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A comprehensive Investigation of Drought and Standard Precipitation Index (SPI)

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Abstract

Drought is a prolonged period of below-average precipitation, leading to a shortage of water for various uses and leading to negative impacts on natural and human systems. Drought can also be defined as a deficiency in the water supply whether atmospheric (precipitation), surface water or ground water sources. It can be categorized into meteorological, agricultural, and hydrological drought depending on the sector and the time scale considered. Drought can have severe impacts on agriculture, ecosystems, and communities, and can lead to food and water shortages, wildfires, and economic losses. Drought is a slow-onset disaster, and its impacts can accumulate over time, making it difficult to predict and manage.

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1. INTRODUCTION

Drought is a prolonged period of below-average precipitation, leading to a shortage of water for various uses and leading to negative impacts on natural and human systems. Drought can also be defined as a deficiency in the water supply whether atmospheric (precipitation), surface water or ground water sources. It can be categorized into meteorological, agricultural, and hydrological drought depending on the sector and the time scale considered. Drought can have severe impacts on agriculture, ecosystems, and communities, and can lead to food and water shortages, wildfires, and economic losses. Drought is a slow-onset disaster, and its impacts can accumulate over time, making it difficult to predict and manage.

The Standardized Precipitation Index (SPI) is a drought index that uses historical precipitation data to provide a standardized measure of dryness (or wetness) for a given location and time period. The index is based on the probability of a certain amount of precipitation occurring in a given month or season, and it ranges from -3 (extremely dry) to +3 (extremely wet). A value of 0 indicates normal precipitation for the time period in question. The SPI is commonly used to forecast drought conditions and to monitor ongoing drought events.

1.1 TYPE OF DROUGHT

There are several types of drought, which can be classified based on their causes, duration, and impacts.

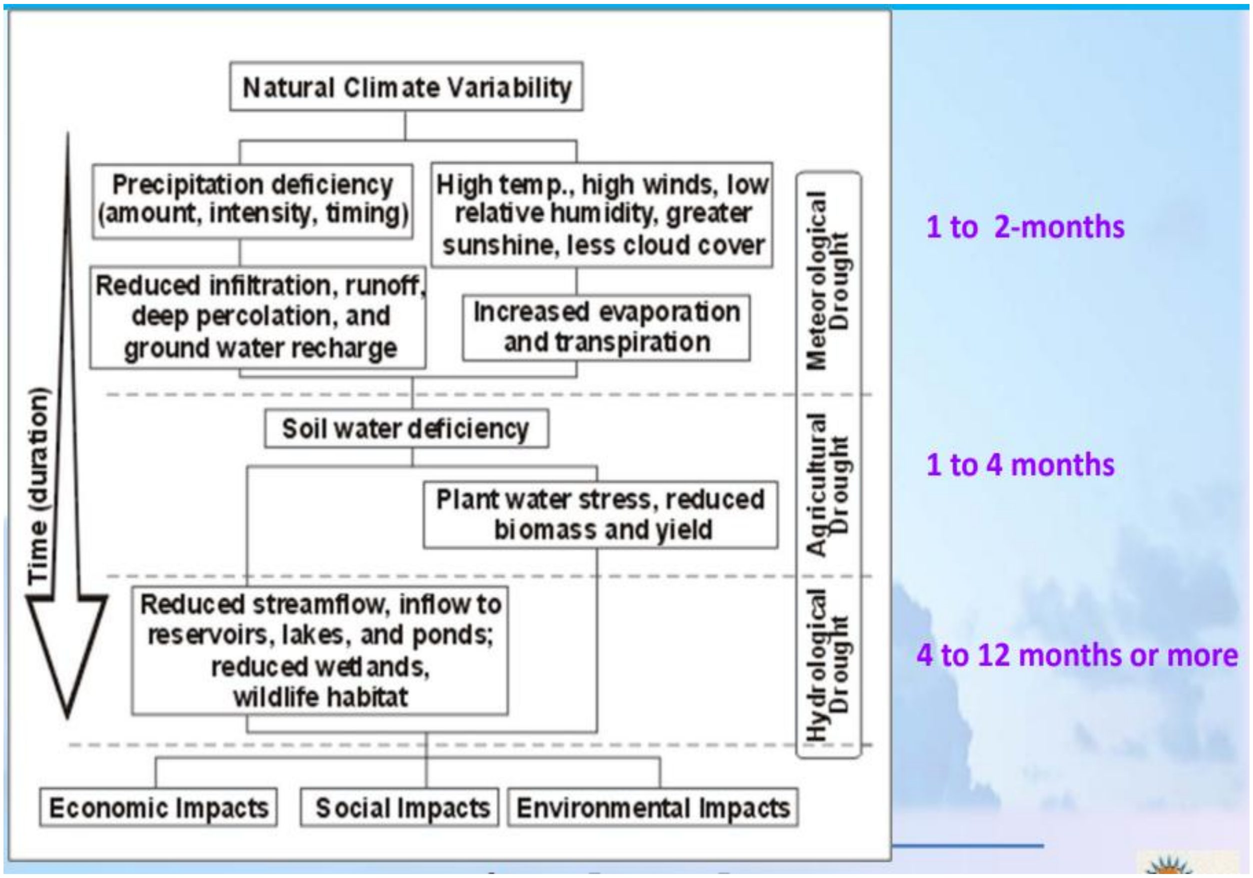

Fig 1: Type of drought and time response[1]

Some common types of drought include:

1.1.1 **Meteorological drought**: Meteorological drought occurs when there is a prolonged period of below-average precipitation. This is the most common type of drought and is typically measured using indices such as the Standardized Precipitation Index (SPI).

Meteorological drought is a prolonged period of below-average precipitation. It is the most common type of drought and is typically measured using indices such as the Standardized Precipitation Index (SPI) or the Palmer Drought Severity Index (PDSI). Meteorological drought can be caused by a variety of factors, including changes in large-scale weather patterns, such as El Niño or La Niña, or by a lack of storm systems that bring precipitation to a particular region.

During meteorological drought, precipitation is less than normal, which leads to a shortage of water for various uses. The shortage of water can lead to negative impacts on natural and human systems, including agriculture, ecosystems, and communities. These impacts can include damage to crops and livestock, water shortages, wildfires, and economic losses. Meteorological drought can also exacerbate other types of drought, such as agricultural and hydrological droughts, by reducing the availability of water resources.

There are several ways to measure meteorological drought, including:

a) Standardized Precipitation Index (SPI): This index uses historical precipitation data to provide a standardized measure of dryness (or wetness) for a given location and time period. The index ranges from -3 (extremely dry) to +3 (extremely wet), with a value of 0 indicating normal precipitation for the time period in question.

b) Palmer Drought Severity Index (PDSI): This index uses a combination of precipitation, temperature, and soil moisture data to provide a measure of drought conditions. The index ranges from -10 (extremely dry) to +10 (extremely wet), with a value of 0 indicating normal precipitation for the time period in question.

c) Percent of Normal Precipitation (PNP): This index compares the actual precipitation for a given time period to the long-term average precipitation for that same period, typically based on a 30-year period.

d) Rainfall Anomaly: This index compares the actual precipitation for a given time period to the long-term average precipitation for that same period and presents the difference in percentage.

e) Rainfall deciles: This index categorizes the observed precipitation into 10 groups, where the lowest 10% of rainfall occurrences are considered as extremely dry and the highest 10% as extremely wet.

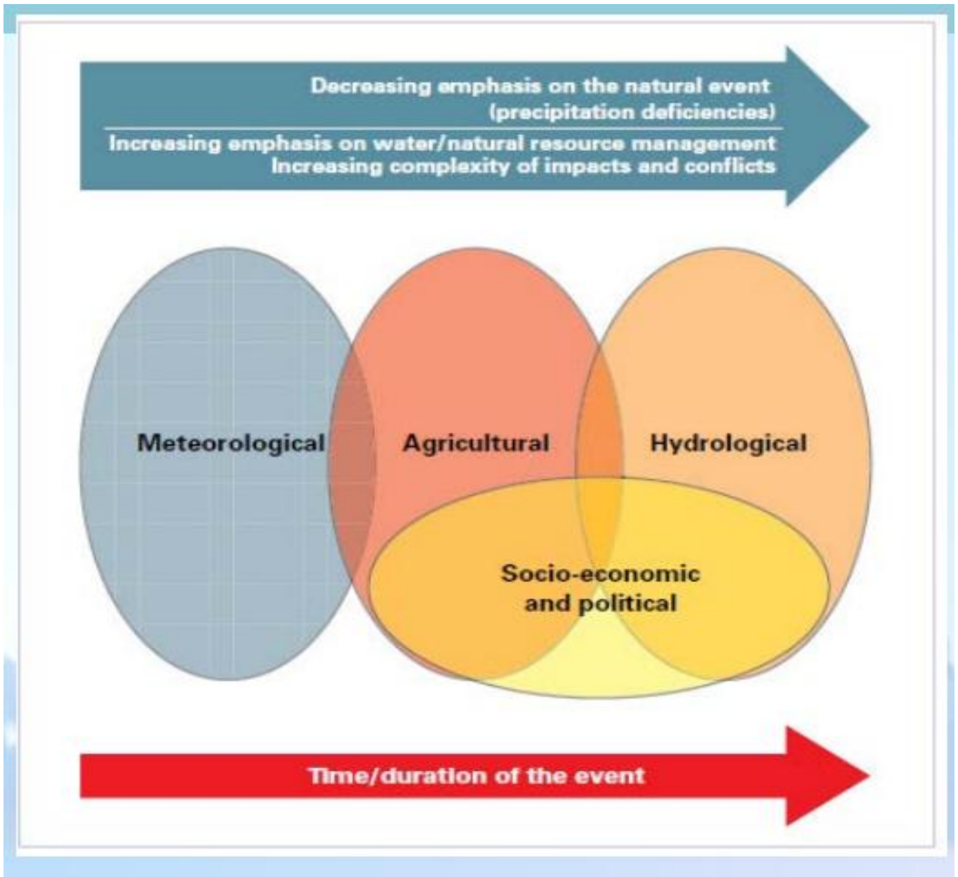

Fig 2:Interrelationships between meteorological, agricultural, hydrological and socio-economic drought.

1.1.2 **Agricultural drought**: Agricultural drought occurs when soil moisture levels are insufficient to support crop growth, even when precipitation is normal. This type of drought can be caused by factors such as high temperatures, high evapotranspiration rates, and poor soil conditions.Agricultural drought, also known as soil moisture drought, occurs when soil moisture levels are insufficient to support crop growth, even when precipitation is normal. This type of drought can be caused by a variety of factors, including high temperatures, high evapotranspiration rates, and poor soil conditions. During an agricultural drought, the lack of water in the soil can lead to stress on crops, making them more susceptible to disease and pests, and reducing their yield. Additionally, it can also lead to a decline in the health of pastures and rangelands, resulting in reduced grazing opportunities for livestock.

Agricultural droughts can be caused by a combination of meteorological drought, hydrological drought and human activities such as over-extraction of water resources, changes in land use, and climate change. Agricultural drought can have significant economic impacts, as it can lead to reduced crop yields and increased costs for irrigation and other water-saving measures.

To mitigate agricultural drought, farmers may use irrigation systems, or practice drought-tolerant farming methods such as crop rotation, soil conservation, and water-efficient irrigation techniques. In addition, forecasting and early warning systems, as well as long-term planning, can help farmers prepare for and cope with drought conditions.

To measure Agricultural drought

Agricultural drought can be measured using a combination of meteorological, hydrological, and agricultural indicators. Meteorological drought is measured by analyzing precipitation, temperature, and evapotranspiration data. Hydrological drought is measured by analyzing soil moisture, stream flow, and groundwater levels. Agricultural drought is measured by analyzing crop growth and yield data. Additionally, remote sensing techniques can also be used to measure vegetation health and productivity. The most commonly used agricultural drought index is the Crop Moisture Index (CMI). It is calculated using a combination of meteorological and soil moisture data. Another commonly used agricultural drought index is the Agricultural Drought Index (ADI). It is calculated using a combination of meteorological, hydrological and agricultural data.

1.1.3 **Hydrological drought:**Hydrological drought occurs when water levels in rivers, lakes, and aquifers fall below normal levels. This type of drought can be caused by factors such as over-extraction of water resources, changes in land use, and climate change.Hydrological drought, also known as water deficit drought, occurs when water levels in rivers, lakes, and aquifers fall below normal levels. This type of drought can be caused by a variety of factors, including over-extraction of water resources, changes in land use, and climate change.

During a hydrological drought, the lack of water in surface and subsurface water sources can lead to shortages for various uses, such as irrigation, drinking, and industrial use. It can also lead to negative impacts on ecosystems, including declines in fish and wildlife populations and changes in the structure and function of wetland and riparian habitats.

The onset of hydrological drought can be gradual and may not be immediately apparent, as it can take time for the effects of reduced precipitation or increased water use to be seen in stream flow and groundwater levels.

Hydrological drought can be mitigated by implementing water conservation measures, such as reducing water usage, increasing water storage capacity, and developing alternative water sources. In addition, forecasting and early warning systems, as well as long-term planning, can help water managers prepare for and cope with drought conditions.

Hydrological drought can be measured by analyzing several indicators, including:

a) Streamflow: Low streamflow levels can indicate a drought. This can be measured by analyzing data from stream gauges or using remote sensing techniques.

b) Groundwater levels: Lower than normal groundwater levels can indicate a drought. This can be measured by analyzing data from wells or using remote sensing techniques.

c) Soil moisture: Low soil moisture levels can indicate a drought. This can be measured by analyzing data from soil moisture sensors or using remote sensing techniques.

d) Reservoir levels: Lower than normal reservoir levels can indicate a drought. This can be measured by analyzing data from reservoir gauges.

e) Baseflow: The baseflow of a river or stream is the flow that is sustained by groundwater discharge and it can be used as an indicator of drought.

f) Drought Indices: Various hydrological drought indices are available, SPI, Standardized Streamflow Index (SSI) and Standardized Runoff Index (SRI).

g) Remote sensing: The use of remote sensing technologies like satellite imagery can be used to measure the changes in vegetation, snow cover, and soil moisture, which can be used as an indicator of drought.

1.1.4 **Socio-Economic drought:**Socio-Economic droughtoccurs when the demand for water exceeds the available supply, leading to water shortages and economic losses.
Socio-Economic drought, also known as water demand drought, occurs when the demand for water exceeds the available supply, leading to water shortages and economic losses. This type of drought can be caused by a variety of factors, including population growth, urbanization, and economic development.

During a socio-economic drought, water shortages can lead to negative impacts on various sectors, such as agriculture, industry, and households. These impacts can include reduced crop yields, increased costs for irrigation and other water-saving measures, and reduced availability of water for drinking and sanitation. Additionally, it can also lead to a decline in the health of pastures and rangelands, resulting in reduced grazing opportunities for livestock.
Socio-Economic drought can also have significant social and economic impacts, as it can lead to conflicts over water resources and can exacerbate poverty and inequality. To mitigate socio-economic drought, water managers may implement measures such as water pricing, water rights and allocation systems, and water conservation and reuse programs. In addition, forecasting and early warning systems, as well as long-term planning, can help water managers prepare for and cope with drought conditions.

1.1.5 **Ecological drought**: Ecological droughtis a condition of dryness that results in water-related ecosystem stress. This can happen even in the absence of meteorological drought.Ecological drought, also known as ecosystem drought, is a condition of dryness that results in water-related ecosystem stress. This can happen even in the absence of meteorological drought. Ecological drought occurs when precipitation is normal or even above normal, but the water availability for the ecosystem is still insufficient. This can happen due to human activities such as damming, over-extraction of water resources, changes in land use, and climate change.

During an ecological drought, the lack of water can lead to a decline in the health of ecosystems, including declines in fish and wildlife populations, changes in the structure and function of wetland and riparian habitats, and reduced biodiversity. It can also lead to increased risk of wildfires, which can have severe impacts on ecosystems and human communities.

To mitigate ecological drought, water managers may implement measures such as water conservation, water quality protection, and ecosystem-based management of water resources. This can include protecting and restoring wetlands and riparian habitats, as well as implementing flow regimes that mimic natural patterns. In addition, forecasting and early warning systems, as well as long-term planning, can help water managers prepare for and cope with drought conditions.

1.1.6 **Flash drought:** can occur quickly, in a matter of weeks, unlike other types of drought which can take months or even years to develop.
Flash drought is a type of drought that can occur quickly, in a matter of weeks, unlike other types of drought which can take months or even years to develop. It is characterized by a sudden and severe drop in soil moisture and streamflow due to a lack of precipitation and high temperatures.

Flash droughts are often triggered by sudden changes in weather patterns, such as a shift from wet to dry conditions or a rapid increase in temperature. These changes can lead to rapid evaporation and transpiration of soil moisture, leaving little water available for plants and animals.

Flash droughts can have severe impacts on agriculture and ecosystems, and can lead to food and water shortages, wildfires, and economic losses. They can also exacerbate ongoing drought conditions, making it difficult for farmers, ranchers and water managers to respond.

2. Causes of Drought

Drought is caused by a variety of factors. Some of the main causes of drought include:

1. Lack of precipitation: Drought happens when there is a prolonged period of below-average precipitation, leading to a shortage of water in the soil and surface reservoirs.
2. High temperatures: High temperatures can increase evaporation and transpiration, which can lead to a faster depletion of water resources.
3. High winds: High winds can cause increased evaporation and transpiration, which can also lead to a faster depletion of water resources.
4. High pressure systems: High pressure systems can cause clear, sunny weather, leading to increased evaporation and transpiration.
5. El Niño/La Niña: El Niño and La Niña are climate patterns that can lead to changes in precipitation patterns, resulting in drought or wetness.
6. Human activities: human activities such as over-extraction of water resources, deforestation, and urbanization can also contribute to drought conditions.

Wetness causes are basically the opposite of drought causes, high precipitation, low temperatures, low winds, low pressure systems,

3. Comparison and combination with drought indices

Drought indices are numerical values or measurements that are used to represent the severity of drought conditions at a location on the time scale. These indices can be based on a variety of factors such as precipitation, temperature, soil moisture, and vegetation health. Examples of commonly used drought indices include the PDSI, SPI, and the Vegetation Drought Response Index (VegDRI)[2]. These indices can be used to monitor drought conditions over time and to help predict future drought events. They are also used to help decision-makers and resource managers respond to drought conditions.

Drought indices can be compared and combined in various ways to provide a more comprehensive understanding of drought conditions. One way to compare drought indices is to use multiple indices that are based on different factors, such as precipitation, temperature, and soil moisture. For example, the PDSI uses a combination of precipitation and temperature to calculate drought conditions, while the SPI is based solely on precipitation. By comparing the values of both indices, one can get a more accurate picture of the drought conditions.

Another way to combine drought indices is to use indices that have been developed for different spatial scales. For example, the VegDRI is designed to assess drought conditions at a local scale, while the PDSI is designed for a larger, regional scale. Combining the values of both indices can give a more detailed understanding of drought conditions across different scales.

Additionally, Drought indices can be combined with other data such as satellite images, meteorological data, and hydrological data, to provide even more detailed information about the conditions.

Overall, comparing and combining different drought indices can help improve the precision and precision of drought monitoring and prediction, and aid in the decision-making process of drought management and mitigation.

4. SPI Calculations

The SPI was developed by Colorado State University researchers Thomas, Nolan and John at the beginning of the 1990s with the goal of proposing an indicator and definition of drought [3] .The PDSI was commonly used to derive the drought index in USat thattime[4], despite limitations like inadequacy in mountainous regions or inconsistency in space. The SPI's theoretical foundation, as laid out by McKee [2] significantly improved in subsequent years.

The SPI is a dimensionless probability index that is calculated in the following order for a given location and time:

(a) A probability density function (PDF) is used to fit data sets. The precision of the SPI values is determined by selecting the parametric distribution. McKeerecommended gamma, but other distributions perform similarly or at least in a similar manner. Pearson III is one of several options that have been tested for various applications [5],[6]Weibull, [7] geometric, but no universal agreement has been reached[4] . The following is a definition of the gamma PDF:[12]

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e$$

where is the gamma function, is a shape parameter, is a scale parameter, and is the amount of precipitation. For twenty additional PDFs, different formulas apply.

(b) Using the results, the cumulative probability of a precipitation event for a specific month and time scale is calculated [9].

c) In addition, the cumulative probability distribution is changed into a standard normal distribution with a mean of zero and a variance of one, the SPI value[8][11].

Parry [13] eloquently illustrate the methodological flowchart from raw precipitation to SPI values, illustrating the distinctions between two distinct European climates. The PDFs' shape and scale parameters may change in response to changes in a region's precipitation pattern over time. According to [14] even a relatively long calibration period yields results that would be significantly impacted by extending the period.

5. Variability

The SPI is a drought index that is based on precipitation data. It is used to assess the severity of drought conditions by comparing the current precipitation to the historical precipitation for the same period. The SPI is calculated by standardizing the precipitation data and expressing it in terms of standard deviations from the mean.

One of the main advantages of the SPI is that it can be calculated for different time scales, such as daily, monthly, or even annually, which allows for flexibility in monitoring drought conditions.

However, the SPI also has some limitations. The main limitation is that it is based solely on precipitation data and does not take into account other factors such as temperature, evaporation, or soil moisture. This means that the SPI may not provide an accurate representation of drought conditions in some cases, particularly in areas where evaporation and transpiration are high.

Another limitation of the SPI is that it is sensitive to the variability in precipitation. In some areas, precipitation can be highly variable, leading to large fluctuations in the SPI values. This can make it difficult to distinguish between drought and non-drought conditions.

In conclusion, the SPI is a widely used and useful drought index, it can be calculated at different time scales, but it is based only on precipitation data and it's sensitive to the variability of precipitation, it should be combined with other data and indices to get a more comprehensive understanding of the drought conditions.

6. The strengths and weaknesses of the SPI

The SPI is a widely used drought index that has several strengths and weaknesses.

a. Strengths:

1. The SPI is based on precipitation data, which is easily accessible and widely available.

2. It can be calculated at different time scales, which allows for flexibility in monitoring drought conditions.
3. The SPI is easy to understand and interpret, which makes it a useful tool for decision-makers and resource managers.
4. The **SPI is a non-parametric index**, meaning it does not require any prior information about the probability distribution of the precipitation, which makes it less sensitive to assumptions about the distribution of precipitation.

b. Weaknesses:

1. The SPI is based solely on precipitation data and does not take into account other factors such as **temperature, evaporation, or soil moisture**.
2. The SPI can be highly variable in some areas. This makes it difficult to differentiate between drought and non-drought conditions.
3. The SPI is not suitable for areas with high evaporation and transpiration since it does not account for the water lost from the soil and vegetation.
4. The SPI may not always be accurate in areas with high variability in precipitation, and can be affected by outliers.
5. Overall, the SPI is a widely used and useful drought index, but it ***should be used in conjunction with other data and indices*** to get a more comprehensive understanding of the drought conditions.

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