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Dynamics of drought and present status of drought prediction- an overview

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PREAMBLE

We suffer due to almost all types of natural hazards. Yet, there is no permanent solution to these disaster related negative impacts. One can understand our limitations in addressing earthquakes, tsunamis, avalanches and unusual cloud bursts. Many wonder why do we continue to suffer year after year due to floods and droughts, when there is vast data available about location and magnitude of these two disasters. Even after significant technological developments in locating drought prone locations and area specific dynamics of droughts through remote sensing our efforts to lessen the impact due to droughts continue to persist due to various factors including lack of co-ordination between experts and suffering common man and farmers.

Occurrence of Droughts and floods in one part of the country or the other has become a regular feature, affecting almost entire population of our country directly or indirectly. 2017 Southwest monsoon has created havoc in the north eastern states, especially Assam. Even though experts predict good rains in 2017, the prolonged dry spells followed by good showers is hurting the farmer in ensuring proper sowing operations. Monsoon aberrations and absence of a set pattern of rains has enhanced percentage of occurrence of agriculture drought. As per standard definition a drought is a period of drier-than-normal conditions that results in water-related problems. Precipitation (rain or snow) falls in uneven patterns across the country leading to indecision regarding sowing operations. The resultant setbacks due to insufficient water availability make farming community socio-economically vulnerable and distraught. This set back reflects in escalation of food prices and over all despondency in the part of rural and urban labour and water crisis resultant setbacks to middle class and at places even upper middle and rich. Drought 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 drought conditions. Drought has greater impacts on poorer communities than on more prosperous communities who have better opportunities to bring in resources from other areas. Drought, however, can be very harsh at times on any type of community, including the rich. Drought prediction at least couple of months before can help agricultural operations significantly. In spite of noteworthy scientific studies involving remote sensing data and on land hydrological parameters we are yet to master the art of proper forecasting. However, in the recent past reasonable success has been achieved. All the details pertaining to basics and state of the art drought forecasting are detailed in this write up, hoping details at one place can help focused future research studies.

Key Words: Drought prediction, Dynamics of drought, meteorological drought, hydrological drought, agricultural drought, impacts of drought, Global Drought Forecasting, droughts in India**.**

DYNAMICS OF DROUGHT AND DROUGHT PREDICTION

There are different types of drought

Drought can call to mind images of dry, cracked earth; low reservoir levels; and barren fields, yet these are actually examples of different types of drought, each of which is measured differently.

We most often think about drought in relation to precipitation, assessing the degree of dryness (in comparison to a local or regional average) and the duration of the dry period. This is known as a *meteorological drought*, which is highly specific to a region as average precipitation may vary considerably both temporally and spatially. We can also think about *hydrological drought*, or how decreased precipitation affects streamflow, soil moisture, reservoir and lake levels, and groundwater recharge. Farmers are most concerned with *agricultural drought* when available water supplies are not able to meet crop water demands. Agricultural droughts can occur for a variety of reasons, including low precipitation, the timing of water availability, or decreased access to water supplies. For instance, earlier snowmelt may not change the total quantity of water available but can lead to earlier runoff that is out of phase with peak water demand in the summer. Thus, it is possible to suffer an agricultural drought in the absence of a meteorological drought. (**Source**: http://www.ucsusa.org/global_warming/science_and_impacts/impacts/causes-of-drought-climate-change-connection.html#.Wc4uCPmCyM8)

Main Contributors of Drought:

Generally speaking, there are three main contributors to drought: (1) land and sea surface temperatures, (2) atmospheric circulation patterns, and (3) soil moisture content. Each of these physical parameters is linked to the others intricately; changing any one of them significantly will typically set up a chain of events that causes the other parameters to change. Sometimes, this chain of events becomes a vicious cycle in which the changing parameters, feeding off one another, are amplified to produce extreme climate conditions-such as flood or drought. Researchers using global climate models find that as average surface temperatures rise there is an increase in water evaporation leading to more extreme weather events. In summer, land surface temperatures are linked directly to the availability of moisture. If the soils are wet, then much of the heat from incoming sunlight is used to evaporate water, so temperatures are kept cooler and there is generally more precipitation. But if the soil is dry, then there is little or no water available to evaporate. Consequently, the incoming sunlight can only continue to warm the surface, thereby making conditions hotter and drier, thus beginning the chain of events leading toward drought. Atmospheric circulation patterns can make or break a vicious drying cycle. As such, soil moisture plays an important role in preventing or prolonging summer droughts. When the ground is wet, water evaporates as the day warms up. The warm, moist air rises until it encounters colder air high above the Earth's surface, leading to afternoon rain showers. The water remains in the ground through the cool night, and the cycle repeats the next day. Dry soil has the opposite effect on rainfall. As the temperature rises during the day, the air near the Earth's surface heats up and rises, but does not contain enough moisture to form rainclouds. As each day passes more moisture is removed from the ground, enhancing the effect.

Scientists observe that atmospheric circulation is closely connected to the surface temperature of the sea. Heat released from the ocean creates temperature gradients in the atmosphere that cause air currents. And because warm water evaporates more readily than cold water, warmer sea surface temperatures contribute to more cloud formation and more rainfall downwind of the general flow of air currents. Using satellite remote sensing data, scientists have confirmed there is a direct relationship between sea surface temperature variations in the Atlantic and Pacific Oceans and large-scale atmospheric circulation patterns that bring rain or dry spells.

(**Source:** https://earthobservatory.nasa.gov/Features/NAmerDrought/NAmer_drought_2.php)

How Droughts hurt

Droughts are some of the most costly economic stressors.

Frequently, droughts are billion dollar weather events and are one of the top three threats to population in the world (along with famine and flooding). There are three main ways droughts impact lives and communities:

1. Farmers are often the first to feel the stresses from drought, and feel them hardest. The *economic impacts* of drought include losses in the timber, agricultural, and fisheries communities. Many of these losses are then passed on to consumers in the form of higher food prices. In less developed countries, once crops fail, famine can become a major problem.
2. *Social impacts* include increased chance of conflict over commodities, fertile land, and water resources. Other social impacts include abandonment of cultural traditions, loss of homelands, changes in lifestyle, and increased chance of health risks due to poverty and hygiene issues.
3. The *environmental impacts* of drought include loss in species biodiversity, migration changes, reduced air quality, and increased soil erosion.

(**Source:** https://www.thoughtco.com/what-causes-droughts-3443828)

Impact due to droughts:

Drought effects are incremental and happen over a long period of time, hence receive little attention in early phases. Due to this, any initiative taken at a later phase of drought yields none too useful results. Drought impact is felt by man, flora and fauna.

Water may become especially polluted during times of drought due to the lack of rain water to dilute industrial and agricultural chemicals. This toxic water can be harmful to plants and animals that use it and make it difficult to clean for drinking water. Crops are also receiving less water by volume. In some areas, farmers may be able to irrigate by pumping from groundwater or surface water like farm ponds. However, as a drought worsens, these options may disappear. In the worst droughts, farmers are unable to maintain their fields because of the drought conditions and the restrictions placed on water. Some farmers and communities will re-locate to other less drought areas in order to sustain a living. The now untended land dries up from the lack of moisture and most plants will not be able to survive in these drought areas. Plants absorb the nutrients from the soil in order to survive. When these nutrients are used up, the plants will begin to wilt. Without water getting into the soil, the ground will dry out and become unstable.

Global Drought Monitoring and Forecasting

Lifeng Luo et al., (2008) carried out intensive study to monitor drought monitoring and forecasting and brought out a very interesting article. Some salient details of their study are detailed below to better plan drought monitoring and forecasting using comprehensive integrated models using satellite remote sensing data coupled with land hydrogological data inputs.

Over many parts of the world, droughts are among the most damaging of natural disasters in human, environmental and economic terms. The consequences of drought are perhaps nowhere more urgent than in Africa where IPCC projections of increase future drought frequency have perilous implications for the livelihood of residents who depend heavily upon ecosystem services. Unlike other natural disasters, droughts develop slowly over large areas and over an extended period of time, making it difficult to identify them until they have become severe and some damage has already occurred. Therefore, accurate quantitative assessment of drought conditions and the prediction of the on-set duration and recovery of droughts in real-time is critical for drought planning and preparedness.

Studies over the last two decades have demonstrated the feasibility of seasonal climate predictions with dynamical climate models. The skill of seasonal predictions is believed to come from the slow varying components of the climate system, mainly tropical Pacific sea surface temperature, although more recently surface soil moisture has also shown certain contributions over transition zones between dry and wet climatic regions (Koster et al., 2000 and 2004). At present, seasonal climate predictions are made routinely at several weather and climate prediction centers and research institutes, including the European Centre for Medium-range Weather Forecasting (ECMWF), and in the U.S. the National Centers for Environmental Prediction (NCEP). The predictions have shown significant skill over the tropics, while in the mid-latitudes their skill is improving, with some models showing skill comparable to the skill from statistical models. There is the expectation that these seasonal dynamical climate forecasts can contribute to the development of seasonal hydrologic prediction capabilities.

However, challenges must be overcome in utilizing seasonal climate forecasts from dynamical climate models in a seasonal hydrologic prediction system. One significant challenge is to correct the biases in climate model predictions, especially those related to precipitation and temperature. Another challenge is to resolve the disparity in spatial scales between the ones resolved in climate models and those needed for hydrologic applications. For instance, the current operational NCEP global coupled ocean-atmosphere model, called the Climate Forecast System (CFS) runs at T62L64 resolution (~1.875 degree in longitude). The climate models in the European Union (EU) DEMETER project provide hind casts at a resolution of 2.5°×2.5°. However, the hydrologic predictions need atmospheric forcing at a much finer resolution. As an example, the North America Land Data Assimilation System (NLDAS), which provides real-time hydrologic simulations across the continental U.S., has adopted a spatial scale of 1/8th degree. Such disparities require a seasonal hydrologic forecast system to spatially downscale the information provided by the climate models to the finer hydrologic scale where the information can be properly used. The third challenge is to create realistic daily atmospheric forcing for hydrologic modeling from the monthly information provided by the climate models. Climate model forecasts are generally only available as a monthly forecast while the hydrologic models are run at daily or sub-daily time steps. To make skilful seasonal hydrologic predictions, a good strategy is needed to overcome these challenges. Scientists have briefly described the methodology for the Drought Monitoring and Prediction System (DMAPS), and presented examples of its implementation for the US and its pilot extension to Africa. (**Source:** Lifeng Luo et al., 2008, Science and Technology Infusion Climate Bulletin, NOAA's National Weather Service, *33rd NOAA Annual Climate Diagnostics and Prediction Workshop, Lincoln, NE, 20-24 October 2008*)

Prediction of floods and droughts is an effective measure for adapting to climate change

Operational water management based on accurate and reliable hydrological predictions can be an effective means of limiting the economic and social damage caused by an increasing frequency and intensity of summer rainstorms, droughts and wintry precipitation. This will require advanced hydrological modelling and prediction. This was put forward by Prof. Albrecht Weerts, special professor Hydrologic Predictability, during his inaugural address at Wageningen University & Research on 2 March, 2017. Prof. Albrecht Weerts explained why we need to improve our ability to predict water levels in rivers, creeks and other hydrological infrastructure. Accurate and reliable predictions that can help us improve the management of our waterways in times of drought, or when floods threat, will have an excellent return on investment, regardless of the extent of the climate change. He has proposed an accurate and reliable national *probabilistic now-casting & forecasting* system for water levels and discharge volumes based on short-term radar precipitation measurements (0-6 hours) combined with high resolution weather forecasting (0-48 hours) that enables smart water management. Such a system can provide a window of time to warn the public and take local measures. Refining hydrological models to be

able to predict smaller scales in space and time (e.g. from daily to hourly and from square kms to hectares) will not automatically lead to better hydrological predictions. "This is due to all sorts of uncertainties in the model structure, parameters and estimated initial conditions. Moreover, before we *use the precipitation forecasts* in our hydrological models, it may be useful to apply a correction to the precipitation forecasts first. We should also make better use the real-time available data on discharge or water levels to adjust the initial condition of the hydrological models to increase the accuracy of the predictions."
(Source:http://www.wur.nl/en/newsarticle/Prediction-of-floods-and-droughts-is-an-effective-measure-for-adapting-to-climate-change.htm)

Humans to Blame for Higher Drought Risk in Some Regions

The world's population relies on the global water cycle for food security and economic prosperity. However, human activities may be jeopardizing this critical resource; new research by *Douville and Plazzotta* confirms that human emissions of greenhouse gases have already begun to alter the water cycle, resulting in a drying trend and increased risk of drought in certain parts of the world. To many researchers, these new findings are not surprising. For more than a decade, observational and numerical modeling studies have predicted that anthropogenic emissions would cause warming that could change the water cycle and expand dry regions.

Nonetheless, other recent studies have cast serious doubts on these predictions. Two studies cautioned that simplified calculations used to process observational data could result in incorrect predictions of evaporation due to warming over land. Other researchers uncovered large uncertainties in climate predictions made by the fifth phase of the Coupled Model Intercomparison Project (CMIP5), a widely used, multimodel tool for climate analysis.

The authors of the new study set out to address these doubts. They performed a three-pronged analysis, investigating both recent observational data and long-term CMIP5 projections of drying trends over the midlatitudes of the northern continents in summertime. In addition, the researchers applied a previously developed algorithm to distinguish between anthropogenic and natural influences on observed variations in sea surface temperatures and sea ice concentration. Then, they performed multiple climate simulations to determine the causes of recent changes in soil moisture and other land-based variables. The results of the analysis suggest that a summertime drying trend has indeed emerged over the midlatitudes of the northern continents and that anthropogenic climate change is the main cause. This drying appears to be the beginning of a long-term drying trend. The findings also suggest that in the absence of direct observations, most CMIP5 models previously underestimated long-term summertime drying. (**Source:** *Geophysical Research Letters*, https://doi.org/10.1002/2017GL075353, 2017)

Rising air pollution worsens drought, flooding, new study finds

Increases in air pollution and other particulate matter in the atmosphere can strongly affect cloud development in ways that reduce precipitation in dry regions or seasons, while increasing rain, snowfall and the intensity of severe storms in wet regions or seasons, says a new study by a University of Maryland-led team of researchers.
The research provides the first clear evidence of how aerosols -- soot, dust and other small particles in the atmosphere -- can affect weather and climate; and the findings have important implications for the availability, management and use of water resources in regions across the United States and around the world, say the researchers and other scientists.

Using a 10-year dataset of extensive atmosphere measurements from the U.S. Southern Great Plains research facility in Oklahoma researchers have uncovered, for the first time, the long-term, net impact of aerosols on cloud height and thickness, and the resultant changes in precipitation frequency and intensity. The study found that under very dirty conditions, the mean cloud height of deep convective clouds is more than twice the mean height under crystal clean air conditions. The probability of heavy rain is virtually doubled from clean to dirty conditions, while the chance of light rain is reduced by 50 percent. The scientists obtained additional support for these findings with matching results obtained using a cloud-resolving computer model.

These new findings of long-term impacts, using regional ground measurements, also are consistent with the findings researchers have obtained from an analysis of NASA's global satellite products in a separate study. Together, they attest to the needs of tackling both climate and environmental changes that matter so much to our daily life. These findings have significant policy implications for sustainable development and water resources, especially for those developing regions susceptible to extreme events such as drought and flood.

Some experts note the significance of the new findings. They pointed out that understanding interactions across clouds, aerosols, and precipitation is one of the grand challenges for climate research in the decade ahead. Findings of this study represent a significant advance in our understanding of such processes with significant implications for both climate science and sustainable development. Scientists have known for a long time that aerosols impact both the heating and phase changes [condensing, freezing] of clouds and can either inhibit or intensify clouds and precipitation. What they have not been able to determine, until now, is the net effect. This study by Li and his colleagues from Maryland University shows that fine particulate matter, mostly from air pollution, impedes gentle rains while exacerbating severe storms. Scientists opine that it adds urgency to the need to control sulphur, nitrogen, and hydrocarbon emissions.

According to climate scientist Steve Ghan of the Pacific Northwest National Laboratory, "This work confirms what previous cloud modeling studies had suggested, that although clouds are influenced by many factors, increasing aerosols enhance the variability of precipitation, suppressing it when precipitation is light and intensifying it when it is strong. This complex influence is completely missing from climate models, casting doubt on their ability to simulate the response of precipitation to changes in aerosol pollution."

Greenhouse gases and aerosol particles are two major agents dictating climate change. The mechanisms of climate warming impacts of increased greenhouse gases are clear (they prevent solar energy that has been absorbed by the earth's surface from being radiated as heat back into space), but the climate effects of increased aerosols are much less certain due to many competing effects outlined above. Until now, studies of the long-term effects of aerosols on climate change have been largely lacking and inconclusive because their mechanisms are much more sophisticated, variable, and tangled with meteorology. While the mechanisms for some of these effects remain uncertain, the well-defined relationships discovered here clearly demonstrate the significance of the effects. Developing this understanding to represent the controlling processes in models remains a future challenge, but this study clearly points in important directions.

Source: Zhanqing Li et al., Long-term impacts of aerosols on the vertical development of clouds and precipitation. *Nature Geoscience*, 2011; DOI: 10.1038/ngeo1313)

Predicting the Future of Drought Prediction

As extreme weather events go, droughts—like the one that singed Russia's wheat crop in 2010 and the one that engulfed the United States in July, 2012 —are about as tricky as it gets. Unlike hurricanes and tornadoes, drought does not have an obvious start or end. In fact, there isn't even a clear definition for it, making it hard to measure and monitor, let alone predict. But with better observations of the earth, oceans, and atmosphere and improvements in computer modeling, scientists think they'll be able to foresee the chances of drought up to a decade in advance, and better predict droughts that arise suddenly or last longer than a few months.

Today, scientists can forecast drought only about three months ahead for most parts of the world with any significant certainty. "Forecasting drought is an inexact science," says Brian Fuchs, a climatologist. According to him drought is typically characterized by slow onset and slow recovery. To pick up signals of something that happens over weeks or months is hard for computer models."

Drought involves a seemingly inexhaustible list of factors—from local ones such as groundwater level, stream flow, soil moisture, and vegetation, to large-scale global weather patterns such as El Niño and La Niña. All of these change over different time periods, from days to decades, and many are tied to each other. Global warming tops off the chaotic mix.

Nevertheless, scientists in the United States have produced some of the most sophisticated tools to monitor and predict drought. Resource planners and policymakers rely mainly on the U.S. Drought Monitor, an online map of dryness that has been updated .The monitor combines several mathematical indices calculated by feeding computer models with temperature, precipitation, and soil moisture data. While monitoring has been done for decades, forecasting drought is still in its infancy. Today, it blends science and art, and the only place it's done on a national scale is at NOAA's Climate Prediction Center (CPC). Twice every month, meteorologists there subjectively produce the U.S. Seasonal Drought Outlook, which predicts conditions for the next three months. To create the Drought Outlook, scientists mix data from the Drought Monitor with soil moisture information and the CPC's three-month forecast of temperature and rainfall. They also incorporate current climate conditions along with past heat and precipitation. An expert stated that more-powerful computers would make it possible to include more-detailed physics and more climate system components. Greater computing prowess would also mean that each simulation step would cover a shorter time and distance—a few minutes and a few kms as opposed to the hours and tens of kms used now. This would improve the ability to capture smaller, more rapid changes in temperature and precipitation.

Other advances expected in the coming years include more extensive ground observation networks and NOAA's next-generation polar satellite, which is equipped with advanced visual and infrared imagers that produce data with a higher temporal and spatial resolution. These will give better temperature, precipitation, and soil moisture data, which will improve the accuracy of drought prediction.

Scientists anticipate that longer-term drought prediction could be possible by 2018. That's when NOAA scientists are expecting to next upgrade the climate model, to include decade-long climate fluctuations. They hope to do this by simulating known long-term ocean fluctuations such as the Atlantic multi-decadal oscillation. Scientists anticipate to see continuing drought monitoring and prediction.

(**Source**: prachipatel,2012,http://spectrum.ieee.org/energy/environment/predicting-the-future-of-drought-prediction)

Global integrated drought monitoring and prediction system

A 2007 ministerial summit with representatives from 70 nations, held in Cape Town, South Africa, recognized the growing problem of drought and its impact on food security and sustainability of water resources, and highlighted the need for a global drought early warning system1. Drought effects are incremental and happen over a long period of time, hence receive little attention in early phases.

Each year droughts result in significant socioeconomic losses and ecological damage across the globe. Given the growing population and climate change, water and food security are major challenges facing humanity. Nearly 1 million people perished in East Africa in the mid-eighties because of a major drought that led to a widespread famine. More recently, in 2010-2011, two events in East Africa and Southeast Asia affected 9 million people, causing famine in East Africa and significant ecological impacts in Southeast Asia. Production of adequate food to avoid food crises requires advanced drought early warning and prediction systems. In particular, a global model is needed that can support regions where famine and food crisis are prevalent because of economic and social instability and climatic variability. In recent years, several research and operational drought monitoring models have been developed. However, drought warning and prediction systems are still the least developed systems among other natural disasters primarily because of the complex processes involved in drought onset and development. On a regional scale, there are a number of drought monitoring tools tailored for local to continental scale applications such as, the U.S. Agency for International Development (USAID) Famine Early Warning System Network (FEWS Net), United States Drought Monitor, African Drought Monitor, and the University of Washington Experimental Surface Water Monitor.

In an interconnected world where a drought in the United States, Russia or Australia could affect global food prices, a regional perspective to drought monitoring and prediction may not be sufficient. Currently, few global drought models are available, including the Global Information and Early Warning System on Food and Agriculture (GIEWS), Humanitarian Early Warning Service (HEWS) by the World Food Programme (WFP), Global Drought Monitor by the University College London (UCL), the Standardized Precipitation-Evapotranspiration Index Global Drought Monitor, and the Global Drought Portal (GDP) by the United States National Climatic Data Center. The aforementioned models, however, do not provide probabilistic forecasts of drought condition for risk assessment. While these outputs are valuable, probabilistic seasonal drought forecasts can substantially improve drought early warning capability.

United Nations Environment Programme (UNEP) report calls for a drought prediction system based on a comprehensive and *integrated* approach that would include multiple drought indicators. While droughts originate from a deficit in precipitation, an effective drought monitoring and prediction system should integrate multiple drought-related variables. The United Nations (UN) Strategy for Disaster Reduction (ISDR) argues that an early warning system should have the following features: (a) Monitoring and predicting components, (b) Risk knowledge, (c) Disseminating information, and (d) Response. Following the above recommendation, the Global Integrated Drought Monitoring and Prediction System (GIDMaPS) is developed to provide drought information based on multiple drought indicators and input data sets. GIDMaPS includes a seasonal probabilistic prediction component that supports *risk knowledge*. The probabilistic forecasts offer essential information for early warning, preventive measures, and mitigation strategies. GIDMaPS provides both monitoring and prediction components, as well as a data dissemination interface. (**Source**: Hao, Z et al., Global integrated drought monitoring and prediction system. Sci. Data 1:140001 doi: 10.1038/sdata.2014.1 (2014)).

A new tool for predicting drought: an application over India

This is the first attempt of application of atmospheric electricity for rainfall prediction. The atmospheric electrical columnar resistance based on the model calculations involving satellite data has been proposed as a new predictor. It is physically sound, simple to calculate and not probabilistic like the standardized precipitation index. After applying this new predictor over India, it has been found that the data solely over the Bay of Bengal (BB) are sufficient to predict a drought over the country as a whole. Finally, two independent new methods to predict drought conditions and a preliminary forecast of the same for India for year 2014 have been given. Unlike the existing drought prediction techniques, the identification of drought conditions in a pre-drought year during 1981–1990 and 2001–2013 over India has been achieved 100% successfully using the suggested new methods. The association between rainfall and this new predictor has also been found on the sub-regional scale. So, the present predictor is expected to get global application and application in climate models. From the analysis, generally, a long period rising trend in aerosol concentration over the BB causes weak monsoon over India but that for a short time i.e. in pre-monsoon period strengthens it**.** (**Source:** M.N.Kulkarni,Sci Rep. 2015; 5: 7680.Published online 2015 Jan 8. doi: 10.1038/srep07680)

Status of preparedness in meeting droughts in India

In India, around 68% of the country is prone to drought in varying degrees. 35% which receives rainfall between 750 mm and 1125 mm is considered drought prone while 33% receiving less than 750 mm is chronically drought prone.

The agriculture drought assessment and monitoring, under National Agriculture Drought Assessment and Monitoring System (NADAMS project), is carried out using multiple satellite data, rainfall, soil moisture index, potential sowing area, irrigation percentage and ground observations. A logical modeling approach is followed to classify the districts into Alert, Watch and Normal during June, July and August and Severe, Moderate and Mild drought conditions during September and October. The monthly Drought Assessment Reports are communicated to all concerned State and national level agencies and also kept on the MNCFC website (www.ncfc.gov.in).

IMD is the designated agency for providing drought early warning and forecasting. Agricultural Meteorology Division, Pune provides timely advice on the actual and expected weather and its likely impact on the various day-to-day farming operations. Drought Research Unit, Pune provides Crop Yield Forecasts. The National Centre for Medium Range Weather Forecasting, a constituent unit of the Department of Science & Technology provides, in consultation with IMD, ICAR and State Agricultural Universities, agro-meteorological advisory service at the scale of agro-climatic zones to the farming community, based on location specific medium range weather forecasts. The Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad and the All India Coordinated Research Projects on Agri-Meteorology and Dryland Agriculture (AICRPAM and AICRPDA) each of them having 25 centres across the country, take part in drought studies pertaining to assessment, mitigation, risk transfer and development of decision support software for drought prone States. Central Arid Zone Research Institute, Jodhpur for assessing agricultural drought situation in 12 arid Districts of western Rajasthan and disseminates bi-weekly crop-weather agro-advisory bulletins to the farmers. Ministry of Earth Sciences in collaboration with ICAR has set up 89 centres for short and medium range monitoring and forecasting of weather. National Agricultural Drought Assessment and Monitoring System Developed by the Department of Space for the Department of Agriculture and Cooperation monitors vegetation cover through satellite data based helping in drought assessment by comparative evaluation of vegetation cover with those of previous years. It prepares State-wise monthly reports. There are institutional mechanisms for drought monitoring and early warning at national and state levels. However, these are considered to be inadequate for meeting the demands of drought management and their capacity needs to be strengthened for the purpose of data collection, analysis and synthesis of information. Crop Weather Watch Group (CWWG), an inter-Ministerial mechanism of Central Govt. meets once a week during rainy season (June-September). The frequency of meetings increases during drought occurrence. (**Source:** http://wrmin.nic.in/forms/list.aspx?lid=312 & https://reliefweb.int/report/india/national-agriculture-drought-assessment-and-monitoring-system)

When the Indian Ocean heats up, the intensity of the monsoon season reduces

A team from the Indian Institute of Meteorology (IITM) in Pune, has recently revealed in the journal *Nature Communications* that the warming of the Indian Ocean, by up to 1.2°C in some areas over the last century, is reducing the intensity of the Indian monsoon season by around 10 to 20% in the country's central, eastern and northern regions.

Scientists made this discovery using an ocean-atmosphere coupled climate model, specially developed by the IITM for making monsoon season forecasts. Thanks to this model, researchers were able to demonstrate that the reduction in rainfall observed over the subcontinent since the 1950s is due to the rapid warming of the ocean. The Intergovernmental Panel on Climate Change (IPCC) anticipates that ocean temperatures will rise further as a result of the greenhouse gas effect. The study goes on to explain the reason for the observed reduction in rainfall associated with the Indian monsoon season. The Indian subcontinent has warmed up by only a very small amount during the last few decades, reducing the summer temperature difference between the ocean and the land, which triggers the monsoon winds. This phenomenon is weakening the monsoon season dynamic and is drying up the subcontinent, bringing harmful consequences for agriculture along the Ganges-Brahmaputra-Meghna basins and the Himalayan spurs, an activity requiring extensive irrigation. Will India continue to dry up? Projections based on the majority of the climate models used in the IPCC's latest evaluation report do not see this trend replicated in future years. Some anticipate quite the opposite: increased rainfall due to increased water vapour in the atmosphere and a far more noticeable warming of the subcontinent in the future. This divergence between current observations and model-based trends underlines the uncertainties involved when it comes to future climate change in the region, particularly in terms of the water cycle and the monsoon regions.(**Source**: Mathew Koll Roxy et al., Drying of Indian subcontinent by rapid Indian Ocean warming and a weakening land-sea thermal gradient. *Nature Communications*, 2015; 6: 7423 DOI: 10.1038/ncomms8423)

Indian monsoon: Novel approach allows early forecasting

The Indian monsoon's yearly onset and withdrawal can now be forecasted significantly earlier than previously possible. A team of scientists developed a novel prediction method based on a network analysis of regional weather data. Future climate change will likely affect monsoon stability and hence makes accurate forecasting even more relevant.

"We can predict the beginning of the Indian monsoon two weeks earlier, and the end of it even six weeks earlier than before -- which is quite a breakthrough, given that for the farmers every day counts. We found that in North Pakistan and the Eastern Ghats, a mountain range close to the Indian Ocean, changes of temperatures and humidity mark a critical transition to monsoon," explains," says Veronika Stolbova from the Potsdam Institute for Climate Impact Research (PIK) and the University of Zurich. Conventionally, the focus has been on the Kerala region on the southern tip of India. Information about monsoon timing is key for Indian farmers to determine when to carry out the sowing. Crops like rice, soybean and cotton are normally grown during the June to September monsoon rainy season. Even a slight deviation of the monsoon can lead to droughts or floods, causing damages. Also, the length of the monsoon is relevant for planning hydro power generation since the rains are necessary to fill the dams and reservoirs.

The scientists tested their method with historical monsoon data. It gives correct predictions for onset in more than 70 percent and for withdrawal in more than 80 percent of the considered years. The main advantage of the proposed approach is that it allows improving the time horizon of the prediction compared to the methods currently used in India. In addition, the new scheme notably improves the forecasting of monsoon timing during years affected by the global weather phenomenon El Nino -- Southern Oscillation (ENSO), particularly in its La Nina phase. This phenomenon significantly alters monsoon timing and decreases the prediction accuracy in existing methods.

Using the network analysis of complex non-linear systems, an advanced mathematical approach, for monsoon forecasting is unprecedented -- yet the approach shows good results. The major innovation, the authors say, is to combine the network analysis with the subtle statistical analyses of the early warning signals for the monsoon onset and withdrawal. These precursor phenomena are often buried by huge piles of weather data and hence get overlooked. We discovered how to use precursors in a new way -- to find regions where critical conditions for an occurrence of the Indian monsoon originate. In the future, this method can also help to unravel mysteries of other climate phenomena.

Global warming due to mankind's greenhouse-gas emissions from burning fossil fuels already affects the Indian monsoon and -- if unabated -- is expected to do even more so in the future. The timing of Indian summer monsoon, on which the livelihoods of many million people depend, is likely becoming more erratic. In view of this early and accurate forecasting has become ever more crucial. Such a forecasting also helps in predicting probable onset of a drought and its duration. (**Source**: Veronika Stolbova et al., 2016. Tipping elements of the Indian monsoon: prediction of onset and withdrawal. *Geophysical Research Letters*, 2016; DOI: 10.1002/2016GL068392)

New method for monitoring Indian Summer Monsoon (ISM)

Researchers from Florida State University have created a tool for objectively defining the onset and demise of the Indian Summer Monsoon -- a colossal weather system that affects billions of people annually. The research scientists outline a methodology that uses rainfall rates to mark the span of the ISM at any given location throughout the affected region.

For generations, scientists have struggled to produce a model for reliably defining the duration of the monsoon. No existing system has allowed researchers to reliably define the parameters of the season at this fine a scale."Current weather forecasting and monitoring protocols focus attention on monsoon onset at one location -- specifically the state of Kerala in the southwest corner of the country -- and extrapolate for the rest of the region. We have gone down to specific locations, we've covered the whole country, and we've objectively defined the onset and demise dates for any given year." Said Prof.Misra.

The lack of a clear, granular and objective benchmark for ISM onset and demise for all areas of the country has been a longtime source of consternation for the Indian people. In some parts of the country, the torrents of rain that characterize monsoon season account for more than 90 percent of the total annual precipitation. Consequently, many rhythms of Indian political and agricultural life can be destabilized by dubious or false claims of monsoon onset. That leads to tremendous amounts of frustration and confusion for the general public and for the people who are trying to monitor the monsoon because nobody has really gotten down to do it at a granular scale. The new system, which ties the onset of the monsoon to location-specific rainfall thresholds, can work to allay that frustration.

Up until now, regional meteorological departments have relied on their own ***ad hoc*** criteria for determining ISM onset, which can often lead to contradicting claims. A more inclusive method will allow officials and researchers throughout the country to define the monsoon season using a standardized system that, through rigorous testing, has been shown to capture ISM evolution comprehensively.

Anchoring the definition of onset and demise solely in local rain rates eliminates the need to rely on less accessible atmospheric variables. This streamlined approach makes it considerably easier to monitor monsoon evolution."Our research enables quite easy real-time monitoring of the onset and demise of the Indian monsoon. We've tested this for 105 years of available data, and this criterion hasn't failed once for any location over India." Misra said. By orienting this novel framework around rates of rainfall in a given area the scientists have effectively removed the necessity for broad extrapolation. With this methodology, a question that has baffled meteorologists for decades finally has a simple, actionable answer.

"You don't need complicated definitions," Misra said. "Now we completely base the definition on rainfall, and it hasn't failed."

(**Source**: Vasubandhu Misra et al., 2017. Local onset and demise of the Indian summer monsoon. *Climate Dynamics*, 2017; DOI: 10.1007/s00382-017-3924-2)

Drought impact in 2017- South Indian Scenario

Southwest Monsoon 2017 has made timely onset over southern parts of Kerala on May 30. With this, we expected rains to pick up pace across Kerala and over parts of Karnataka and Tamil Nadu. One and all eagerly awaited good monsoon owing to the dwindling status of water reservoirs in southern parts of the country. According to the statistics, these reservoirs reported acute shortage of water i.e. below 10% even in June. Condition in many reservoirs even during third week of August is very depressing. This has cited major cause of concern for the agriculture sector for the region down south, which is also already battling worst drought of the decade. Moreover, lack of irrigation has further worsened the situation. Blame it all on the fluctuating Monsoon rains during the last three years. While 2014 and 2015 were the severe drought years, 2016 despite recording normal Monsoon rains left the southern region parched. Last year, Kerala was deficit by 34%, South Interior Karnataka-21%, Coastal Karnataka 21% and Tamil Nadu by 19%.However, this year, Skymet Weather has predicted Southwest Monsoon to be marginally below normal at 95% with an error margin of +/- 5%. In fact, weather models indicated correctly that June would likely to witness good Monsoon rains. Unfortunately, failure of monsoon in July and below normal rainfall in August and September considerably dampened the spirits of farmers in almost all the southern states, especially Telangana. Unexpected continuous good spell of rains in October, fortunately, improved the condition and helped in reasonable quantities of inflows in to many reservoirs in Telangana and parts of Andhra Pradesh. However, this delayed monsoon affected Kharif crops. Many are afraid that even these belated good Monsoon rains from the fourth week of September will not be enough to improve the overall agriculture output. It is essential to closely examine the soil fertility levels and overall impact of weak monsoon from July till third week of September and take curative measures to ensure the negative impact on soil fertility will not adversely affect the long term nutrient capacity of soil mantle.

As per the data released by the Central Water Commission on May 25, 2017, the southern region has 31 reservoirs having total live storage capacity of 51.59 BCM. The Southern region includes states of Andhra Pradesh, Telangana, Karnataka, Kerala and Tamil Nadu. As per Reservoir Storage Bulletin, the total live storage available in these reservoirs is 3.92 BCM which is 8% of total live storage capacity of these reservoirs. The storage during corresponding period of last year was 11% and average storage of last ten years during corresponding period was 17% of live storage capacity of these reservoirs. Thus, storage during current year is less than the corresponding period of last year and is also less than the average storage of last ten years during the corresponding period. As per Press Information Bureau,Government of India, Ministry of Water Resources, dated 4th August in **t**he Southern region that includes States of Andhra Pradesh, Telangana, AP&TG (Two combined projects in both states) Karnataka, Kerala and Tamil Nadu status of 31 reservoirs is as follows. There are 31 reservoirs under CWC monitoring having total live storage capacity of 51.59 BCM. The total live storage available in these reservoirs is 14.28 BCM which is 28 % of total live storage capacity of these reservoirs. The storage during corresponding period of last year was 30% and average storage of last ten years during corresponding period was 46% of live storage capacity of these reservoirs. Thus, storage during current year is less than the corresponding period of last year and is also less than the average storage of last ten years during the corresponding period.

Situation is very tough for southern states as reservoirs have reached to dead storage. There is no water left for agriculture. Now to assess the meteorological drought of southern states, Skymet Weather has calculated the Standardized Precipitation Index (SPI), a widely used index to characterize meteorological drought on a range of timescales. On long timescales, the SPI is closely related to groundwater and reservoir status. On short timescales, the SPI can be related to soil moisture or the agricultural drought. Generally, SPI varies between +3 to -3. Positive values suggest floods and negative drought.

SPI analysis is done over 3 scenarios. In first scenario, weather experts have assumed that the rainfall will be normal, whereas the second and third scenarios are generated for 5% and 10% extra rainfall till December 2017. Through the combined analysis, it can be said that under assumed scenario of forecasted precipitation, the water availability issue in these sub divisions will remain severe in the season. From agricultural point of view, water backlog may not be filled in this region. So, we can see in both sub-divisions for 9-monthly and 12-monthly SPI that if normal or 5% more than normal or 10% more than normal rainfall occurred from June-2017 to Dec-2017, then also hydrological drought won't be made less effective(**Source**: https://www.skymetweather.com › Weather News and Analysis).

This prediction has been proved wrong with copious mount of monsoon rains in about a month starting from third week of September, exposing the limitations of our prediction capabilities. As per information released by Ministry of Water resources, Govt of India the total live storage available in these reservoirs as on 26th October, 2017 is 34.15 BCM which is 66% of total live storage capacity of these reservoirs. The storage during corresponding period of last year was 50% and average storage of last ten years during corresponding period was 69% of live storage capacity of these reservoirs. Thus, storage during current year is better than the corresponding period of last year but is less than the average storage of last ten years during the corresponding period.
(**Source**:http://pib.nic.in/newsite/pmreleases.aspx?mincode=38)

With the Nagarjunasagar dam reaching a comfortable storage level, and Srisailam dam already being filled, and with more inflows expected for at least another week, both Telangana state and Andhra Pradesh are readying to seek fresh indents of around 250 tmc ft of water for raising the Rabi crop. Allotment of additional water to these two states depends on various factors, including onset of North east monsoon and sustenance of water levels in these reservoirs(P.S: Unfortunately the north east monsoon has not added any additional amount of water, due to its failure in Telangana and many parts of Rayala Seema till end of November, 2017, making releasing of sufficient quantities of water difficult from big and medium reservoirs for Rabi season, further exposing our limitations in predicting intra seasonal precipitation). Effective implementation of various water dependent projects has become a guessing game, exposing our limitations of predicting drought situation in some vulnerable segments in the next 6 months.

Effective implementation of global models-impediments and apt strategy

While perturbed by the painful reality, as scientists it is our bounden duty to address this recurring problem. Let us look in to global initiatives (detailed in the earlier subsections) and try to implement recent advancements in drought prediction to lessen negative impact. Until such time we collect good quality dense data using different modes of data acquisition and without fear or favour implement global strategies(after setting aside area specific temporal and spatial details) we will continue to make errors in our prediction, leading to below par preparedness.

Although some droughts last a single season and affect only small areas, the instrumental and paleo-climate records show that droughts have sometimes continued for decades and have impacted millions of square kms in North America, West Africa, East Asia and even India. To cross the spectrum of potential drivers and impacts, drought information systems have multiple sub-systems which include an integrated risk assessment, communication and decision support system of which early warning is a central component and output. An early warning system is much more than a forecast – it is a linked risk information (including people's perception of risk) and communication system that actively engages communities involved in preparedness. There are numerous drought warning systems being implemented at different scales of governance. Indian scientists can draw on the lessons of over 21 drought early warning systems around the world, in both developing and developed countries and at regional, national and community levels. The successes illustrate that effective early warning depends upon a multi-sectoral and interdisciplinary collaboration among all concerned actors at each stage in the warning process from monitoring to response and evaluation. However, the links between the community-based approach and the national and global EWSs are relatively weak, as evidenced from our response to El Nino impact during the last three to four years. These impacts can lead to drought in many parts of our country, unless close knit co-operation in data dissemination at regional and global level is achieved at the earliest opportunity. Using the rich experience of information systems across the globe, agro meteorologists and disaster management experts can identify pathways for knowledge management and action at the relevant scales for decision-making in response to a changing climate.
(**Source:** Weather and Climate Extremes,Volume 3, June 2014, Pages 14-21; https://doi.org/10.1016/j.wace.2014.03.005)

CONCLUSION

We have been facing droughts and floods regularly in one part of the country or the other, due to monsoon variability and intra monsoon fluctuations .Our scientific efforts have not yielded proper results, due to various factors, including the limitations of our research options and approaches. If not exactly, the accuracy in area specific monsoon onset and withdrawal predictions can significantly help us in knowing in advance to a considerable extent onset of drought, its intensity and duration. For the success of these predictions aerially and temporally we have to continuously upgrade our prediction models by using significant successes achieved by international research organisations. Scientists have found that the frequency of heat waves accompanied by drought has increased not only in magnitude but in area too over the past three decades in Gujarat and central parts of our country, making this segment of the country vulnerable to become chronic drought prone region. Researchers believe intricate relationship of land surface processes, soil moisture, evapotranspiration and local climate could play vital role in making a region drought prone. As such researchers should increase agro-meteorological data collection stations in these parts to enhance success rate in drought prediction. The recent spurt in research focused on Indian Summer Monsoon clearly indicates that international weather experts are fully aware of the adverse impact on millions of South Asians due to even minor aberrations in the prediction models. Making use of the interest shown by international weather experts we can achieve much better results in the near future, thereby helping one and all, including in particular the farming community, residing in vulnerable segments of our country.

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This write up has been prepared extracting internet based relevant information from different studies. The extracted information was then screened and linked to develop this write up. Source of every sub topic is given in the text to help the interested readers.

Compliance with Ethical Standards:

The author declares that he has no conflict of interest and adheres to copyright norms.

Quotations on Drought

Nature, like a loving mother, is ever trying to keep land and sea, mountain and valley, each in its place, to hush the angry winds and waves, balance the extremes of heat and cold, of rain and drought, that peace, harmony and beauty may reign supreme.

Elizabeth Cady Stanton (1815-1902) was an American suffragist, social activist, and abolitionist.

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God has cared for these trees, saved them from drought, disease, avalanches, and a thousand tempests and floods. But he cannot save them from fools.

John Muir (1838 -1914) was a Scottish-American naturalist, author, environmental philosopher.

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Any party which takes credit for the rain must not be surprised if its opponents blame it for the drought.

Dwight Morrow (1873 -1931) was an American businessman, diplomat, and politician.

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Friends are "annuals" that need seasonal nurturing to bear blossoms. Family is a "perennial" that comes up year after year, enduring the droughts of absence and neglect. There's a place in the garden for both of them.

Erma Bombeck (1927-1996) was an American humorist.

***

For most of the history of our species we were helpless to understand how nature works. We took every storm, drought, illness and comet personally. We created myths and spirits in an attempt to explain the patterns of nature.

Ann Druyan (1949--) is an American writer and producer specializing in the communication of science.

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I think we are bound to, and by, nature. We may want to deny this connection and try to believe we control the external world, but every time there's a snowstorm or drought, we know our fate is tied to the world around us

Alice Hoffman (1952--) is an American novelist and young-adult and children's writer.

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The world is a drought when out of love.

B*randon Boyd (1976--) is an American singer, songwriter, musician, author and artist.*

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"Not every dream grows on every land, so you got to watch out! "Sugar cane" dreams should find the environment where there is flooding of great ideas from great people. It will die off if it is planted at the place where the drought of discouragement is a well cherished culture!"

***Israelmore Ayivor** (1989--) is an inspirational writer, blogger and Life Skills Entrepreneur.*