Drought Indices

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This article originally appeared in a longer form on the National Drought Mitigation Center (NDMC) webpage, http://drought.unl.edu/index.htm. The NDMC works to minimize impacts and vulnerabilities of drought by providing risk management strategies and recommendations.

Introduction

Drought indices assimilate 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 for decision-making than raw data. Although none of the major indices is inherently superior, some indices are better suited for certain regions or uses than others. For example, the Palmer Drought Severity Index (PDSI) is useful for large areas of uniform topography and is widely used by the U.S. Department of Agriculture to determine when to grant emergency drought assistance. On the other hand, decision makers in western states, with mountainous terrain and complex regional microclimates, often supplement PDSI values with other indices such as the Surface Water Supply Index (SWSI), which takes snowpack and other unique conditions into account, and the Standardized Precipitation Index, (SPI) which identifies emerging droughts sooner than the PDSI and is computed on various timescales. The National Drought Mitigation Center (NMDC) now uses the SPI as its primary tool to monitor moisture supply conditions. This article provides an introduction to major drought indices used in the United States, however other indices do exist or are in development.

Percent of Normal Precipitation

Overview: The percent of normal is a simple calculation well suited to the needs of TV weathercasters and general audiences.
Pros: Quite effective for comparing a single region or season.
Cons: Easily misunderstood, because "normal" is a mathematical construct that does not necessarily correspond with expected weather patterns.

The percent of normal precipitation is one of the simplest measurements of rainfall for a location. Analyses using percent of normal are very effective when used for a single region or a single 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, including monthly, seasonal, annual, or water year. Normal precipitation for a specific location is considered to be 100%.

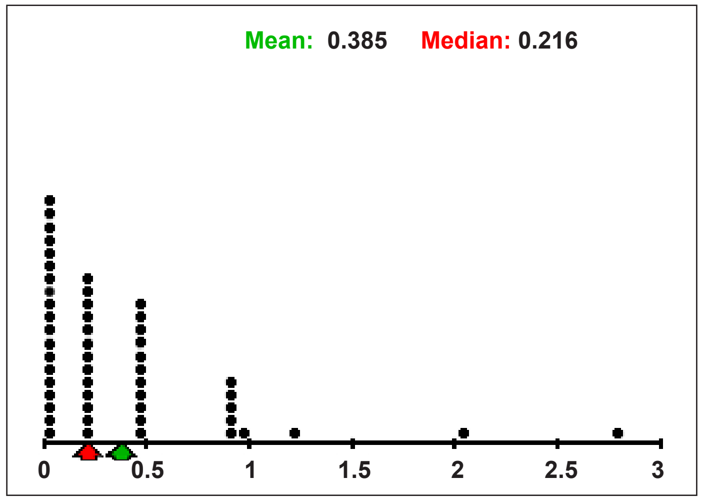

Figure 1a. Example of hypothetical data showing how the mean can be higher than the median. If the majority of data points are low, a few high data points skew the distribution, resulting in a higher mean value in comparison to the median.

A disadvantage of using the percent of normal precipitation is that the mean, or average precipitation is often not the same as the median precipitation. Median precipitation is the middle value of all the individual precipitation measurements; it is always the 50th percentile. Precipitation on monthly or seasonal scales is not normally distributed, so use of the percent of normal implies a normal distribution where the mean and median are considered to be the same. In the west, although precipitation amounts are often low, there also are some very wet days. The resulting distribution gives a mean (normal) that is higher than the median because the infrequent wet events skew the distribution (Figure 1a). The actual amount of precipitation tends to be closer to the median than the mean. Therefore, if one is expecting average (normal) precipitation on any given day, he will usually get a value that is below average.

Because the value of normal depends on time and location, one cannot compare the frequency of the departures from normal between time periods or locations. This makes it difficult to link a particular value of a departure with a specific impact occurring as a result. Therefore, mitigating the risks of drought based on the departures from normal is not a useful decision-making tool when used alone (Willeke et al., 1994).

The Palmer Drought Severity Index (PDSI) and other Palmer Indices

Overview: The PDSI is 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: It was the first comprehensive drought index developed in the U.S.

Cons: Palmer values may not identify droughts as early as the other indices; it is less well suited for mountainous land or areas of frequent climatic extremes; it is highly complex.

The Palmer Drought Severity Index (PDSI) is a meteorological drought index, which provides a standardized measurement of moisture conditions to compare between locations and over time (Palmer, 1965). The PDSI estimates duration and intensity of drought events by measuring departure of the moisture supply based on a supply-and-demand concept of the water balance equation. The PDSI incorporates precipitation and temperature data, and local Available Water Content of the soil from an unspecified period that best corresponds to past 9-12 months. Past conditions are incorporated because long-term drought is cumulative, so the intensity of drought at a particular time is dependent on the current conditions plus the cumulative patterns of previous months. From the inputs, all the basic terms of the water balance equation are determined, including evapotranspiration, soil recharge, runoff, and moisture loss from the surface layer. The equations are described in Palmer's original study (1965) and in the more recent analysis by Alley (1984). By accounting for moisture conditions in the past, the PDSI estimates when a drought (or wet spell) begins, ends, and the duration of the event (Palmer, 1965; Alley, 1984). The Palmer Hydrological Drought Index (PHDI) is a derivative of the PDSI. It is based on daily inflow (precipitation) and soil moisture storage (Karl and Knight, 1985).

The PDSI generally ranges from -4.0 to +4.0 and it is designed so that, an extreme drought (-4.0) in one climate division has the same meaning in terms of the moisture deficit as an extreme drought in any other climate division (Alley, 1984). The PDSI is typically calculated on a monthly basis, and a long-term archive of monthly PDSI values for every climate division in the United States is available from the National Climatic Data Center from 1895 through the present. In addition, weekly PDSI values are calculated for the climate divisions during every growing season and are available in the Weekly Weather and Crop Bulletin (see On the Web box).

Palmer Classifications	
4.0 or more	Extremely Wet
3.0 to 3.99	Very Wet
2.0 to 2.99	Moderately Wet
1.0 to 1.99	Slightly Wet
0.5 to 0.99	Incipient Wet Spell
0.49 to - .49	Near Normal
-0.5 to -0.99	Incipient Dry Spell
-1.0 to -1.99	Mild Drought
-2.0 to -2.99	Moderate Drought
-3.0 to -3.99	Severe Drought
-4.0 or less	Extreme Drought

Figure 1b. The PDSI classification ranges from -4.0 or less (extreme drought) to 4.0 or more (extremely wet).

Alley (1984) identified three primary benefits of the PDSI. The PDSI provides decision makers with a measurement of the abnormality of recent weather events for a region and places current conditions in a historical perspective. It also provides spatial and temporal representations of historical droughts. The PDSI has been widely used for a variety of applications across the U.S. It is most effective at 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 been used to trigger actions associated with drought contingency plans (Willeke et al., 1994). Finally, water managers find it useful to supplement PDSI values with PHDI values as a way to analyze additional hydrological information important to water management decisions in the West.

The limitations of the PDSI involve its inability to fully characterize hydrologic, climatic, and geographical parameters and variance in such parameters within river basins, in the US or in other countries (Alley, 1984; Karl and Knight, 1985). Drawbacks 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 PDSI is sensitive to the Available Water Content of a soil type. The two soil layers within the water balance computations are simplified and may not be accurately representative of a location. Thus, applying the index for a climate division may be too general.
- Snowfall, snow cover, and frozen ground are not included

- in the index. All precipitation is treated as rain, so that the timing of PDSI 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.
- The PDSI does not account for streamflow, lake and reservoir levels, and other longer-term hydrologic impacts of drought (Karl and Knight, 1985).
- Human impacts on the water balance, such as irrigation, are not considered.
- The PDSI is applied within the United States but has little acceptance elsewhere (Kogan, 1995).
- 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 more difficult.

Crop Moisture Index (CMI)
Overview: A Palmer derivative, the CMI reflects moisture supply in the short term across major crop-producing regions.
Pros: Identifies potential agricultural droughts.
Cons: Not useful in long-term drought monitoring.

The Crop Moisture Index (CMI) uses a meteorological approach developed by Palmer (1968) to monitor week-to-week crop conditions. In comparison to the PDSI, which 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 weekly mean temperature and total precipitation within a climate division, and incorporates the CMI value from the previous week. The CMI responds rapidly to changing conditions, and it is weighted by location and time, so weekly maps of the U.S. can be used to compare moisture conditions at different locations. The CMI is part of the USDA/JAWF Weekly Weather and Crop Bulletin (see On the Web box).

Because the CMI is designed to monitor short-term moisture conditions for a developing crop, it is not a good long-term drought-monitoring tool Its 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 limiting characteristic is that the CMI typically begins and ends each growing season near zero. This prevents the CMI from being used to monitor moisture conditions outside the general growing season, especially in droughts that extend over several years. In addition, the CMI may not be applicable during seed germination at the beginning of the growing season.

Surface Water Supply Index (SWSI)
Overview: The SWSI is designed to complement the Palmer Indices in western states where mountain snowpack is a key element of water supply. The SWSI is calculated by river basin, based on snowpack, streamflow, precipitation, and reservoir storage.
Pros: It represents water supply conditions unique to each basin.
Cons: Changing a data collection station or water management policies requires that new algorithms be calculated; the index is unique to each basin, which limits interbasin comparisons.

The Surface Water Supply Index (SWSI) was designed to complement the Palmer Indices for moisture conditions across the state of Colorado (Shafer and Dezman, 1982), however, now most western starts calculate their own SWSI (see page 12 for the current Colorado SWSI). The Palmer Indices are not designed for large topographic variations across a region, and do not account for snow accumulation and subsequent runoff. In contrast, SWSI incorporates mountain snowpack levels and was designed specifically to asses surface water conditions. The objective of the SWSI is to incorporate both hydrological and climatological features into a single index value for each major river basin in the west (Shafer and Dezman 1982). These values are standardized to allow comparisons between basins. Four inputs are used to calculate SWSI: snowpack, streamflow, precipitation, and reservoir storage. Because water supply is dependent on the season, snowpack, precipitation, and reservoir storage are used to compute SWSI during the winter (November-April). During the summer months, (May-October) streamflow replaces the snowpack component in the SWSI equation.

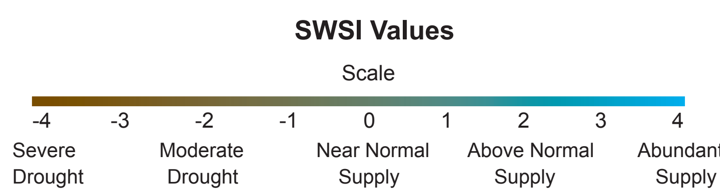

Figure 1c. SWSI scale ranges from -4, (severe drought) to +4 (abundant water supply).

The SWSI has been used, along with the PDSI, to trigger the activation and deactivation of the Colorado Drought Plan. It has been modified and applied in other western states as well, such as Wyoming and Utah. One of its advantages is that it is simple to calculate and gives a representative measurement of surface water supplies across the state. In addition, each input component (streamflow, reservoir storage, snowpack, etc.) is given a weight depending on its typical contribution to the surface water within each basin. Therefore it gives a more accurate picture of water supplies than the other indices that primarily focus on precipitation inputs.

The SWSI has several limitations. 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). If any existing stations are discontinued within a basin or region, new stations must be added with new frequency distributions for each input component to ensure SWSI is calculated the same each month. Extreme events also cause a problem if the events are beyond the historical time series, so the index must be reevaluated to include these events within the frequency distribution of a basin component. Changes in 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).

Standardized Precipitation Index (SPI)

Overview: The SPI is an index based on the probability of precipitation for any time scale.

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. Many drought planners appreciate the SPI's versatility.

Cons: SPI values based on preliminary data may change.

The Standardized Precipitation Index (SPI) reflects the impact of drought on the availability of different water resources. It is designed to quantify the impacts of precipitation deficit on groundwater, reservoir storage, soil moisture, snowpack, and streamflow for multiple time scales. Soil moisture conditions respond to precipitation anomalies on a relatively short scale. Groundwater, streamflow, and reservoir storage reflect the longer-term precipitation anomalies. Therefore, SPI was originally calculated for 3, 6, 12, 24, and 48–month time scales. The SPI is used operationally to monitor conditions across Colorado since 1994 (McKee et al., 1995), and is being monitored at the climate division level for the contiguous United States by the NDMC and the Western Regional Climate Center (WRCC). The NDMC and High Plains Regional Climate Center also provides daily SPI maps broken down by region and for the United States (see On the Web box; see page 11 for current SPI maps of the IMW region).

SPI Values	
2.0+	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 and less	Extremely Dry

Figure 1d. SPI values range from -2 (extremely dry) to +2.0 (extremely wet). The IWCS SPI page is 11.

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, and negative values indicate less than median precipitation (Figure 1d). Because the SPI is normalized, wetter and drier climates can be represented in the same way.

While the SPI can monitor wet periods, it is typically used to assess the length and magnitude of drought events. A drought event occurs when the SPI is continuously reaches an intensity of -1.0 or less (Figure 1d). 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. Drought magnitude is the positive sum of the SPI for each month during the drought event.

Based on an analysis of stations across Colorado, the SPI is in the mild drought category 34% of the time, in moderate drought 9.2% of the time, in severe drought 4.4% of the time, and in extreme drought 2.3% 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 a very unlikely 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).

Conclusion

While the PDSI is the oldest and most well known, the SPI is the most widely used index for understanding the magnitude and duration of drought events. Most water supply planners like the SWSI, but they find it useful to consult one or more other indices before making a decision. It is important to know the benefits and limitations of each index in order to decide which one is the most useful for any particular application. Users should consult agencies such as the NDMC, the WWA, and State Climatologists for additional information and insight on strengths and weaknesses of each index.

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On the Web

- Weekly updated Palmer Drought Severity Index (PDSI): http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/palmer.gif.
- NOAA Weekly Crop Moisture Index (CSI) maps: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/regional_monitoring/cmi.gif.
- USDA/JAWF Weekly Weather and Crop Bulletin: http://www.usda.gov/oce/weather/pubs/Weekly/Wwcb/index.htm.
- SWSI information can be found on the NRCS website for each western state.
- Monthly Surface Precipitation Index (SPI) maps: http://drought.unl.edu/monitor/spi.htm; http://www.wrcc.dri.edu/spi/spi.html.
- SPI program files: http://drought.unl.edu/monitor/spi/program/spi_program.htm.