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Cover illustration: Maasai tribesman walking through drought-stricken landscape, Kenya. © Jonathan and Angela (Getty Images)

NOTE

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FOREWORD

Throughout the course of human history, drought has been a problem affecting our welfare and food security. Of all human endeavours, agriculture was perhaps the first sector for which humans recognized the strong relationships between crops and weather. Short-term rainfall deficits prompted early humans to find alternative food crops. However, even a single year with a severe drought during the rainy season resulted in crop failures, which most likely led to humans migrating to other areas. Therefore, in early human history, even limited droughts had large impacts.

In recent times, short-term drought adaptation mechanisms have improved, but extended periods of drought are now the main concern for human welfare and food security. These periods of dryness, when coupled with other climatic factors, such as extreme rainfall and wind events or unsustainable agricultural and development patterns, can result in land degradation and, if unchecked, in increases in desert land areas or desertification. During the 1970s and 1980s, West Africa experienced an extended period of drought that led to widespread concern about these issues. The aggregate impact of drought can be quite negative on the economies of developing countries, in particular. For example, GDP fell by 8 to 9 per cent in Zimbabwe and Zambia in 1992 and 4 to 6 per cent in Nigeria and Niger in 1984. Over 250 million people are directly affected by land degradation and desertification. In addition, some one billion people in over 100 countries are at risk. They include many of the world's poorest and most marginalized citizens. Hence, combating desertification is an urgent priority in the global efforts to ensure food security and the livelihoods of millions of people who inhabit the drylands.

As vulnerability to drought has increased globally, greater attention has been directed to reducing the risks associated with its occurrence through the introduction of planning to enhance operational capabilities such as climate and water supply monitoring and building institutional capacity, and mitigation measures that are aimed at reducing the impacts of drought.

Important components of effective drought management are improved drought monitoring and early warning systems. The fight against drought and desertification receives a high priority in WMO's Strategic Plan, particularly under the Agricultural



M. Jarraud, Secretary-General

Meteorology Programme, the Hydrology and Water Resources Programme and the Technical Cooperation Programme. WMO actively involves the National Meteorological and Hydrological Services (NMHSs), the regional and sub-regional meteorological centres and other bodies in the improvement of hydrological and meteorological networks for systematic observations and exchange and analysis of data. WMO also works closely with other UN agencies and international organizations to develop long-term strategies aimed at promoting meteorological and hydrological activities that contribute to better drought monitoring and use of medium- and long-range weather forecasts and to assist in the transfer of knowledge and technology.

At its 58th ordinary session, the United Nations General Assembly declared 2006 to be the International Year of Deserts and Desertification (IYDD). In doing so, the General Assembly underlined its deep concern for the exacerbation of desertification, particularly in Africa, and noted its far-reaching implications for the implementation of the Millennium Development Goals (MDGs), which are to be met by the year 2015. The IYDD presents a golden opportunity to convey the message strongly and effectively in the sense that issues of drought, land degradation and desertification are global problems that must be addressed. It also provides an impulse to strengthen the visibility and importance of the drylands issue on the international environmental agenda, while providing a timely

reminder to the international community of the huge challenges that still lie ahead.

The United Nations Convention to Combat Desertification (UNCCD) and WMO have been longstanding partners in developing and promoting the issues related to drought monitoring, preparedness, mitigation, land degradation and desertification. As part of its implementation activities for IYDD, WMO has prepared this brochure to explain the various concepts and challenges of drought monitoring and early warning systems. This brochure also details the considerable progress that has been made on these issues in some drought-prone countries by highlighting several case studies from around the world.

I wish to thank Mr Donald Wilhite, Director of the National Drought Mitigation Center and Professor of the School of Natural Resources of the University of Nebraska (USA), for preparing this informative brochure. We hope that this document will be useful to countries looking to develop or enhance their own drought monitoring and early warning capabilities.



(M. Jarraud)
Secretary-General

INTRODUCTION

Drought is an insidious natural hazard characterized by lower than expected or lower than normal precipitation that, when extended over a season or longer period of time, is insufficient to meet the demands of human activities and the environment. Drought is a temporary aberration, unlike aridity, which is a permanent feature of climate. Seasonal aridity, that is, a well-defined dry season, also needs to be distinguished from drought, as these terms are often confused or used interchangeably. The differences need to be understood and properly incorporated in drought monitoring and early warning systems and preparedness plans.

Drought must be considered a relative, rather than an absolute, condition. It occurs in both high and low rainfall areas and virtually all climate regimes. Drought is often associated only with arid, semi-arid and sub-humid regions by scientists, policymakers and the public. In reality, drought occurs in most countries, in both dry and humid regions. Drought is a normal part of climate, although its spatial extent and severity will vary on seasonal and annual time-scales. In many countries, such as Australia, China, India and the United States of America, drought occurs over a portion of the country each year. Owing to the frequent occurrence of drought and the profound impacts associated with it, governments should devote more attention to the development of

a national strategy or policy to reduce its economic, social and environmental consequences. A critical component of that strategy is a comprehensive drought monitoring system that can provide early warning of drought's onset and end, determine its severity and deliver that information to a broad clientele in many climate- and water-sensitive sectors in a timely manner. With this information, the impacts of drought can be reduced or avoided in many cases.

Drought is a regional phenomenon and its characteristics differ from one climate regime to another. A few examples of the contrasting temperature and precipitation regimes of various regions are shown in Figure 1. Drought occurs in each of these locations, but characteristics such as frequency and duration vary appreciably. New Delhi's precipitation pattern is distinctly monsoonal, with maximum precipitation occurring from June to October, with the greatest concentration in July, August and September. Tunis has a distinctly Mediterranean-type (dry summer) climate regime. Nairobi's precipitation distribution is distinctly bi-modal, with peak rainfall expected from March through May and a second concentration in November and December. London's precipitation is evenly distributed throughout the year. In each example, a significant departure from these regimes for an extended period of time will result in impacts in climate- and water-sensitive sectors. Impacts are also



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regional in nature, reflecting exposure to the hazard and the vulnerability of society to extended periods of precipitation deficits. Impacts are a measure of vulnerability. Risk is a product of exposure to the hazard and societal vulnerability.

Drought by itself is not a disaster. Whether it becomes a disaster depends on its impact on local people, economies and the environment and their ability to

cope with and recover from it. Therefore, the key to understanding drought is to grasp its natural and social dimensions. The goal of drought risk management is to increase society's coping capacity, leading to greater resilience and a reduced need for government or donor interventions in the form of disaster assistance. Drought monitoring and early warning are major components of drought risk management.

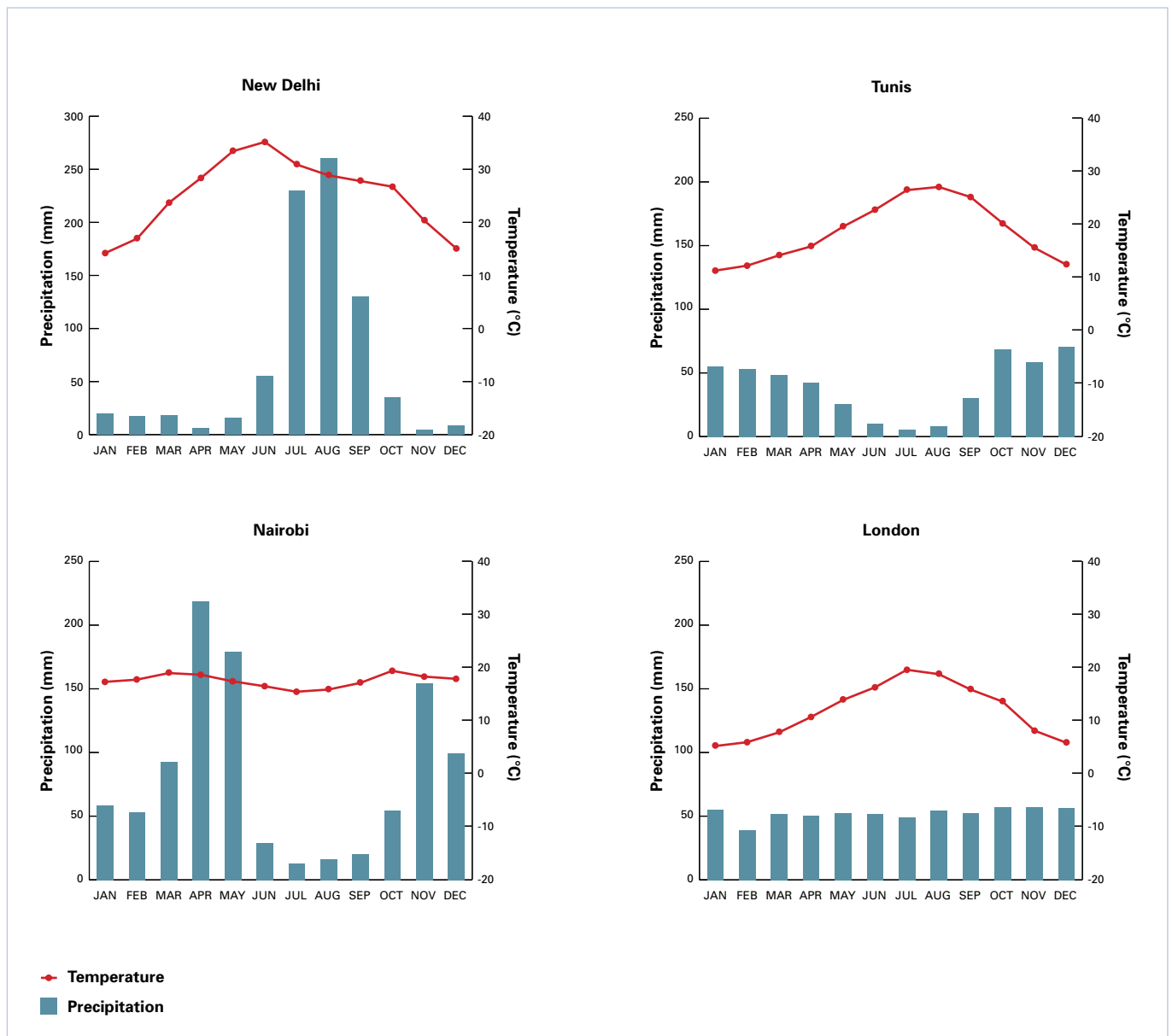


Figure 1. Climographs illustrating monthly temperature and precipitation regimes for New Delhi, Tunis, Nairobi and London. (Source: National Drought Mitigation Center, University of Nebraska–Lincoln, USA)

DROUGHT AS A HAZARD: CONCEPTS AND DEFINITIONS

Drought differs from other natural hazards in various ways. Drought is a slow-onset natural hazard that is often referred to as a creeping phenomenon. It is a cumulative departure from normal or expected precipitation, that is, a long-term mean or average. This cumulative precipitation deficit may build up quickly over a period of time, or it may take months before the deficiency begins to appear in reduced stream flows, reservoir levels or increased depth to the groundwater table. Owing to the creeping nature of drought, its effects often take weeks or months to appear (Figure 2). Precipitation deficits generally appear initially as a deficiency in soil water; therefore, agriculture is often the first sector to be affected.

It is often difficult to know when a drought begins. Likewise, it is also difficult to determine when a drought is over and according to what criteria this determination should be made. Is an end to drought heralded by a return to normal precipitation and, if so, over what period of time does normal or above normal precipitation need to be sustained for the

drought to be declared officially over? Since drought represents a cumulative precipitation deficit over an extended period of time, does the precipitation deficit need to be erased for the event to end? Do reservoirs and groundwater levels need to return to normal or average conditions? Impacts linger for a considerable period of time following the return of normal precipitation. Therefore, is the end of drought signalled by meteorological or climatological factors, or by the diminishing negative impact on human activities and the environment?

Another factor that distinguishes drought from other natural hazards is the absence of a precise and universally accepted definition. There are hundreds of definitions, adding to the confusion about the existence of drought and its degree of severity. Definitions of drought should be region and application specific or impact specific. Droughts are regional in extent and, as previously stated, each region has specific climatic characteristics. Droughts that occur in the North American Great Plains will differ from

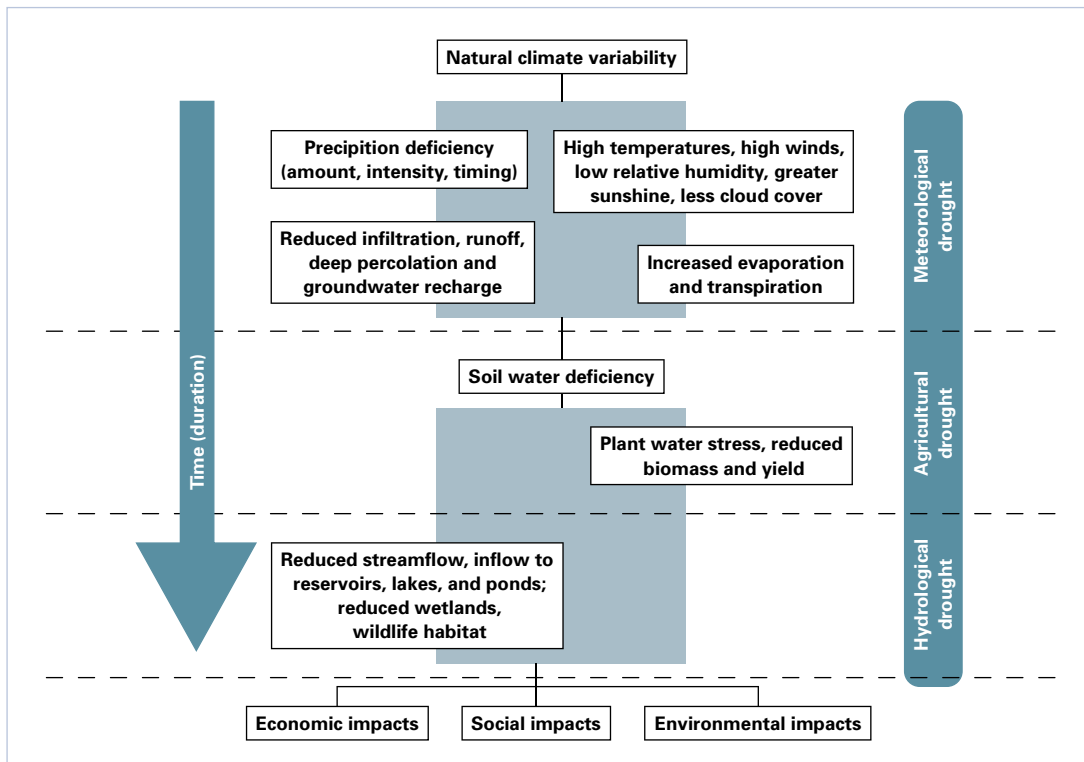


Figure 2. Sequence of drought occurrence and impacts for commonly accepted drought types. All droughts originate from a deficiency of precipitation or meteorological drought but other types of drought and impacts cascade from this deficiency. (Source: National Drought Mitigation Center, University of Nebraska–Lincoln, USA)



those in Northeast Brazil, southern Africa, Western Europe, eastern Australia or the North China Plain. The amount, seasonality and form of precipitation differ widely between each of these locations.

Temperature, wind and relative humidity are also important factors to include in characterizing drought from one location to another. Definitions also need to be application specific because drought impacts will vary between sectors. Drought conjures different meanings for water managers, agricultural producers, hydroelectric power plant operators and wildlife biologists. Even within sectors, there are many different perspectives of drought because impacts may differ markedly. For example, the effects of drought on crop yield may vary considerably for maize, wheat, soybeans and sorghum because they are planted at different times during the growing season and do not have the same water requirements

and sensitivities to water and temperature stress at various growth stages.

Drought impacts are non-structural and extend over a larger geographical area than damages that result from other natural hazards such as floods, tropical storms and earthquakes. This, combined with drought's creeping nature, makes it particularly challenging to quantify impacts and even more challenging to provide disaster relief for drought than for other natural hazards. These characteristics have hindered the development of accurate, reliable and timely estimates of the severity and impacts, such as drought early warning systems and ultimately, the formulation of drought preparedness plans. Similarly, it is difficult for disaster officials tasked with responding to drought to deal with the large spatial coverage usually associated with its occurrence.

TYPES OF DROUGHT

Droughts are commonly classified by type as meteorological, agricultural, hydrological and socio-economic.

Meteorological drought is usually defined by a precipitation deficiency threshold over a predetermined period of time. The threshold chosen, such as 75 per cent of normal precipitation, and duration period, for example, six months, will vary by location according to user needs or applications. Figure 3 illustrates three characterizations of drought for three different countries based on precipitation departures from normal, deciles and the Standardized Precipitation Index (SPI). Meteorological drought is a natural

event and results from multiple causes, which differ from region to region. Agricultural, hydrological and socio-economic drought, however, place greater emphasis on the human or social aspects of drought, highlighting the interaction or interplay between the natural characteristics of meteorological drought and human activities that depend on precipitation to provide adequate water supplies to meet societal and environmental demands.

Agricultural drought is defined more commonly by the availability of soil water to support crop and forage growth than by the departure of normal precipitation over some specified period of time. There

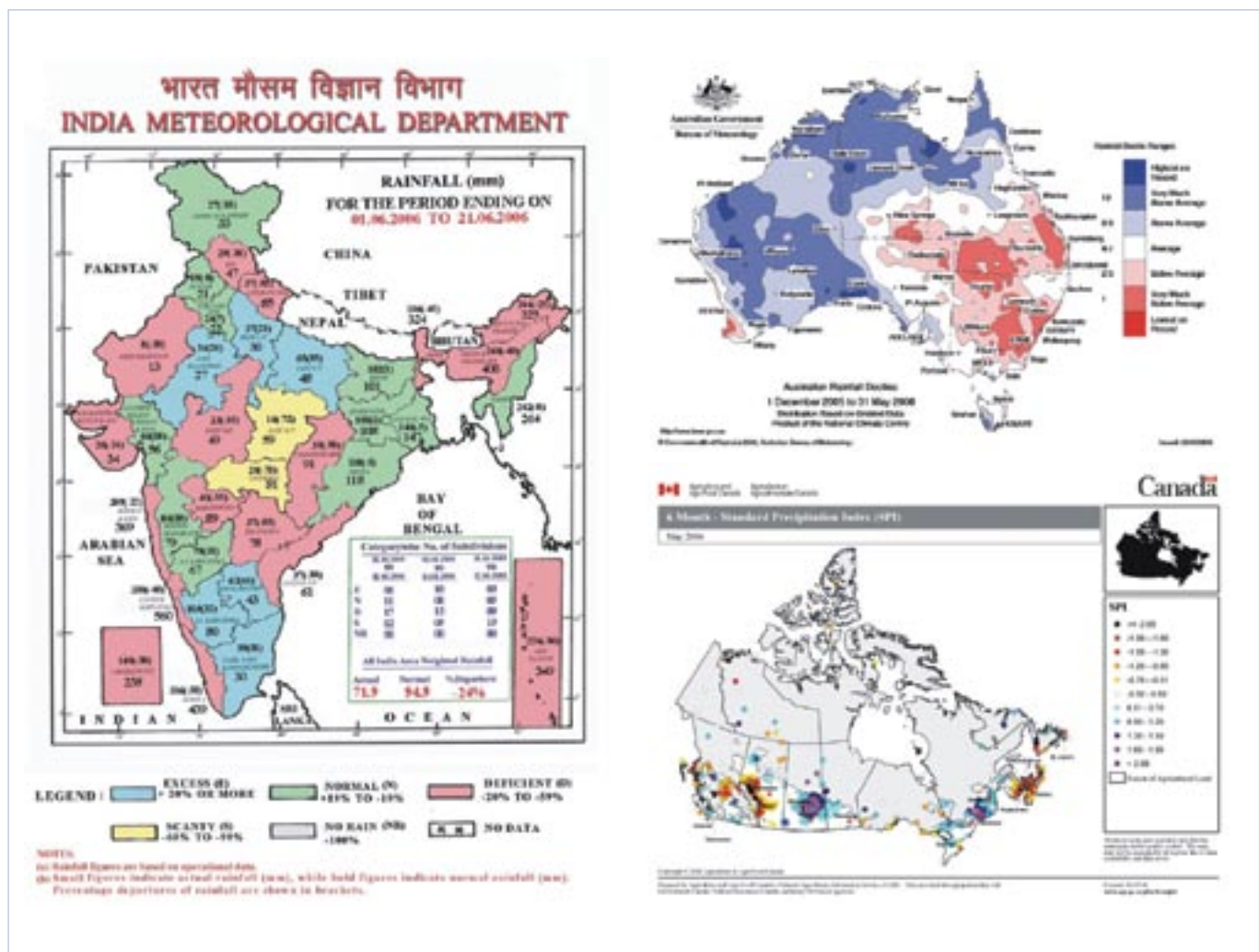


Figure 3. Meteorological drought expressed as percentage departure from normal precipitation for India, precipitation deciles for Australia and the Standardized Precipitation Index for Canada. (Sources: Indian Meteorological Department, Australian Bureau of Meteorology and Prairie Farm Rehabilitation Administration and Agriculture Canada, respectively)



is no direct relationship between precipitation and infiltration of precipitation into the soil. Infiltration rates vary, depending on antecedent moisture conditions, slope, soil type and the intensity of the precipitation event. Soil characteristics also differ: some soils have a high water-holding capacity while others do not. The latter are more prone to agricultural drought.

Hydrological drought is even further removed from the precipitation deficiency since it is normally defined by the departure of surface and subsurface water supplies from some average condition at various points in time. Like agricultural drought, there is no direct relationship between precipitation amounts and the status of surface and subsurface water supplies in lakes, reservoirs, aquifers and streams because these hydrological system components are used for multiple and competing purposes, such as irrigation, recreation, tourism, flood control, transportation, hydroelectric power production, domestic water supply, protection of endangered species and environmental and ecosystem management and preservation. There is also a considerable time lag between departures of precipitation and the point at which these deficiencies become evident in surface and subsurface components of the hydrologic system. Recovery of these components is slow because of long recharge periods for surface and subsurface water supplies. In some drought-prone areas, such as the western United States, snow pack accumulated during the winter months is the primary source of water during the summer. Reservoirs increase the resilience of this region to drought because of their ability to store large amounts of water as a buffer during single- or multi-year drought events.

Socio-economic drought differs markedly from the other types of drought because it reflects the relationship between the supply and demand for some commodity or economic good, such as water, livestock forage or hydroelectric power, that is dependent on precipitation. Supply varies annually as a function of precipitation or water availability. Demand also fluctuates and is often associated with a positive trend as a result of increasing population, development or other factors.

The interrelationship between these types of drought is illustrated in Figure 4. Agricultural, hydrological and socio-economic drought occur less frequently than meteorological drought because impacts in these

sectors are related to the availability of surface and subsurface water supplies. It usually takes several weeks before precipitation deficiencies begin to produce soil moisture deficiencies leading to stress on crops, pastures and rangeland. Continued dry conditions for several months at a time bring about a decline in stream flow and reduced reservoir and lake levels and, potentially, a lowering of the groundwater table. When drought conditions persist for a period of time, agricultural, hydrological and socio-economic drought occur, producing associated impacts. During drought, not only are inflows to recharge surface and subsurface supplies reduced but demand for these resources increases dramatically as well. As shown in Figure 4, the direct linkage between the main types of drought and precipitation deficiencies is reduced because water availability in surface and subsurface systems is affected by how these systems are managed. Changes in the management of these water supplies can either reduce or aggravate the impacts of drought. For example, the adoption of appropriate tillage practices and planting more drought-resistant crop varieties can diminish the impact of drought significantly by conserving soil water and reducing transpiration.

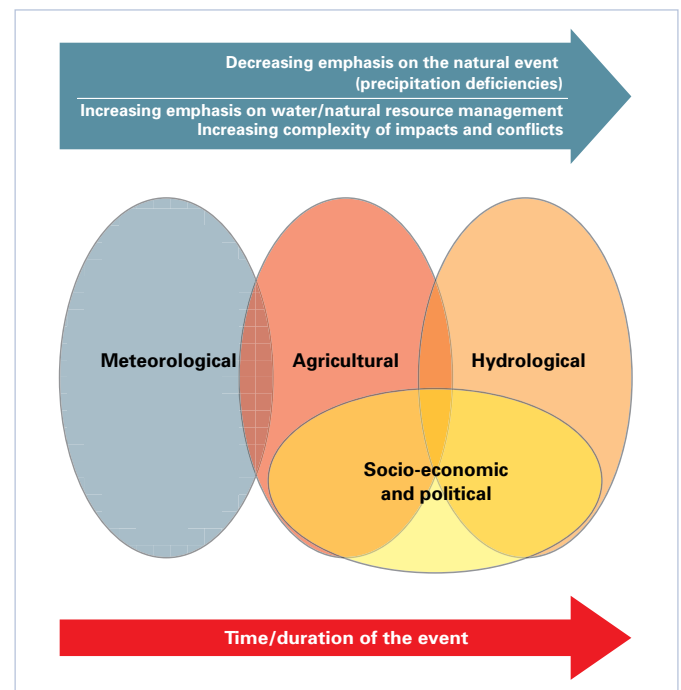


Figure 4. Interrelationships between meteorological, agricultural, hydrological and socio-economic drought. (Source: National Drought Mitigation Center, University of Nebraska–Lincoln, USA)

CHARACTERIZING DROUGHT AND ITS SEVERITY

Droughts have three distinguishing features: intensity, duration and spatial coverage. Intensity refers to the degree of the precipitation shortfall and/or the severity of impacts associated with the shortfall. It is generally measured by the departure from normal of a climatic parameter such as precipitation, an indicator such as the reservoir level or an index such as SPI.

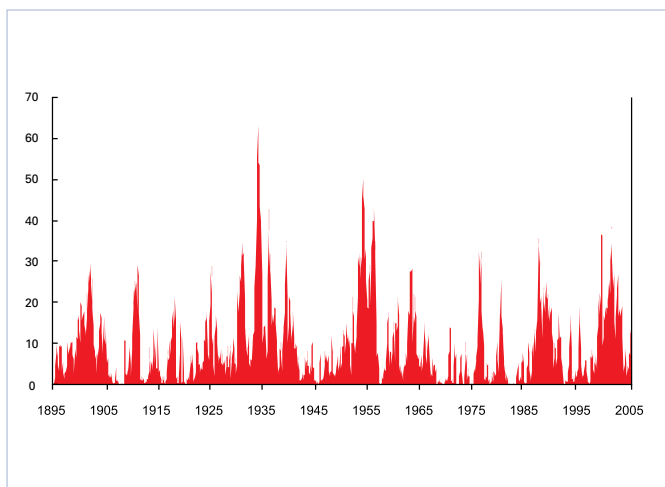


Figure 5. Percentage of the United States affected by severe to extreme drought, January 1895 to May 2006. (Source: National Drought Mitigation Center, University of Nebraska–Lincoln, USA; based on data from the National Climatic Data Center/NOAA)

Another essential characteristic of drought is its duration. Droughts can develop quickly in some climatic regimes, but usually require a minimum of two to three months to become established. Once a drought begins, it can persist for months or years. The magnitude of drought impacts is closely related to the timing of the onset of the precipitation shortage, its intensity and the duration of the event. For example, a dry winter may have few impacts in many middle latitude, temperate climates because of the reduced demand for water during those months. Developing a better understanding of the frequency, duration and spatial extent of drought from the paleo-record, for example, tree rings or lake sediments, can be very instructive because it provides planners with critically important information from periods outside of the instrumental period of record.

Droughts also differ in their spatial characteristics. The areas affected by severe drought evolve gradually, and regions of maximum intensity, such as epicentres, shift from season to season and year to year in the event of multi-year droughts. In larger countries, such as Brazil, China, India, the United States or Australia, drought would rarely, if ever, affect the entire country. During 1934, one of the most severe drought years in United States' history, 65 per cent of the country was affected by severe or extreme drought (Figure 5). That was the maximum spatial extent of drought between 1895 and 2005.



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THE CHALLENGES OF DROUGHT MONITORING AND EARLY WARNING

A drought early warning system is designed to identify climate and water supply trends and thus to detect the emergence or probability of occurrence and the likely severity of drought. This information can reduce impacts if delivered to decision makers in a timely and appropriate format and if mitigation measures and preparedness plans are in place. Understanding the underlying causes of vulnerability is also an essential component of drought management because the ultimate goal is to reduce risk for a particular location and for a specific group of people or economic sector.

There are numerous natural drought indicators that should be monitored routinely to determine the onset and end of drought and its spatial characteristics. Severity must also be evaluated on frequent time steps. Although all types of droughts originate from a precipitation deficiency, it is insufficient to rely solely on this climate element to assess severity and resultant impacts because of factors identified

previously. Effective drought early warning systems must integrate precipitation and other climatic parameters with water information such as stream flow, snow pack, groundwater levels, reservoir and lake levels, and soil moisture into a comprehensive assessment of current and future drought and water supply conditions.

Monitoring drought presents some unique challenges because of its distinctive characteristics. Some of the most prominent challenges are as follows:

- Meteorological and hydrological data networks are often inadequate in terms of the density of stations for all major climate and water supply parameters. Data quality is also a problem because of missing data or an inadequate length of record;
- Data sharing is inadequate between government agencies and research institutions, and the high cost of data limits their application in drought monitoring, preparedness, mitigation and response;
- Information delivered through early warning systems is often too technical and detailed, limiting its use by decision makers;
- Forecasts are often unreliable on the seasonal timescale and lack specificity, reducing their usefulness for agriculture and other sectors;
- Drought indices are sometimes inadequate for detecting the early onset and end of drought;
- Drought monitoring systems should be integrated, coupling multiple climate, water and soil parameters and socio-economic indicators to fully characterize drought magnitude, spatial extent and potential impact;
- Impact assessment methodologies, a critical part of drought monitoring and early warning systems, are not standardized or widely available, hindering impact estimates and the creation of regionally appropriate mitigation and response programmes;
- Delivery systems for disseminating data to users in a timely manner are not well developed, limiting their usefulness for decision support.



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