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An Overview of Drought, its Impacts and Management

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ABSTRACT: Drought is a natural event that can have significant impact on the economy. Droughts are recognized as an environmental disaster and have attracted the attention of environmentalists, ecologists, hydrologists, meteorologists, geologists and agricultural scientists. Droughts occur in virtually all climatic zones, such as high as well as low rainfall areas and are mostly related to the reduction in the amount of precipitation received over an extended period of time, such as a season or a year. Temperatures; high winds; low relative humidity; timing and characteristics of rains, including distribution of rainy days during crop growing seasons, intensity and duration of rain, and onset and termination, play a significant role in the occurrence of droughts. In this paper attempts to provide a review of fundamental concepts of drought, classification of droughts, drought indices, historical droughts using paleoclimatic studies, and the relation between droughts and large scale climate indices. Conclusions are drawn where gaps exist and more research needs to be focussed.

KEYWORDS: Drought indices, Groundwater droughts, large scale climate indices, Paleoclimatic study for droughts.

I. INTRODUCTION

Droughts and floods are the two extreme natural events that can have considerable economic, societal and environmental impacts. Conventionally, drought is a prolonged period of receiving less precipitation than normal over a large area. The occurrence of drought is very complicated to define, quantify, and monitor, mainly due to the large number of variables involved in the phenomenon. Based on the choice of interest, drought can be defined in a number of ways, such as meteorological, hydrological, agricultural and socioeconomic drought (Shiau et al., 2012). Hydrological drought occurs as a result of a significant decrease in the water availability in the land phase of the hydrological cycle (Sardou et al., 2014). Several variables are used to describe hydrological drought, but stream flow is the predominant variable from the view point of variation of the quantity of water (Nalbantis, 2008). Assessment of hydrological drought plays a key role in water management (Weng et al., 2015). Moradi et al. (2011) investigated meteorological drought characteristics in Fars province of Iran using a standardized precipitation index. The importance of drought management cannot be overstressed as it impacts our economic sectors and daily activities to a great extent (Santos et al., 2011). Drought conditions also impact energy production, both in terms of water availability for hydropower and cooling water in electricity generation, river navigation, agricultural and public water supply (Feyen et al., 2009). Obtaining detailed information on previous drought variations may allow water managers and planners to properly manage water resources for future risk of drought (Xu et al., 2015). Each hydrological drought event is characterized through four parameters, namely, drought index (its severity), time of onset and its duration, areal extent, and its frequency of occurrence (Sardou and Bahremand, 2014). The prediction of these parameters is generally conducted through various drought indices used in the literature (e.g. Shafer and Dezman, 1982, Weghorst, 1996, Palfai, 2002, Nalbantis, 2008, Vicente-Serrano et al., 2012). These indices either use stream flow as an individual input variable or in combination with other variables in the hydrological cycle. For instance, the surface water supply index (SWSI) takes reservoir storage, streamflow, snowpack and precipitation as an input parameter (Shafer and Dezman, 1982). Similarly, the reclamation drought index (RDI) uses temperature as an additional input parameter with the above parameters (Weghorst, 1996). Nalbantis (2008) introduced stream flow drought index (SDI) that requires only stream flow data as an input parameter and thus reduces calculation difficulties and the data requirements from

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Visit: www.ijirset.com

Vol. 7, Issue 10, October 2018

other sources. Wong et al. (2013) applied statistical tools and models to investigate the connection between meteorological drought characteristics and hydrological drought characteristics.

II. NEED FOR DROUGHT RESEARCH

Assessment of droughts is of primary importance for freshwater planning and management. This requires understanding historical droughts in the region as well as impacts of droughts during their occurrences. Therefore, understanding different concepts of droughts will be helpful for developing models to investigate different drought properties, which is beyond the scope of the present discussion. The motivation for current discussion is due to the developments in global drought scenarios during recent years, which are discussed in what follows.

IMPACT OF CLIMATE CHANGE ON DROUGHTS

Climate change is now recognized as one of the major threats for the planet earth in the twenty-first century. According to the Intergovernmental Panel on Climate Change (IPCC) report (IPCC, 2007), instrumental observations over the past 157 years show that temperatures at the surface have risen globally, with significant regional variations. For the global average, warming in the last (20th) century has occurred in two phases, from the 1910s to the 1940s (0.35 °C), and more strongly from the 1970s to the present (0.55 °C). An increasing rate of warming has taken place over the last 25 years, and 11 of the 12 warmest years on record have occurred in the past 12 years. In general, this warming intensifies the global hydrological cycle (e.g., Milly et al., 2002) and it is well established that the earth's mean surface temperature has been increasing following the last glacial maximum 21,000 years ago (Clark et al., 1999), thus increasing the globally averaged precipitation, evaporation, and runoff. The consequence of global warming is not the change in the averages but the overall increase of extreme events. Among the extreme meteorological events, droughts are possibly the most slowly developing ones, that often have the longest duration, and at the moment the least predictability among all atmospheric hazards. Studies on how climate change will affect various ecosystems have been conducted as an international effort on many fronts. Most of these studies address the effect in terms of changes in discharge caused by changed precipitation and temperature, the effects varying widely with the adopted scenarios and catchment type (e.g., Gleick, 1987; Karl and Riebsame, 1989; Lettenmaier and Gan, 1990; Panagoulia, 1992).

However, unlike floods analyzes of changes in drought characteristics due to climate change impacts have not been explored fully. Amongst recent studies on understanding drought impacts, Szep et al. (2005) have found that local soil moisture conditions in East Hungary became drier in the 20th century, parallel to the hemispherical changes. Andreadis and Lettenmaier (2006) have examined agricultural and hydrological droughts in USA, and have observed that droughts have, for the most part, become shorter, less frequent, and cover a smaller portion of the country over the last century except southwest and parts of the interior of the west, where trends in drought characteristics, that are mostly opposite to those for the rest of the country, especially in the case of drought duration and severity, have increased. In another study, Mishra and Singh (2009) highlighted the changes in drought severity-area-frequency due to climate change scenarios and compared with historical droughts for Kansabati River basin in India.

It is now accepted that droughts in future pose a threat to climate sensitive economic sectors, specifically agriculture, and have therefore necessitated the assessment of potential impacts of climate change on crop production at various scales. This will help develop measures to reduce agricultural vulnerability and thereby secure livelihoods of those who depend on agriculture. The following section discusses how droughts have affected different continents around the globe during recent decades to draw attention to the necessity for understanding droughts.

IMPACT OF DROUGHTS AROUND THE GLOBE DURING RECENT DECADES

Droughts produce a complex web of impacts that span many sectors of the society, including economy and may reach well beyond the area experiencing a drought. They are a widespread phenomenon (Kogan, 1997), since about half of the earth's terrestrial surfaces are susceptible to them. More importantly, almost all of the major agricultural lands are located there (USDA, 1994). Of all the 20th century natural hazards, droughts have had the greatest detrimental impact (Bruce, 1994; Obasi, 1994). In recent years, large scale intensive droughts have been observed on all continents, affecting large areas in Europe, Africa, Asia, Australia, South America, Central America, and North America (Le

International Journal of Innovative Research in Science, Engineering and Technology

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Visit: www.ijirset.com

Vol. 7, Issue 10, October 2018

Comte, 1995; Le Comte, 1994) and high economic and social costs have led to increasing attention to droughts (Downing and Bakker, 2000). The impact of droughts on different continents around the globe is now discussed.

IMPACT OF DROUGHTS AROUND THE GLOBE DURING RECENT DECADES IN ASIA

According to a recent IPCC study, production of rice, maize and wheat in the past few decades has declined in many parts of Asia due to increasing water stress, arising partly from increasing temperature, increasing frequency of El Niño events and reduction in the number of rainy days (Bates et al., 2008). For examples, during 1999–2000, up to 60 million people in Central and Southwest Asia were affected by a persistent multi-year drought, one of the largest from a global perspective (IRI, 2001), with Iran, Afghanistan, Western Pakistan, Tajikistan, Uzbekistan and Turkmenistan experiencing the most severe impacts.

In another example, frequent severe droughts in 1997, 1999 to 2002 in many areas of northern China caused large economic and societal losses (Zhang, 2003). In 2000, agricultural areas affected by droughts were estimated to exceed 40 million hectares. Because of droughts, water shortage, desertification, and dust storms accompanied the drying climate in both rural and urban areas. For instance, during 1972–1997, there were 20 years during which the Yellow River experienced drying-up (zero streamflow) episodes, and the earlier start time and longer periods of the drying-up have become more frequent since the early 1990s. The severe drought of 1997 in northern China resulted in a period of 226 days with no streamflow in the Yellow River, which is the longest drying-up duration on record. It is also observed that there has been an increased risk of droughts since the late 1970s, as global warming progresses and produces both higher temperatures and increased drying (Zou et al., 2005; Dai et al., 2004).

India is amongst the most vulnerable drought-prone countries in the world; a drought has been reported at least once in every three years in the last five decades. What is of concern is its increasing frequency. Since the mid-nineties, prolonged and widespread droughts have occurred in consecutive years, while the frequency of droughts has also increased in recent times (FAO, 2002; World Bank, 2003).

IMPACT OF DROUGHT: INDIAN SCENARIO

The disaster risks associated with drought is a recurrent feature in India. There are evidences of continuous famine for 12 years during 310–298 BC during the region of Chandra Gupta Maurya. During a severe drought in 1917–1918, the River Jhelum dried up completely in Kashmir¹. On an average, 28% of the geographical area of India is vulnerable to drought⁷. Meteorologically, $\pm 19\%$ deviation of rainfall from the long-term mean is considered 'normal' in India. Deficiency in the range 20–59% represents 'moderate' drought, and more than 60% is 'severe' drought⁷. Aberrations in the total volume and pattern of rainfall from the SW monsoon are primarily responsible for droughts in India. Studies have revealed that El Niño phase of the Southern Oscillation (ENSO) too has impacted droughts in India. The country has experienced 22 large-scale droughts; five of them were severe. The drought-prone areas are confined mainly to the peninsular and western parts of the country, and there are only few pockets in the central, eastern, northern and southern parts. These regions suffer drought mostly due to the cumulative effects of changing precipitation pattern, excessive water utilization and ecologically unsuitable agriculture practices¹. It has been reported that 26 mha (795 mha of geographical area) is subjected to different degrees of water stress and drought conditions, which includes 38.7 mha of arid areas and of 7 mha of cold deserts. About 107 mha of the country spread over administrative districts in several states is affected by drought

III. DROUGHTS AS NATURAL HAZARDS

A natural hazard is a threat of a naturally occurring event that will have a negative effect on people or the environment and drought is a kind of natural hazard which is further aggravated by growing water demand. The reasons for the occurrence of droughts are complex, because they are dependent not only on the atmosphere but also on the hydrologic processes which feed moisture to the atmosphere. Once dry hydrologic conditions are established the positive feedback mechanism of droughts sets in, where the moisture depletion from upper soil layers decreases evapotranspiration rates, which, in turn, lessen the atmospheric relative humidity. The lesser the relative humidity the less probable the rainfall becomes, as it will be harder to reach saturation conditions for a regular low pressure system over the region. Only

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Vol. 7, Issue 10, October 2018

disturbances which carry enough moisture from outside the dry region will be able to produce sufficient rainfall to end drought conditions (Bravar and Kavvas, 1991).

Droughts rank first among all natural hazards when measured in terms of the number of people affected (Obasi, 1994; Hewitt, 1997; Wilhite, 2000b). Although as a natural hazard, droughts differ from other natural hazards in several ways (Wilhite, 2000a). First, the onset and the end of a drought are difficult to determine, the impacts of a drought increase slowly, often accumulate over a considerable period and may linger for years after termination. Therefore, a drought is often referred to as a creeping phenomenon. Second, it is difficult to define a drought which leads to confusion for not having a universal definition of drought. Third, drought impacts are non-structural and spread over large geographical areas than damages that may result from other natural hazards. In contrast to floods, hurricanes, earthquakes, and tornadoes a drought affects water bodies of water resources structures and it seldom results in structural damage. For this reason, the quantification of the impact and the provision for relief are far more difficult for droughts than for other natural hazards (Wilhite, 2000a). Fourth, human activities can directly trigger a drought unlike other natural hazards, with exacerbating factors such as overfarming, excessive irrigation, deforestation, over-exploiting available water, and erosion, adversely impacting the ability of the land to capture and hold water.

Bryant (1991) ranked hazard events based on their characteristics and impacts. Key hazard characteristics used for ranking included the degree of severity, the length of event, total areal extent, total loss of life, total economic loss, social effect, long-term impact, suddenness, and occurrence of associated hazards. It was found that drought stood first based on most of the hazard characteristics. Other natural hazards, which followed droughts in terms of their rank, are tropical cyclones, regional floods, earthquakes, and volcanoes.

IV. TYPES OF DROUGHT INDICES

Several drought indices have been derived in recent decades. Commonly, a drought index is a prime variable for assessing the effect of a drought and defining different drought parameters, which include intensity, duration, severity and spatial extent. It should be noted that a drought variable should be able to quantify the drought for different time scales for which a long time series is essential. The most commonly used time scale for drought analysis is a year, followed by a month. Although the yearly time scale is long, it can also be used to abstract information on the regional behavior of droughts. The monthly time scale seems to be more appropriate for monitoring the effects of a drought in situations related to agriculture, water supply and ground water abstractions (Panu and Sharma, 2002). A time series of drought indices provides a framework for evaluating drought parameters of interest.

A number of different indices have been developed to quantify a drought, each with its own strengths and index (RAI; van Rooy, 1965), deciles (Gibbs and Maher, 1967), crop moisture index (CMI; Palmer, 1968), Bhalme and Mooly drought index (BMDI; Bhalme and Mooley, 1980), surface water supply index (SWSI; Shafer and Dezman, 1982), national rainfall index (NRI; Gommès and Petrassi, 1994), standardized precipitation index (SPI; McKee et al., 1993, 1995), and reclamation drought index (RDI; weaknesses. They include the Palmer drought severity index (PDSI; Palmer 1965), rainfall anomaly Weghorst, 1996). The soil moisture drought index (SMDI; Hollinger et al., 1993) and crop-specific drought index (CSDI; Meyer and Hubbard, 1995) appeared after CMI. Furthermore, CSDI is divided into a corn drought index (CDI; Meyer and Pulliam, 1992) and soybean drought index (SDI; Meyer and Hubbard, 1995), and vegetation condition index (VCI; Liu and Kogan, 1996). Besides these indices, indices of Penman (1948), Thornthwaite (1948, 1963), and Keetch and Byram (1968) have been used in limited cases (Hayes, 1996). Heim (2002) gave a comprehensive review of 20th century drought indices used in the United States.

Based on the studies for drought indices, practically all drought indices use precipitation either singly or in combination with other meteorological elements, depending upon the type of requirements, which were also suggested by WMO (1975). For example, a combination of hydrometeorological variables includes: temperature and precipitation (Marcovitch's index, 1930; Palmers index, 1965; Crop moisture index, 1968), precipitation and soil moisture (moisture adequacy index, 1957; Keetch-Bryam drought index, 1968) and only precipitation (SPI, 1993).

The following section discusses commonly used drought indices, their usefulness, and comparison between different indices.

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Visit: www.ijirset.com

Vol. 7, Issue 10, October 2018

STANDARDIZED PRECIPITATION INDEX

The standardized precipitation index (SPI) for any location is calculated, based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed to a normal distribution so that the mean SPI for the location and desired period is zero (McKee et al., 1993; Edwards and McKee, 1997). The fundamental strength of SPI is that it can be calculated for a variety of time scales. This versatility allows SPI to monitor short-term water supplies, such as soil moisture which is important for agricultural production, and long-term water resources, such as groundwater supplies, streamflow, and lake and reservoir levels. Soil moisture conditions respond to precipitation anomalies on a relatively short scale. Groundwater, streamflow, and reservoir storage reflect the long-term precipitation anomalies. For example, Szalai et al. (2000) examined how strong the connection of SPI is with hydrological features, such as streamflow and groundwater level at stations in Hungary. Correlation of SPI with streamflow was the highest on a 2-month timescale, while for groundwater levels the best correlations were found at widely different time scales. They also concluded that agricultural drought (proxied by soil moisture content) was replicated best by SPI on a scale of 2–3 months. SPI has been used for studying different aspects of droughts, for example, forecasting (Mishra and Desai, 2005a; Mishra et al. 2007), frequency analysis (Mishra et al. 2009), spatio temporal analysis (Mishra and Desai, 2005b; Mishra and Singh, 2009) and climate impact studies (Mishra and Singh, 2009).

PALMER DROUGHT SEVERITY INDEX (PDSI)

Using precipitation and temperature for estimating moisture supply and demand within a two-layer soil model, Palmer (1965) formulated what is now referred to as the Palmer drought index (PDI). This was the first comprehensive effort to assess the total moisture status of a region. Since its inception, some modified versions of PDSI have evolved. For example, Karl (1986) described a modified version known as the Palmer hydrological drought index (PHDI) which is used for water supply monitoring. For operational purposes, a real time version of PDSI, called modified PDSI (PDI), was introduced by Heddinghaus and Sahol (1991).

PDSI is perhaps the most widely used regional drought index for monitoring droughts. The index has been used to illustrate the areal extent and severity of various drought episodes (Palmer, 1967; Karl and Quayle, 1981) and to investigate the spatial and temporal drought characteristics (Lawson et al., 1971; Klugman, 1978; Karl and Koscielny, 1982; Diaz, 1983; Soule, 1993; Jones et al., 1996) as well as to explore the periodic behavior of droughts (Rao and Padmanabhan, 1984), monitoring hydrologic trends, crop forecasts, and assessing potential fire severity (Heddinghaus and Sahol, 1991), droughts over large geographic areas (Johnson and Kohne, 1993), and drought forecasting (Kim and Valdes, 2003; Özger et al., 2009).

STANDARDIZED RUNOFF INDEX (SRI)

This index is based on the concept of standardized precipitation index (SPI), discussed earlier. Shukla and Wood (2008) derived standardized runoff index (SRI) which incorporates hydrologic processes that determine the seasonal loss in streamflow due to the influence of climate. As a result, on month to seasonal time scales SRI is a useful complement to SPI for depicting hydrological aspects of droughts.

BASED ON REMOTE SENSING

The normalized difference water index (NDWI) is a more recent satellite-derived index from the NIR and short wave infrared (SWIR) channels that reflect changes in both the water content and spongy mesophyll in vegetation canopies. NDWI calculated from the 500-m SWIR band of MODIS has recently been used to detect and monitor the moisture condition of vegetation canopies over large areas (Xiao et al., 2002; Jackson et al., 2004; Maki et al., 2004; Chen et al., 2005; Delbart et al., 2005). Because NDWI is influenced by both desiccation and wilting of vegetative canopy, it may be a more sensitive indicator than normalized difference vegetation index (NDVI) for drought monitoring.

DROUGHT MONITORS (DM)

NOAA, USDA and national drought mitigation derived a weekly drought monitor (DM) product that incorporates climatic data and professional input from all levels (Svoboda, 2000). The key parameters are objectively scaled to five DM drought categories. The classification scheme includes categories D0 (abnormally dry area) to D4 (exceptional

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 10, October 2018

drought event, likened to a drought of record) and labels indicating the sectors being impacted by droughts (A for agricultural impacts, W for hydrological impacts, and F to indicate the high risk of wildfires). A limitation of DM lies in its attempt to show droughts at several temporal scales (from short term drought to long-term drought) on one map product (Heim, 2002).

COMPARISON OF DROUGHT INDICES

Several attempts have been made to compare indices to find the most suitable indices for specific objectives of drought monitoring. There has been a lot of comparison between SPI and PDSI for monitoring droughts. Some of the differences include: (i) special characteristics of PDI vary from site to site (example: USA case study by Guttman (1999)) while those of SPI do not vary from site to site. Also, PDI has a complex structure with an exceptionally long memory, while SPI is an easily interpreted, simple moving average process. Therefore, SPI can be used as the primary drought index, because it is simple, spatially invariant in its interpretation, and probabilistic, so it can be used in risk and decision analysis (Guttman, 1998). (ii) SPI is more representative of short-term precipitation than PDSI and thus is a better indicator for soil moisture variation and soil wetness (Sims et al., 2002). (iii) SPI is a better predictor of crop production, as it represents the moisture state of soil better (Quiring and Papakyriakou, 2003). (iv) SPI provides a better spatial standardization than does PDSI with respect to extreme drought events (Lloyd-Hughes and Saunders, 2002). (v) Based on 14 well-known drought indices using a weighted set of six evaluation criteria, Keyantash and Dracup (2002) found that SPI was a valuable estimator of drought severity. (vi) SPI detects the onset of a drought earlier than PDSI (a case study: Texas, by Hayes et al. (1999)).

Based on seven drought indices, Morid et al. (2006) compared the performances in the Tehran province of Iran. The indices included deciles index (DI), percent of normal (PN), standard precipitation index (SPI), China-Z index (CZI), modified CZI (MCZI), Z-Score, and effective drought index (EDI). The results showed that SPI, CZI and Z-Score performed similarly with regard to drought identification and responded slowly to drought onset. DI appears to be very responsive to rainfall events of a particular year, but it has inconsistent spatial and temporal variation. SPI and EDI have been found to be able to detect the onset of a drought, its spatial and temporal variation consistently and EDI has been found to be more responsive to the emerging drought and perform better.

It can be inferred from the above discussion that the performance of drought indices is region specific. This is due to the variability in meteorological variables as well as streamflow characteristics which are generally used for deriving indices..

V. USE OF PALEOCLIMATOLOGY IN DROUGHT STUDIES

Paleoclimatology is the study of climate considered on the scale of the entire history of earth. It uses records from ice sheets, tree rings, sediments, and rocks to determine the past state of the climate system on earth. Paleoclimatic data offer a way to evaluate the severity, duration, and extent of twentieth-century droughts in the context of the past two millennia (e.g., Overpeck, 1996). The following section discusses different techniques of the use of paleoclimatic data for understanding the historical drought of a region.

TREE RING RECONSTRUCTION FOR DROUGHT STUDIES

Paleoclimatology studies, and especially dendroclimatology (it is the science of determining past climates from tree rings), form a valuable source of information for analyzing drought recurrences. Tree rings probably offer the best means of reconstructing large scale and highly resolved patterns of climate (Fritts, 1991; Cook and Kairiukstis, 1990). For example, Woodhouse and Overpeck (1998) reviewed a wide range of the paleoclimatic literature, including a variety of data sources like tree-ring data and instrumental records, and suggested that droughts more severe than those of the 1930s and 1950s, which had the most severe impact on the continental United States, were likely to occur in the future. Also, there is evidence for multidecadal droughts during the late thirteenth and sixteenth centuries that were of much greater severity and duration than those of the twentieth century (Woodhouse and Overpeck, 1998). Another example includes: Gedalof et al. (2004) used a network of 32 drought sensitive tree-ring chronologies to reconstruct mean water year flow on the Columbia River at Dalles, Oregon, since 1750. Their findings suggest that the relationship between drought and streamflow has changed over time.

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Visit: www.ijirset.com

Vol. 7, Issue 10, October 2018

Tree-ring data have been employed to formulate yearly time series relationships with drought indices, PDSI, PHDI, and ZNDX. As an example, Cook et al. (1999) described the development of summer drought reconstructions using PDSI for the continental United States at a 2° latitude × 3° longitude grid estimated from a dense network of annual tree-ring chronologies. In China Li et al. (2007) presented drought reconstruction for Northcentral China based on PDSI. Recently, well verified tree-ring based reconstructions have been undertaken in USA, for example, for the Sacramento River basin (Meko et al., 2001), the Gila River (Meko and Graybill, 1995), Crater Lake (Peterson et al., 1999), the Colorado River (Hidalgo et al., 2001). Oceanic and atmospheric anomalies, whereas the 1970–1988 droughts are associated with global tropical oceanic and atmospheric conditions mainly linked to ENSO.

VI. DROUGHT MANAGEMENT AND CHALLENGES

Unsustainable land and water management practices are the main culprits of drought intensification in both developing and developed nations. In many situations, drought assistance or relief measures provided by governments and donor agencies exacerbate the societal vulnerability to drought and also move societies away from their traditional wisdom and pro-active risk management approach, making people more dependent on externalities. The goal of risk management is to promote adoption of preventive or risk-reducing mechanisms and strategies that will mitigate the impacts of future drought events, and thereby reducing societal vulnerability. This paradigm shift in disaster management emphasizes preparedness, mitigation and improved EWS over emergency response and relief assistance. Thus, the role of science and technology in sustainable drought management needs to be propagated and popularized. A drought management strategy consists of the following components

Weather and communication satellites | Spectral band Tiros-N NOAA – 6, 8, 10 NOAA – 7, 9, d, H, I, J

(A) METEOROLOGICAL SATELLITE

1 0.55–0.90 0.58–0.68 0.58–0.682 0.725–1.00 0.725–1.003 3.55–3.93 3.55–3.934 10.50–11.50 10.50–11.505 Nil 11.50–12.50

Altitude resolution 833–870 km Image swath width Large area coverage – 1 km; Global area coverage – 4 km Repeat coverage 2253 km TIROS (USA) 1965 Daily world wide MIBUS 1964–1978 Measurement and picture transmission NOAA Night-time picture, TV coverage and 24 h weather Geo-stationary Severe storm support, geo-stationary, atmospheric condition Operational environmental satellite Rainfall, volcanic eruption, fire detection, oceanography

(B) COMMUNICATION SATELLITE

Satellite: Functions: Strays WordStar Global message/position services Teledesic-LEO Iridium High-speed computer link

INSAT 2E (Launch) 2A 10-7-1992 Communication 12-transponders normal C2B 23-7-1993 5-transponders lower C2C 7-10-1995 INSAT 1-9903A 2000-2001

DROUGHT ASSESSMENT

This can be done either by monitoring the drought causing conditions or by predicting and forecasting the weather conditions.

MONITORING: Technical/scientific means of monitoring are necessary to provide early warning of droughts and to also provide an objective and transparent definition of droughts to be used in the allocation of resources. But, at present the use of information available is partial and unsystematic. It requires strengthening of the institutional relationship between early warning and decision making

PREDICTABILITY: As drought is very much linked with the performance of the monsoon, it can be predicted by monitoring rainfall over the target region and taking into account previous rainfall history of the monsoon seasons.

Vulnerability analysis: Vulnerability expresses the degree of susceptibility to a hazard. Its analysis bridges the gap between impact assessment and policy formulation by directing attention to the underlying causes rather than post-disaster impacts. Vulnerability to drought is dynamic and is influenced by a multitude of factors, including population

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Vol. 7, Issue 10, October 2018

growth and regional shifts in population, urbanization, technology, government policies, land use and other natural resource management practices, desertification processes that reduce the productivity and the natural resource base, water use trends, and level of environmental awareness. Individually, these factors are important because they may increase or decrease vulnerability.

EARLY WARNING SYSTEM: The objective of designing a EWS is to keep track of leading indicators (agro-climatic, market socio-economic indicators and late anthropometric indicators) to get ample lead-time to intervene at the drought onset phase itself. However, most interventions based on late indicators force the governments to adopt a crisis management approach to deal with drought-induced food insecurity stresses. There are many deficiencies in this approach, as it does not reduce vulnerability to drought in the long run. The effective warning systems should have meteorological/agricultural information, production estimates, price trends of food and feed, availability of drinking water and household vulnerability, so that a variety of indices related to production, exchange and consumption could be addressed.

VII. CONCLUSIONS

In view of four types of droughts which include meteorological, hydrological, agricultural and socio-economic droughts, it will be appropriate to introduce groundwater drought as another important type of drought. Understanding a groundwater drought will remain a challenge for water resources planners. This is because of large exploitation of groundwater due to limited surface water as well as understanding complicated hydrogeological processes with respect to the change in the dynamics of hydro-meteorological variables with changes in land cover.

There is a continuous effort going on to derive efficient drought indices with the hope of better monitoring drought conditions which can be useful for early warning as well as to derive better drought parameters. It is observed that drought indices can only reflect drought conditions based on hydro-meteorological variables but it is unable to quantify the economic losses. There is room to improve drought indices further to get better information. Drought indices can be explored further, considering needs of the user in the region and classifying droughts based on their severity. For example, with a similar amount of annual precipitation in two regions one with lower population and the other higher population, it is obvious that a region with higher population will be more susceptible to drought. However, when the drought conditions are defined based on precipitation then the derived drought indices will reflect similar droughts in both regions, however it is not so in actual conditions. Therefore, the water demand of the region needs to be incorporated in drought indices.

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Vol. 7, Issue 10, October 2018

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Vol. 7, Issue 10, October 2018

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