a drought or wet spell were arbitrarily selected based on Palmer's study of central Iowa and western Kansas and have little scientific meaning.
- The Palmer Index is sensitive to the AWC of a soil type. Thus, applying the index for a Climate Division may be too general.
- The two soil layers within the water balance computations are simplified and may not be accurately representative for a location.
- Snowfall, snow cover, and frozen ground are not included in the index. All precipitation is treated as rain, so that the timing of PDSI or PHDI values may be inaccurate in the winter and spring months in regions where snow occurs.
- The natural lag between when precipitation falls and the resulting runoff is not considered. In addition, no runoff is allowed to take place in the model until the water capacity of the surface and subsurface soil layers is full, leading to an underestimation of runoff.
- Potential evapotranspiration is estimated using the Thornthwaite method. This technique has wide acceptance, but it is still only an approximation.

Several other researchers have presented additional limitations of the Palmer Index. McKee et al. (1995) suggested that the PDSI is designed for agriculture, but does not accurately represent the hydrological impacts resulting from longer droughts. The Palmer Index is also applied within the United States and has little acceptance elsewhere (Kogan 1995). One explanation for this is provided by Smith et al. (1993), who suggested that it does not do well in regions where there are extremes in the variability of rainfall or runoff. Examples in Australia and South Africa were given.

Another weakness in the Palmer Index is that the “extreme” and “severe” classifications of drought occur with a greater frequency in some parts of the country than in others (Willeke et al. 1994). “Extreme” droughts in the Great Plains occur with a frequency greater than 10%. This limits the accuracy of comparing the intensity of droughts between two regions, and makes planning response actions based on a certain intensity more difficult.

Crop Moisture Index (CMI)

The Crop Moisture Index (CMI) uses a meteorological approach to monitor week-to-week crop conditions. It was developed by Palmer (1968) from procedures within the calculation of the PDSI. Whereas the PDSI monitors long-term meteorological wet and dry spells, the CMI was designed to evaluate short-term moisture conditions across major crop producing regions. 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. The CMI responds rapidly to changing conditions, and it is weighted by location and time so that maps, which commonly display the weekly CMI across the United States, can be used to compare moisture conditions at different locations. Weekly maps of the CMI are available as part of the USDA/JAWF *Weekly Weather and Crop Bulletin* (http://www.usda.gov/agency/oce/waob/jawf/wwcb/graphics/cma.gif).

Description: a Palmer derivative, reflects moisture supply in the short term across major crop-producing regions, is not intended to assess long-term droughts.
Pros: identifies potential agricultural droughts
Developed by: W.C. Palmer, 1968
Weekly maps: http://www.investaweather.com/investaweather/daily/map/cmi.gif

Because it is designed to monitor short-term moisture conditions affecting a developing crop, the CMI is not a good long-term drought monitoring tool. The CMI's rapid response to changing short-term conditions may provide misleading information about long-term conditions. For example, a beneficial rainfall during a drought may allow the CMI value to indicate adequate moisture conditions, while the long-term drought at that location persists. Another characteristic of the CMI that limits its use as a long-term drought monitoring tool is that the CMI typically begins and ends each growing season near zero. This limitation prevents the CMI from being used to monitor moisture conditions outside the general growing season, especially in droughts that extend over several years. The CMI also may not be applicable during seed germination at the beginning of a specific crop's growing season.

Surface Water Supply Index (SWSI)

Description: designed to complement the Palmer in the state of Colorado, where mountain snowpack is a key element of water supply; calculated by river basin, based on snowpack, streamflow, precipitation, reservoir storage
Pros: represents water supply conditions unique to each basin
Cons: changing a data collection station or water management requires that new algorithms be calculated, and the index is unique to each basin, which limits interbasin comparisons
Developed by: Shafer and Dezman, 1982

The Surface Water Supply Index (SWSI) was developed by Shafer and Dezman (1982) to complement the Palmer Index for moisture conditions across the state of Colorado. The Palmer Index is basically a soil moisture algorithm calibrated for relatively homogeneous regions, but it is not designed for large topographic variations across a region and it does not account for snow accumulation and subsequent runoff. Shafer and Dezman designed the SWSI to be an indicator of surface water conditions and described the index as "mountain water dependent," in which mountain snowpack is a major component.

The objective of the SWSI was to incorporate both hydrological and climatological features into a single index value resembling the Palmer Index for each major river basin in the state of Colorado (Shafer and Dezman 1982). These values would be standardized to allow comparisons between basins. Four inputs are required within the SWSI: snowpack, streamflow, precipitation, and reservoir storage. Because it is dependent on the season, the SWSI is computed with only the snowpack, precipitation, and reservoir storage in the winter. During the summer months, streamflow replaces snowpack as a component within the SWSI equation.

The procedure to determine the SWSI for a particular basin follows: monthly data are collected and summed for all the precipitation stations, reservoirs, and snowpack/streamflow measuring stations over the basin. Each summed component is normalized using a frequency analysis gathered from a long-term data set. The probability of non-exceedence -- the probability that subsequent sums of that component will not be greater than the current sum -- is determined for each component based on the frequency analysis. This allows comparisons of the probabilities to be made between the components. Each component has a weight assigned to it depending on its typical contribution to the surface water within that basin, and these weighted components are summed to determine a SWSI value representing the entire basin. Like the Palmer Index, the SWSI is centered on zero and has a range between -4.2 and +4.2.

The SWSI has been used, along with the Palmer Index, to trigger the activation and deactivation of the Colorado Drought Plan. One of its advantages is that it is simple to calculate and gives a representative measurement of surface water supplies across the state. It has been modified and applied in other western states as well. These states include Oregon, Montana, Idaho, and Utah.

Monthly SWSI maps for Montana are available from the Montana Natural Resource Information System. http://nris.mt.gov/wis/supply4.html/

Several characteristics of the SWSI limit its application. Because the SWSI calculation is unique to each basin or region, it is difficult to compare SWSI values between basins or regions (Doesken et al. 1991). Within a particular basin or region, discontinuing any station means that new stations need to be added to the system and new frequency distributions need to be determined for that component. Additional changes in the water management within a basin, such as flow diversions or new reservoirs, mean that the entire SWSI algorithm for that basin needs to be redeveloped to account for changes in the weight of each component. Thus, it is difficult to maintain a homogeneous time series of the index (Heddinghaus and Sabol 1991). Extreme events also cause a problem if the events are beyond the historical time series, and the index will need to be reevaluated to include these events within the frequency distribution of a basin component.

Reclamation Drought Index

The Reclamation Drought Index (RDI) was recently developed as a tool for defining drought severity and duration, and for predicting the onset and end of periods of drought. The impetus to devise the RDI came from the Reclamation States Drought Assistance Act of 1988, which allows states to seek assistance from the Bureau of Reclamation to mitigate the effects of drought.

As with the SWSI, the RDI is calculated at a river basin level, and incorporates the supply components of precipitation, snowpack, streamflow, and reservoir levels. The RDI differs from the SWSI in that it builds a temperature-based demand component and a duration into the index. The RDI is adaptable to each particular region and its main strength is its ability to account for both climate and water supply factors.

Oklahoma has developed its own version of the RDI and plans to use the index as one tool within the monitoring system designated in the state's drought plan. The RDI values and severity designations are similar to the SPI, PDSI, and SWSI.

Description: like the SWSI, the RDI is calculated at the river basin level, incorporating temperature as well as precipitation, snowpack, streamflow and reservoir levels as input
Who uses it: the Bureau of Reclamation, the State of Oklahoma as part of their drought plan
Pros: by including a temperature component, it also accounts for evaporation
Cons: because the index is unique to each river basin, interbasin comparisons are limited
Developed by: the Bureau of Reclamation, as a trigger to release drought emergency relief funds

RDI Severity Designations		
Drought	Designation	Wetness
0 to -1.5	Normal to Mild	0 to 1.5
-1.5 to -4.0	Moderate	1.5 to 4.0
<-4.0	Extreme	>4.0

Deciles

Arranging monthly precipitation data into deciles is another drought-monitoring technique. It was developed by Gibbs and Maher (1967) to avoid some of the weaknesses within the "percent of normal" approach. The technique they developed divided the distribution of occurrences over a long-term precipitation record into tenths of the distribution. They called each of these categories a "decile." The first decile is the rainfall amount not exceeded by the lowest 10% of the precipitation occurrences. The second decile is the precipitation amount not exceeded by the lowest 20% of occurrences. These deciles continue until the rainfall amount identified by the tenth decile is the largest precipitation amount within the long-term record. By definition, the fifth decile is the median, and it is the precipitation amount not exceeded by 50% of the occurrences over the period of record. The deciles are grouped into five classifications.

Description: groups monthly precipitation occurrences into deciles, so by definition, "much lower than normal" weather can't occur more often than 20 percent of the time
Who uses it: Australian drought authorities
Pros: provides an accurate statistical measurement of precipitation
Cons: accurate calculations require a long climatic data record

The decile method was selected as the meteorological measurement of drought within the Australian Drought Watch System because it is relatively simple to calculate, and requires less data and fewer assumptions than the Palmer Drought Severity Index (Smith et al. 1993). In this system, farmers and ranchers can only request government assistance if the drought is shown to be an event that occurs only once in 20-25 years (deciles 1 and 2 over a 100-year record) and has lasted longer than 12 months (White and OíMeagher 1995). This uniformity in drought classifications, unlike a system based on the percent of normal precipitation, has assisted Australian authorities in determining appropriate drought responses. One disadvantage of the decile system is that a long climatological record is needed to calculate the deciles accurately.

Decile Classifications for Dry and Wet Periods

Deciles 1-2	lowest 20%	much below normal
Deciles 3-4	next lowest 20%	below normal
Deciles 5-6	middle 20%	near normal
Deciles 7-8	next highest 20%	above normal
Deciles 9-10	highest 20%	much above normal

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