Meteorological and Hydrological Drought Assessment – A Review

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***Abstract*—Drought conditions result from a lack of precipitation and this has many effects on the surrounding land and weather conditions. It can have many devastating effects on communities and the surrounding environment. The amount of devastation depends on the strength of the drought and the length of time an area is considered to be in the drought condition. The occurrence of drought event creates a complex web of impacts that spans to many sectors of ecology, environmental, social and economy. It has both direct and indirect effect on the mankind. Hence, a proper knowledge and understanding of this inevitable natural hazard is very essential for the management and planning before or during a drought. In this paper several research papers on meteorological and hydrological drought assessment methods are reviewed. Literature dealing with drought assessment based on indices and drought indicators are reviewed. Research papers based on meteorological drought assessment using indices are studied in detail and classified based on the type of indicators involved as metrological drought assessment using precipitation and evaporation. Similarly, literature on hydrological drought assessment using surface water and groundwater are reviewed in this paper.**

***Keywords*— Meteorological drought, Hydrological drought, Drought indices and drought indicators.**

I. INTRODUCTION

Water is one of the nature's precious gift to mankind. Being, the driving force of life, water plays an important role of balancing the entire ecosystem. Its presence is incessantly required for a sustainable development to take place. When a shortage of water occurs over an area for an extended period of time, it has many effects on the ecology of that place. Extensive literature is available on droughts with respect to definition, methods of analysis and management procedures. Review of literature will always help one to have information and to perceive significance of the current status of the problem to be dealt with.

II. EARLIER RESEARCH

A. General

Drought is an insidious natural hazard that results from lower levels of precipitations than what is considered normal. When this phenomenon extends over a season or a longer period of time, the precipitation is insufficient to meet the demands of human activities and the environment. Droughts are regional in extent and each region has specific climatic characteristics. The amount, seasonality and form of precipitation differ widely among each location. Drought is viewed in different ways by different constituency of water users. Hence, there is no single definition of drought ***(Wilhite and Glantz, 1985)***. Hence the drought assessment methods also differ from one place to another depending upon the drought indicator which is predominant in that location.

B. Drought Assessment

1. Drought Indicators

Shaban Amin In this study, the hydrological drought in Lebanon has been analyzed using various drought indicators, by expressing the numerical values, from available records, into graphical relations and on time series. This enables to attain a comprehensive figure of trends for different hydrological drought indicators.

The decrease in the indicators such as;1. Rainfall by 12%, 2. Snow cover by 16%, 3. Discharge in rivers by 23%, 4. Groundwater level by 26%, 5. Number of Springs by43% and 6. Reservoir storage by 79% indicates an alarming status of hydrological drought.

2. Drought Indices

Zargar Amin, ***et.al*, (2011)** The paper, presents an overview of various drought indices available, out of which 6 indices namely the Percent of normal, Deciles, Standardized Precipitation Index (SPI), Palmer Drought Severity Index (PDSI), US Drought Monitor (USDM) and Normalized Difference Vegetation Index (NDVI) were explained in detail and it also reviews drought characterization, based on Conceptual and Operational definitions, severity, duration & spatial distribution and frequency, magnitude (cumulated deficit), predictability, rate of onset, & timing. This knowledge can be used in applications such as drought forecasting, declaring drought levels, contingency planning and impact assessment respectively.

C. Meteorological Drought Assessment

1. *Precipitation*

Vu Minh Tue, *et.al*, (2015) In the Central Highland of Vietnam, which is located southeast of the Indochina Peninsula, between longitudes 11ºN to 15ºN and latitudes 107ºE to 109ºE, a meteorological drought assessment was done using Standardized Precipitation Index (SPI for 12months time scale) for five different types of precipitation data sets (1990 - 2005): Regional Climate Model (RCM), having 25km spatial resolution includes the simulated precipitation data set from 1) Weather research and forecasting model (WRF) and 2) Providing regional climates for impacts studies (PRECIS), Gridded Observation Data with spatial resolution 0.25º consist of 3) Asian Precipitation Highly Resolved Observational Data Integration Towards Evaluation of water resources data (APHRODITE, referred to in this paper as APH) and 4) Tropical Rainfall Measuring Mission (TRMM) data and 5) Station data (STA) of 13 rainfall stations.

The analysis from RCMs showed close estimation for the number of drought events to station data and gridded observations. In terms of Drought Deficit and frequency, the RCMs matched the station data better than gridded observations. The drought trend was carried out using a Modified Mann–Kendall trend test which yielded no clear trends that suggested the need for longer records of data.

Karavitis, Christos A, *et.al,* (2011) The Standardized Precipitation Index (SPI) was used to determine the duration and magnitude of the meteorological drought in Greece, located at the southeastern tip of Europe. The SPI for 1, 3, 6, 12 and 24 months is calculated using calculation algorithm programmed in a Fortran 95 giving monthly rainfall data obtained from 46 precipitation stations, covering the period 1947–2004, as input. Then, the values of SPI were spatially distributed by the geo-statistical method of kriging using the SURFER 9 software package for obtaining the areal extent of the drought severity.

The result identified that the severe drought years and areas with significant drought problem. It has been concluded that, overall, SPI described well the drought conditions in Greece.

M. C. Sashikkumar, *et.al,* (2013) Assessment of meteorological drought has been done in the Chittar sub-basin of Thamiravaruni basin for a period of 30years, using the rainfall data form 15 rain gauge stations, with GIS for incorporating spatial and temporal variation of water resources data. Using the IMD method and the rainfall data analysis the meteorological drought was assed and the statistical parameters like mean, standard deviation, co-efficient of variation, skewness and kurtosis were identified respectively.

A meteorological drought index was developed showing the drought occurrence of once in every 3 to 5 years and the drought risk areas were mapped using Arc view GIS 3.2a software which identifies the area requiring urgent drought proofing measures.

2. *Evaporation*

G. Tsakiris, *et.al,* (2007) The meteorological drought, in the Mornos (571 km^2) and Nestos (2.314 km^2) river basins of Greece were assessed using a new index called the Reconnaissance Drought Index (RDI) along with other two well established methods namely the Standardized Precipitation Index (SPI) and the Deciles. The RDI method has been introduced in order to include the evapotranspiration losses, which is the major loss in Mediterranean region due to its high temperature.

The correlation between the RDI and the other two indices were found for the 2 basins and it has been concluded that the Reconnaissance Drought Index (RDI) has many advantages over the widely used indices for assessing meteorological drought, as it is expected to be a more sensitive and more comprehensive index for comparisons of drought conditions between different parts of the world.

D. *Hydrological Drought Assessment*

1. *Surface Water*

Hossein Tabari, *et.al,* (2013) Using the Streamflow Drought Index (SDI), a hydrological drought assessment was done in the province of West Azerbaijan, with an area of 39487 km^2, located on the northwest of Iran, for a period of 34years (from 1975–1976 to 2008–2009) using the monthly observed stream flow data were collected from 14 hydrometric stations. Four overlapping time periods (3, 6, 9 and 12 months) were utilized within each hydrological year (Oct–Sept makes one complete hydrological year) and the positive and negative SDI values reflect the wet and dry (hydrological drought) conditions respectively.

It has been concluded that, all four-time series indicated that, almost all the stations experienced extreme droughts during the study period and also the extreme drought events have occurred mainly in the last 12 years, from 1997–1998 to 2008–2009. The hydrological years of 1998–1999, 1999–2000 and 2000–2001 were the driest years during the examined period.

Muthiah Manikandan, *et.al,* (2015) The study analyzes the hydrological drought, using the Streamflow Drought Index (SDI) with the available monthly streamflow data, in the Aliyar sub basin of 574.75 km^2 area. It also uses the Theory of Runs for the assessment of the major components of the hydrologic drought event, namely the Drought Duration (D_d), Drought Severity (S_e), Drought Intensity (I_e) and the extreme drought event for a run and finally the drought Severity-Frequency (SF) curves are drawn based on the weighted annual cumulative drought severity and average annual drought severity.

It has been inferred from the case study that, the basin has experienced prolonged and severe droughts in terms of severity and durations in the 1970s, 1980s and

2000s. In particular, the persistent and prolonged drought of 1972-1974 and 1982-1985, 2002-2004 seriously affected the study area. Also, the highest annual average severity that observed in the year 1972-73 and the drought that occurred in 2003-04 has an associated return period of 100 years and 2 years respectively.

2. *Groundwater*

Krishnaveni. M et.al, **(2006)** the hydrological drought in the Palar river basin is assessed using the Herbst's method. The Palar River basin in Tamil Nadu, having an area of 18,300 km^2, and annual average rainfall of 1040mm an lies between latitudes 12° 14' and 13° 37' north and longitudes 77°48' and 80°14' east. 30years of groundwater level data in 80 observation wells, within the basin is used in calculating the drought index. The drought risk index (ratio of total drought severity to total duration of drought) was established at each observation well and the drought risk map was generated using the Mapinfo GIS software.

It has been concluded that, high water level fluctuations during drought period indicates severe exploitation of groundwater and the drought risk map shows that the tail end blocks of the basin were extremely prone to drought.

E. *Impact of Meteorological drought on Hydrological drought*

Vasiliades Lampros, *et.al,* (2009) A comparison of Hydrological drought in river discharges, soil moisture and Palmer drought indices (PDI-Metrological drought indices), was been carried out in Thessaly, Greece having catchment area of 9500 km^2, using the UTHBAL – a conceptual water balance model respectively for a period of 1960–2002. The Pearson correlation coefficients between the continuous standardized series of river discharges, soil moisture and the four PDIs - PDSI (Palmer drought severity index), Weighted PDSI, PHDI (Palmer hydrological drought index) and Moisture Anomaly Z-index (Palmer Z-index) are found to be positive.

It is concluded form the study that Considering river discharges, higher correlations have been obtained with the Weighted PDSI followed by the PDSI for all study watersheds. Considering soil moisture, higher correlations have been obtained with the moisture anomaly Palmer Z-index.

Nalbantis, *et.al,* (2009) In this paper, the hydrological drought is investigated using Streamflow Drought Index (SDI), for four over lapping time periods 3 (Oct–Dec), 6 (Oct–March), 9 (Oct–June) and 12 months (Oct–Sept) in a hydrological year, using the monthly streamflow data, from 1970-71 to 1999-2000. It also proposes a methodology for assessing hydrological drought using SPI, based on precipitation data, from 1963-64 to 1991-92, which was further extended up to 1999-2000, when the streamflow information is lacking. The SDI values were regressed on the concurrent SPI values for the period. from 1970–71 to 1991–92. More specifically, a linear function of SPI was found to predict SDI to an accuracy level which is sufficient for characterizing drought severity. This involves prior calibration of a simple regression equation with modified SPI as the explanatory variable and SDI as the explained variable.

Further, the non - stationary Markov chain is applied for predicting the frequency of drought occurrence for both SDI based on streamflow and SDI predicted form the precipitation data through SPI. This results in the frequency of state transition matrices, which is a tool for predicting drought state in real time. The methodology is finally validated using reliable data form the Evinos river basin (Greece).

Shraddhanand Shukla, *et.al,* (2008) The Standardized Runoff Index (SRI) is compared with the Standardized Precipitation Index (SPI), in the Feather River basin, California for a period of 1955–2005. The surface runoff is simulated using a hydrologic model, which is physically based, semi-distributed macroscale called Variable Infiltration Capacity (VIC) model. The SRI is calculated with the above simulated series of spatial runoff and then compared with the SPI which was calculated using the monthly precipitation series (for 3, 6, 9 and 12months time periods) after they have been standardized in terms of percentile or standardized index, which results in high correlation between the two indices.

The study concludes by saying, the SRI can be used as a single drought index which combines both the climate as well as the hydrologic context prevailing in an area. This is because; the spatial runoff simulated using the VIC model takes the precipitation as input, which is an indicator of meteorological drought which directly describes the effects of climate anomalies on current hydrologic conditions.

Lin Zhao, *et.al,* (2014) A comparative analysis of frequency, severity, beginning & ending and duration to identify streamflow drought′s response to meteorological drought was carried out in the Jinghe River Basin, in the central part of the Loess Plateau in the northwestern China having an area of 45412 km^2, using Standardized Precipitation Index (SPI) and the Standardized Runoff Index (SRI) respectively. Using the Pearson correlations between SRI and different timescales of SPI (1–12 months), the 4-month SPI was selected as the most suitable time scale.

By, comparing the graphs of SRI and 4 months SPI, it has been identified that, 11 meteorological drought and 6 streamflow drought events have occurred from 1970-1990. The Streamflow drought has lagged meteorological drought for about 127 days and the frequency of streamflow drought was less than meteorological drought. Also, it was noted that. the magnitude of streamflow drought is greater than meteorological drought.

Bahram Saghafian, *et.al,* (2015) A hydrological drought early warning method has been developed, for the Urmia lake basin in the northwest of Iran, by creating rainfall threshold curves for different probabilities occurrence (10, 50 and 90%). Initially, the 9 month SDHI (Standardized Hydrologic Index) was chosen for drought assessment, since high correlation was found between the SDHI9 and 18month basin averaged rainfall. Then, for each month, a regression model was developed such that mean of past 18-month rainfall and the current month SHDI9 represented its input and output, respectively and through an inverse modeling framework, (18-month) rainfall threshold values associated with different hydrological drought severity states under several probabilities of occurrences were identified. Finally, the rainfall threshold curves were drawn and it was concluded that, the 50% threshold curve had the best overall performance.

F. Drought in relation with Seasons and Climate

A.P. Ramaraj, *et.al* To study the the sustainability of rainfall and determine the drought variation over Southern Zone of Tamil Nadu (covering the sub basins: Vaigai, Sitrar, Thamraparani, Numbiar, Pachaiyar, Kludar, Arjunar, Kodumudiyaar, Manimuthar and Periyar), the Precipitation Ratio (PA) and the Standardized Precipitation Index (SPI) were used, for which 30 years of historical rainfall data (1981-2010) was needed. The data was divided into different seasons such as Cold Weather Period (CWP - January and February), Hot Weather Period (HWP - March to May), South West Monsoon (SWM - June to September) North East Monsoon (NEM - October to December) and Annual period to study the rainfall stability and drought variability by calculating PA and SPI respectively.

It was concluded that the regions adjacent to the Western Ghats and regions near the coastal areas showed typically contrasting rainfall features (moderate drought had maximum occurrence during Northeast monsoon at Virudhunagar district while minimum occurrence at Madurai district). Overall, moderate drought events had considerable occurrence.

Francis H.S. Chiew, *et.al*, (1998) The teleconnections between E1 Nino/Southern Oscillation ENSO and Australian rainfall, streamflow and drought, by applying the empirical method of Ropelewski and Halpert (1986) is investigated using; *a)* 79years of continuous monthly rainfall data from 336 stations throughout Australia (1910-1988); *b)* The Palmer Drought Severity Index (PDSI) is used as a drought indicator in this study. PDSI values are calculated from rainfall and pan evaporation data for 289 locations; *c)* Monthly streamflow data from 80 unregulated catchments, for 83years are used and; *d)* The Southern Oscillation Index (SOI) and the sea surface temperature (SST) are the two most widely used indicators of ENSO.

The analysis is summarized as vectors of the first harmonic fits. The length of the vector describes the strength of the E1 Nino-hydroclimate teleconnection and the direction indicates when the maximum signal occurs. It has been concluded that the dry conditions in Australia tend to be associated with E1 Nino. Below-normal rainfall, PDSI and streamflow are consistently identified in the 'El Nino' years.

Julián Báez Benitez, *et.al*, (2014) This paper deals with, analysis meteorological drought events (1964-2011) in Paraguay in central South America, covering an area of 406.752 km^2, using Standardized Precipitation Index (SPI) for 3, 6 and 12 months at 20 stations and also, to determine the relationship between the drought events and La Nina.

The occurrence, the frequency, the intensity and the trend of drought in the context of climate change in Paraguay, as well as their relation with La Nina is studied and it is concluded that, although there is a strong coincidence between severe drought occurrence and La Niña events only in the years of 1971–72, 1975–76 and 1988–89, when there were 2 or more severe drought events and no positive SPI events in Paraguay. This implies there is a low correlation between La Niña and the drought events. The results indicate that not all La Niña events are responsible for drought in the country.

III. Conclusion

Through the detailed study of several research papers, a deep knowledge of meteorological and hydrological drought assessment methods is obtained. This helps in determining the drought severity and duration in an area depending on the predominant drought indicator of that place. The research papers based on drought in relation with seasons and climates helps us in knowing the seasonal variation of drought in an area though out a year.

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