

Estimation of Drought Intensities over States of India

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Abstract— *In peninsular India, droughts are often observed as recurring events. They have interrelated impacts on the socio-political, socio-economic, and environmental conditions. The consequences of droughts are population shifts, alteration of the social structure, vast economic hardship, and notable environmental franticness. Most common drought impacts are degradation of farmland, significant increase in wind erosion, downfall in natural flora and fauna, spoliation of air quality, pest infestations, and stressed water supply. As tremendous economic, environmental and social impacts are associated with droughts, it becomes very important to have an early warning system, which can warn the local administration to take necessary strides ahead of time to tackle such circumstances. The main purpose of this study is to propose a best way to estimate drought conditions in the states of India, which has faced serious water shortages in the past. This work presents innovative drought modelling procedures by taking into consideration the inherent uncertainty feature in drought evolution. To account objectively for the uncertainty: Time series trend analysis and probabilistic statistical methodologies were considered with a set of simplifying assumptions. The necessary formulations and their quantitative applications through numerical solution approaches were presented for identifying critical drought areas. Drought indices like normalized deviation, dryness index, standardized precipitation index (SPI) and Bhalme and Mooley index (BMI) should be applied on the meteorological data to quantify droughts. The results obtained from Probabilistic statistical analysis and drought indices then should be compared. The methodology considered results in explaining variation in the drought severity across the regions. This work provides concrete solutions for designing an early warning system for drought prediction, as it is now known that which station is to be monitored while dealing with a particular region.*

Keywords— *Drought, Time series, Trend Analysis, Drought indices, Standardized precipitation index, Bhalme and Mooley Index.*

I. INTRODUCTION

For subsistence of any civilization, it is dependent upon the availability of various significant natural resources such as water, soil, minerals and energy, and a technology, which must be used to harness them for modern scientific research with sustainable efforts. However, about one third of the world's population lives in areas with water scarcity, moreover about 1.1 billion people lacks resources of safe drinking water. Drought (7.5%) is the second most geographically extensive hazard following floods (11%) of the earth's land area. Droughts have a gradual "creeping" feature, with slow developments and prolonged imprints on the daily activities of human.

Since 1970s to early 2000, percentage of area affected by serious drought has doubled up (Hisdal and Tallaksen, 2003). Moreover, the major factor provoking more intense and frequent drought is considered to be continuously rising global temperature. With increase in global temperatures world is likely to experience more hot days and heat waves (Nagarajan, 2009). As per measurement's recorded by balloon and satellite pattern of earth's temperature tends to exceed the normal in past few decades indicating pattern of greenhouse warming. Due to which even a small rise in temperature is likely to be accompanied by many other changes in climatic conditions. The severity and duration of both wet as well as drier period is expected to increase. This condition leads to more than one third of earth's surface to vulnerable drought and desertification.

As compared to arid and semi-arid regions, people of humid regions have high confidence in their water resources and, therefore they may not feel water scarcity impacts in time. Consequently, droughts may be more drastic in humid regions than arid regions. Agricultural aspects are highly affected as a result of droughts in these regions. Among the primary drought hazards are crop yield, animal husbandry, hydroelectric energy generation, reductions and decrease in industrial products and navigation problems in low river flows. On the other hand, secondary effects include soil erosion, dust storms, forest fires, increase in plant diseases, insect hurdle, decrease in social and individual health, pollution concentration increase, deterioration in water quality, and so forth. From the above factors, it is clear that droughts have drastic consequences on the local population, and there is an esteem need to take effective steps in order to mitigate the repercussions.

II. METHODOLOGY

The study presents proposed drought estimation procedures by taking into consideration the inherent uncertainty of climatic variables in drought evolution. To account objectively for the present uncertainty: statistical, probabilistic methodologies and various indices of drought are employed with asset of simplifying assumptions. The necessary formulations and their quantitative applications through numerical solutions are presented for identifying critical drought regions and zones geographically. The present study proposes the uses Time Series Analysis, Probabilistic Statistical and Indices approach for estimation of drought conditions in states of India. The various method used for obtaining the objectives so defined are discussed in detail with previous literature. Meteorological drought has been the focus of this

study because analysis of precipitation data gives the first indication of an impending drought condition. Apart from precipitation, other meteorological variables used in this study include maximum and minimum temperature.

III. RESEARCH AND DEVELOPMENT IN THE FIELD OF TIME SERIES TREND ANALYSIS OF CLIMATIC VARIABLES

To forecast meteorological drought using time series analysis a study was carried out by **Davis and Rappoport, 1974**. In this study exponential smoothening and autoregressive-moving average (ARMA) were employed to forecast monthly PDSI. Best ARMA model was formulated by mean square error (MSE) using autocorrelation and partial autocorrelation functions of severity index values. Monthly data for the period of 1929-1969 were utilized. Monthly forecast for the period of 1970-1972 was generated using autoregressive moving average and exponential smoothening. Then These forecasts were compared with myopic forecasts. The mean square errors of the forecast with myopic model was 0.65, for ARMA model was 0.63 and for exponential smoothening model was 0.79. From the mean square error calculations, it is clear that there is statistically no significant difference between the forecasts given by the Box-Jenkins and myopic models. In the semiarid climate of Greece a study was carried out by **Loukas et al. 2002** to examine the hydroclimatic variability of droughts at a regional scale. The moisture anomaly Z-index of the Palmer Drought Severity Index (PDSI) was employed for a quantitative description of droughts by using monthly time series of precipitation and temperature at 28 meteorological stations over Greece for the period 1957-1983. The country was classified into five homogenous regions by using factor analysis and ascending hierarchical clustering technique. The resultant groupings appeared to be in agreement with local topography and climatic classification of Greece. The variability and the change of droughts within each region were assessed using various statistical methods. Linear trend analysis showed that only the increasing trends are statistically significant indicating that, in general, drought severity is decreased during the analysed period. Analyses of the common consecutive drought periods for all stations within a climatic region indicated that droughts, with duration of one to three months, are extended over the whole region irrespective to region and are the most frequent drought durations for all regions. Finally, the common monthly droughts are, usually, mild and moderate for all regions, only the western, and the Peloponnesian regions of Greece experience severe droughts. A study was carried out to find the changing pattern of rainfall over Maharashtra in the district scale by **Guhathakurta and Saji, 2013**. The conclusion shows that the impact of climate changes on temporal and spatial patterns over smaller spatial scales is clearly noticed in this analysis. Significant decreasing trends in monthly rainfall are being observed in many districts of Maharashtra reported. A study was carried out to analyse the time series characteristics of rainfall data for Sokoto metropolis for 40 years by **Abdulrahim, M. A. et al. 2013**, to understand drought management. Time series analysis was carried out on the data obtained from Nigeria Meteorological Agency, Sokoto by employing tests (trend, cycle, seasonal and decomposition analyses) using additive and multiplicative modelling approach. The study resulted in an increasing trend in rainfall amount over the metropolis within the period under review. Seasonal analysis showed a good concentration of rainfall in the months of June, July and August, while decreases in September, while months of March, April, and October showed some showers of rainfall sometimes. This implied that the months of January, February, March, April, May, November and December are dry months/period. To analyze spatial characteristics of temporal trends for precipitation and drought severity index at 55 stations across South Korea for the period of 1980-2015, **Azam et al., 2018**, carried out a study. This study also incorporates the usefulness of different trend tests while addressing issue of serial correlation. The study results did not showed any significant change or trend in annual rainfall, whereas, significant trends were observed in south coast regions during winter, late spring, and summer. The magnitude of these trends showed an increase from January to August and a decrease from August onward. Drought severity showed a significant increasing trend, mainly on the northeast coast. Frequent droughts were observed in late winter, early spring, and early autumn by drought frequency analysis. A case study in Woleka Sub-basin of Ethiopia, was carried out by **Asfaw, A. et al., 2018**, to examine the spatiotemporal dynamics of variables in the context of changing climate, focussing on the countries where rainfall is only source for agriculture. Trend analysis has been employed to inspect changing rainfall and temperature conditions in the region. Data was subjected to PDSI, Precipitation Concentration index, rainfall anomaly and coefficient of variation. Time series trend was detected by using Mann-Kendal Test. PDSI value showed the increasing trend of number of drought years. There was a significantly declining trend for the annual and kiremt rainfall, and insignificant decreasing trend for belg rainfall. The Mann-Kendall test result showed significantly increasing trend for mean, minimum and minimum average temperatures, while insignificant increasing trend for maximum temperature.

IV. RESEARCH AND DEVELOPMENT IN THE FIELD OF PROBABILISTIC APPROACH IN HYDROLOGY

To Characterize drought with a probabilistic approach, **Mishra, A. K. et al. 2009**, carried out a study, this study investigates distribution of drought interval time, mean drought inter-arrival time, joint probability density function and transition probabilities of drought events in Kansabati River basin in India. The SPI series is employed in the investigation. The time interval of SPI is found to have a significant effect of the probabilistic characteristics of drought. The theoretical model was developed for comparing probability of occurrence of drought with SPI for 1, 3, 6, 9, 12, and 24 month, which were then, compared with the observed drought intervals. It was found to give quite realistic results. In Fuzhou City, carried out a study to determine the impact of storm time and extreme precipitation and its change using a joint probabilistic approach by **Kui Xu et al., 2014**. The change point at the year of 1984 detected by Mann-Kendall and Pettitt's tests divides the extreme precipitation into two subsequences. For each of the joint behaviour of extreme precipitation and storm tide is estimated by joint probability. Results show that the joint probability has increased by more than 300% on an average after 1984 with a confidence limit of 95%. This study concluded that the drainage systems should be designed considering both the parameters simultaneously in order to be prepared for the likely floods

with minimum risk to loss of life and property and environment. A study was carried out to develop a regionalized joint probability approach to estimate flood in Eastern New South Wales, Australia by **Caballero and Rahman, 2014**. This study investigates design flood in ungauged catchments to create a rational design for the catchments. This method developed can be applied to all the countries and their states. In this study gamma distribution was used for rainfall and run-off data, it was concluded that probabilistic approach provided more accurate design flood estimates than the currently recommended at-site Design Event Approach.

V. Research and Development in the Field of Estimation of Drought Indices

There are many drought indices, which are used to quantify droughts. One such index is Palmer Index. Palmer [12] developed a general methodology for evaluating the meteorological anomaly (drought) in terms of an index which permits space and time comparisons of drought severity. Palmer Drought Severity Index (PDSI) so developed requires precipitation, temperature and available water holding capacity of the soil for calculation. The moisture anomaly index (Z-index) is part of the PDSI and it is a measure of how monthly moisture levels compare to expected values calculated based on at least 30 years of data. This index is used for measuring agricultural drought. Therefore, it was not used in this study, as meteorological drought was the main concern of this work. In order to determine the large scale droughts and floods a numerical drought index based on monthly monsoon rainfall and duration was developed by **Bhalme and Mooley, 1980**. The drought intensity equation serves the dual purpose of assessing the intensity of drought as well as flood. Bhalme and Mooley Index (BMI) so developed required a series of monthly precipitation data over a period. The objective of the study was to determine drought area index (DAI) as well as Flood are index (FAI) for large-scale drought and flood over India during 1891-1975. For developing the equation, four monthly (July to September) data was considered over the most drought affected regions. Later, **Bhalme et al. 1983** again carried out a study on the basis of his earlier study to seek the fluctuation in drought/flood area over India and its relationship with southern oscillations. From the BMI, it was clear that the method produced realistic results over a tropical country such as India and it is evident that this index could be applied to any other tropical country. The number of large-scale droughts and floods tends to equalize over a long period of time, which can occur over India around 15 times each in a century. It was found that, there had been frequent large-scale droughts during two periods 1891-1920 and 1961-1975, separated by a long period with few large-scale droughts. Power spectrum analysis revealed a weak triennial cycle in the DAI series and a highly significant quasi-periodicity of 20 years in FAI series, which seemed to expand and contract with a period near double sunspot cycle. Thus, the Bhalme and Mooley index was used in this study to identify the drought-affected regions. A study was carried out to analyze and modify (where necessary) three drought indices namely: PDSI, BMI, SPI, and to study their application over East Africa by **Ntale and Gan, 2003**. Original PDSI was modified with potential runoff and Z index to get more realistic results. SPI was also improved by using Log Pearson Type III distribution. Also, BMI produced results that were highly correlated to those of modified PDSI, which suggested that precipitation alone could explain most of the variability of East Africa droughts. The Palmer Drought Severity Index (PDSI) has been used for more than 30 years to quantify the long-term drought conditions for a given location and time. However, a common critique of the PDSI is that the behaviour of the index at various locations is inconsistent, making spatial comparisons of PDSI values difficult, if not meaningless. **Wells et al., 2004** developed a self-calibrating Palmer Drought Severity Index (SC-PDSI). The SC-PDSI automatically calibrates the behaviour of the index at any location by replacing empirical constants in the index computation with dynamically calculated values. An evaluation of the SC-PDSI at 761 sites within Nebraska, Kansas, Colorado, Wyoming, Montana, North Dakota, and South Dakota, as well as at all 344 climate divisions shows that it is more spatially comparable than the PDSI, and reports extreme wet and dry conditions with frequencies that would be expected for rare conditions. A study was carried out to detect drought events in spatial and temporal domain by using SPI over Greece by **Livada and Assimakopoulos, 2007**. Precipitation data from 23 stations well spread over Greece was used. From the estimation of the SPI on 3-, 6- and 12-months' time scales it is evident that the frequency of mild and moderate drought conditions is approximately of the same order of magnitude over the whole Greek territory. Frequencies present a small reduction moving from north to south and from west to east. A study was carried out by **Kumar et. al., 2009** to compute SPI for low rainfall and high rainfall districts of Andhra Pradesh. Monthly rainfall data from June to October for 39 years were used to compute Standardized Precipitation Index (SPI) values based on two-parameter gamma distribution for a low rainfall and a high rainfall districts of Andhra Pradesh state, India. Comparison of SPI with actual rainfall and rainfall deviation from the mean indicated that SPI values under-estimate the intensity of dryness/wetness when the rainfall is very low/very high, respectively. It was concluded that the scatter plots of rainfall deviation v/s SPI indicated less sensitivity of SPI to low rainfall events. By evaluating the normality assumption of the SPI distributions, the spectral features of the series and, the presence of climatic trends in the datasets, **Blain, 2012** described monthly series of the Standardized Precipitation Index obtained from four weather stations of the State of São Paulo, Brazil. It was observed that the Pearson type III distribution was better than the gamma 2-parameter distribution in providing monthly SPI series closer to the normality assumption inherent to the use of this standardized index. The spectral analyses carried out in the time frequency domain did not established a dominant mode in the analysed series. A study was carried out to compute the SPI and use it to assess drought occurrences in Cameroon by **Guenang and Kamga, 2014**. It was found that the suitable distribution best fit the data depended upon the station location and on the time interval used for aggregation of precipitation. It was also found that objective drought thresholds are station specific for sub annual scales but that the spatial distributions are coherent. For longer scales, most of the stations had the same threshold. For most of the stations, drought magnitude and duration increased with time for both short and long time scales, showing the consequences of reduction in precipitation.

VI. CONCLUSIONS

The literature review of the time series analysis shows the trend of the climatic variables over a time period indicate estimate either increases or decreases. As Increase in temperatures, and decrease in rainfall are often associated with drought (Wilhite, 1992; 2000). Therefore, trend analysis of past climatic data can help in predicting as well as forecasting the future trends of climatic variables. By employing the time series trend analysis emerging climatic conditions can be easily estimated. From the literature review of probabilistic approach for estimating drought. Statistical approach can be indulged to find out the best fit distributions to the climatic variables. Then the joint probability of occurrence of n % increase in Temperature than its long-term mean and n % decrease in Rainfall than its long-term mean can be determined from the fitted CDF. This analysis only determines the probability of increase in temperature & decrease in rainfall at a particular region. This increase in temperature & decrease in rainfall at a location indicate toward emerging drought conditions. As the discussed approaches can only be giving a probabilistic idea of emerging drought, a deterministic approach should also be employed in order to estimate the drought characteristics. The probabilistic analysis indicate the probability of occurrence drought approaching condition while indices study classify the regions under different category of drought. Drought characteristics can be calculated using drought indices like Normalized Deviation, SPI, Dryness Index and Bhalme Mooley index. The results from all the indices then can be compared with ground realities and the standard classifications of the indices, to completely assess the true situation. The present study concludes that by employing all the three approaches-Time series trend analysis, probabilistic statistical methodologies and drought quantification by drought indices the estimate of drought can be made more accurate and precise. Although there are limitations to each of the methodology applied. The results of one methodology alone cannot be sustained to be reasonable. Therefore probabilistic as well as deterministic approaches altogether gives the best results and can be employed to the climatic variables to see the emerging as well as current occurring drought conditions at different regions. From this work a concrete solutions can be derived for designing an early warning system for drought prediction, as it is now known that which station is to be monitored while dealing with a particular region.

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