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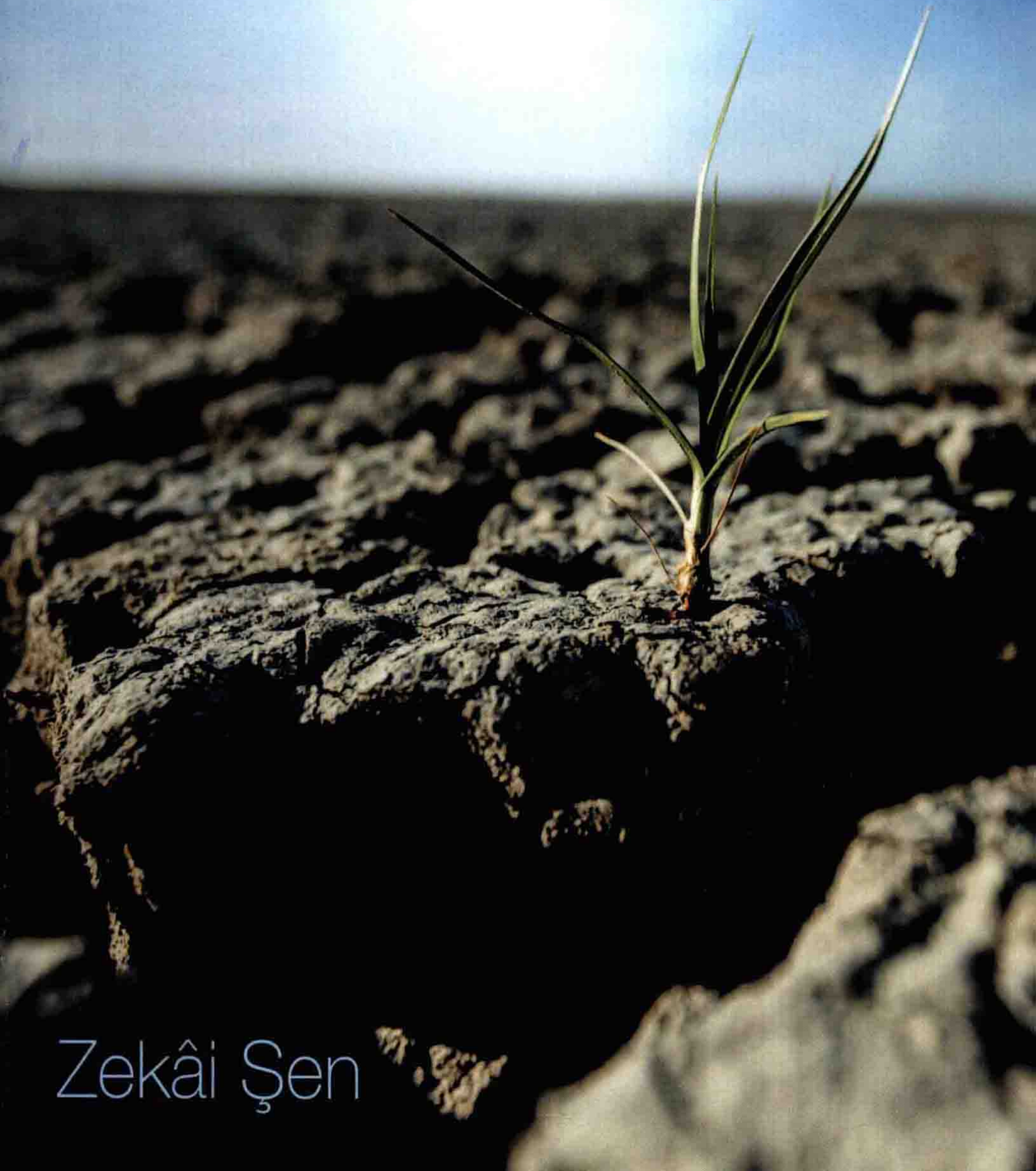
Applied Drought Modeling, Prediction, and Mitigation



Zekâi Şen

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By

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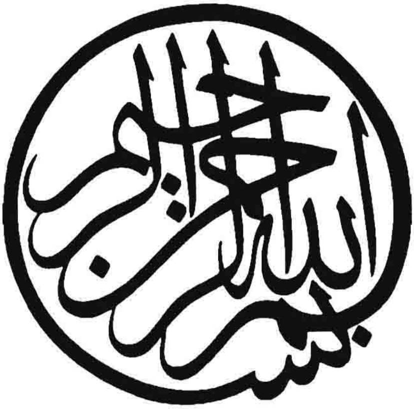
Dedication



Noah phenomenon—(great flood, wet spell)

Joseph phenomenon—(drought, dry spell)

There is sensitive balance in nature as a sequence of dry and wet periods, which needs care for their preservations without destroying the balance in the environment. This book is dedicated to those who care for such a balance by logical, rational, scientific, and ethical applications for the sake of other living creatures' rights.

Preface

The sustainability of any society is dependent on different precious material resources such as water, energy, and technology, which must be traced by modern scientific research work outputs application so as not to meet with any restrictive, shortage, stress, or scarcity situations. Among the natural hazards phenomena, the most effective one for the long run is the continuation of dry spells (water demand deficiency), which occurs in the form of drought and leaves different imprints on the society at large. Droughts have a gradual "creeping" feature, with slow developments and prolonged effects on the daily activities of human life.

In general, settlers in humid regions have high confidence in their water resources supply and, therefore, they may not feel water scarcity impacts in time. Consequently, droughts may be more harmful in humid regions than arid regions. Accordingly, especially agricultural investments may be inflicted at maximum harm rates as a result of unexpected drought periods. Among the primary drought hazards are crop yield, animal husbandry, hydroelectric energy generation, reductions and decrease in industrial products, and navigation problems in low river flows. On the other hand, secondary effects include soil erosion, dust storms, forest fires, increase in plant diseases, insect hurdle, decrease in social and individual health, pollution concentration increase, deterioration in water quality, and so forth. In the literature simple drought descriptors are presented based on a single or few hydrometeorological variables such as rainfall, precipitation, solar irradiation, and wind speed. Rather than their individual applications, their joint assessments are given for the first time in this book by statistical ensemble averages and fuzzy inference system approaches. All of these indicate the importance of drought preparedness, early warning, proper drought modeling, and appropriate predictions. In this book the list of economic, environmental, and social drought impacts are explained in detail, and it gives the impression that there is no sector that may be safe from drought implications.

The most significant part of drought identification, assessment, and prediction studies is the modeling procedures that furnish the foundation for proper strategic planning, management, application, and implementation of output principles in a society prior the next drought occurrence. This book presents innovative drought modeling procedures by taking into consideration the inherent uncertainty feature in drought evolution. To account objectively for the uncertainty, probabilistic, statistical, stochastic, and fuzzy methodologies are employed with a set of simplifying assumptions. The necessary formulations and their quantitative applications through numerical solution approaches are presented for temporal and spatial drought durations, total end average deficits, and intensity with the necessary areal coverage extension formulations.

Drought events are explained in the last two chapters from the climate change and mitigation points of view with an emphasis on water resources supply and demand patterns, rainfall and runoff harvestings, groundwater recharge possibilities, and proper risk and hazard management points of view. As one of the mitigation procedures, weather modification and its application in Istanbul City, Turkey, is explained with some new formulations and it is recommended that at its present scientific level the weather modification (cloud seeding) procedures are not successfully applicable; therefore, cloud seeding must remain in the scientific research domain without practical, fruitful outputs. Different engineering structural drought combat procedures are explained and a list of recommendations for drought mitigation is provided.

The author has gained vast experience during a long stay as a staff member at the King Abdulaziz University Faculty of Earth Sciences and recently at the Faculty of Meteorology and Arid Lands, Excellency Center for Climate Change Research, Jeddah, Kingdom of Saudi Arabia. He became acquainted with different desertification, drought, groundwater recharge, water harvesting, and hydrogeological water management procedures and strategies and published numerous papers in top scientific journals. Another part of his extensive experience comes from meteorology, hydrology, and hydraulic studies at the Technical University of Istanbul, Turkey, in addition to the Turkish Water Foundation concerning the conjunctive and separate surface and groundwater resources under uncertainty principles and scientific modeling studies leading to predictions. His long experience for about 5 years in the workgroup of the Intergovernmental Panel on Climate Change (IPCC), as the freshwater resources chapter lead author provided a global picture and scientific views about possible climate change impacts on precious water resources including vulnerability, combat, and mitigation.

Most of the content of this book includes experience gained during the stay of the author in the Kingdom of Saudi Arabia; hence, he would like to extend his cordial appreciation to his colleagues at different faculties at the King Abdulaziz University and to its high-level administrators. The author would like to extend his appreciation to the Saudi Geological Survey (SGS), Jeddah, and Prince Sultan Research Center for Environment, Water, Desert, King Saud University, Riyadh, where he also gained experience. Similar gratefulness is also extended to the Turkish Water Foundation and Istanbul Technical University, and to those who made constructive suggestions during the preparation of this book.

I wrote several books in Turkish, English, and Arabic and many scientific papers, but nothing gives me the happiness as being at the service of people who seek scientific knowledge and information. Any fruitful impact of this book will make the author spiritually very content and happy. Finally, whatever my achievements, under their foundations is the patience and continuous support of my wife Fatma Şen, who deserves thanks from the bottom of my heart.

Zekâi Şen
Erenköy, Istanbul, Turkey
March 13, 2015

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Introduction

CHAPTER OUTLINE

1.1 GENERAL

Water is a major essential commodity for the survival of all living creatures. Life sustainability is not possible without it. Abundance of water brings comfort, whereas in its scarceness life becomes miserable. Human beings are dependent on water in almost every activity within the environment. If water is scarce or not available in sufficient quantities at a location, then human beings migrate to better water resources locations, which are riverbanks, lakes, seashores, oases, or shallow groundwater reservoirs. Evolution and development of any civilization has roots in water-related management activities. Such activities are the starts of social gatherings, cultures, and civilizations. The history of civilizations indicates that even in dry lands groundwater resources had dominant roles through shallow wells or natural springs. Any civilization is under the pressure of internal and external impacts and urges for food security, which cannot be achieved without water security. Water resources have been and still are under internal and external pressures. The foundation of any civilization

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includes irrigation and agriculture, land use, seeding, and the quality control of products through technological developments, all of which drive the economic system of the society. Mismanagement of water resources, acid rains pollution, overexploitation, and other human activities play roles in the appearance, continuity, areal extent, and severity of droughts.

Even though the selection of settlement locations are made by humans, natural events such as droughts, floods, earthquakes, and others are among the external hazards that may affect societies at any time without preparedness against the final consequences. For instance, extreme water events such as droughts and floods should be managed in such a way that extra amounts of water should be stored in some way so as to be of benefit during future dry spells when the water supply may fall short of meeting the demand. Otherwise, the society may go through a water stress period until a suitable supply is either found from an engineering point of view or by the reoccurrence of abundant rainfall events. These days, water scarcity and stress increase day after day. Among the main reasons for water scarcity are the following points:

1. Increase in world population.
2. Burst in urbanization.
3. Increase in the needs of industrial production.
4. Differences in water distribution, movement, contamination, pollution, and deteriorations may result in undesirable ecological consequences.
5. During the last 25–30 years, due to global warming, greenhouse effects, and as a result of climate change, exploitable water resource quantities are bound to decrease in many parts of the world.

The most important effect of climate change on water resources is increase in the overall uncertainty associated with the management and supply of freshwater resources. Significant hydrological components such as storms, rainfall, stream flow, soil moisture, and evaporation are substantially random in their behavior and, accordingly, hydrologists or water specialists try to quantify them in terms of uncertain scientific methodologies; namely, probability, statistics, and at-large stochastic approaches ("see chapters: Temporal Drought Analysis and Modeling; Regional Drought Analysis and Modeling; Spatiotemporal Drought Analysis and Modeling") and, most recently, as chaotic and fuzzy systems ("see chapter: Basic Drought Indicators"). These scientific approaches provide predictions on the bases that the surrounding environmental effects and the climatic change are all stationary. Hence, classical approaches assume that the pattern of the local environmental and global climatic changes in the recent past will be repeated in the near future. It must not be forgotten at this stage that, certainly, the future pattern of climatic change and its consequences will not look like the past behaviors. It is, therefore, necessary to try and manage water supply systems with more care about the undesirable possible future extreme drought cases. This brings into the equation the concept of risk and management under a risky environment with probabilistic assessments and modeling ("see chapter: Climate Change, Droughts, and Water Resources").

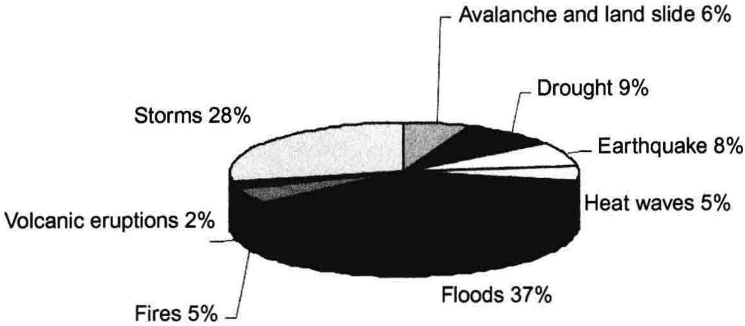

FIG. 1.1 Natural disaster percentages (WMO, 2005).

Water-related disasters (droughts, floods, hurricanes, typhoons, tsunamis) inflict a terrible toll on human life and property, far greater than earthquake damages (Fig. 1.1). About 90% of natural hazards are related to air, climate, and water.

Human activities should be planned in such a way that significant reduction of vulnerability can be made prior to drought occurrence ("see chapters: Climate Change, Droughts, and Water Resources; Drought Hazard Mitigation and Risk"). Nowadays, there is extensive knowledge, information, and capacity to disperse warnings even to the remotest places on the Earth, which help to alert people to take the necessary precautions against any natural disaster danger, in general, and drought effects, in particular.

On a global scale, very intensive and extensive drought distribution was observed during 1982–84. The most vulnerable parts of the world were West Africa, Sudan-Sahel, east and southeast Africa, southern and southeastern parts of Asia, the western Pacific and Australia, and southern parts of the United States.

Among the secondary effects of droughts are soil erosion, and consequent dust storms, forest fires, plant diseases, insect plagues, decrease of personal and public hygiene, increased concentration of pollutants, degradation of water quality, harmful effects on wildlife, and deterioration in the quality of the visual landscape. While floods, earthquakes, and cyclones are disasters associated with extreme events, droughts are the result of the low extremes such as unavailability of sufficient water. They seldom cause dramatic losses of human life except through famine. Generally, drought assessments at any point in a region can be achieved by taking into consideration time series records of the concerned variable. The first studies by Gumbel (1958) considered the probability of the lowest records during fixed periods. They are point wise instantaneous evaluations and, therefore, neither the drought coverage nor the areal extent can be modeled. Rather uncertain temporal and areal drought extensiveness must be modeled and predicted by quantitative methodologies such as probabilistic, statistical, stochastic, and (recently) fuzzy logic rule approaches (Şen, 2010). The first quantitative drought definition and studies by considering the threshold levels were due to Yevjevich (1967); later, various convenient applications were carried out by different authors (Downer et al., 1967; Llamas and Siddiqui, 1969; Saldarriaga and Yevjevich, 1970; Millian and Yevjevich, 1971; Guerrero-Salazar and Yevjevich, 1975; Şen, 1976, 1977, 1980a,b).

These methodologies provide quantitative gains in drought modeling and prediction; especially, initiation and continuation of agricultural drought triggers major problems between different water-dependent sectors. Uncertainty, lack of information, and ignorance about convenient methodological applications cause an increase in drought problems over time.

Consistent methodologies are not as easily available for drought modeling and prediction as for flood analysis. The most essential part of drought studies is its definition. Wilhite and Glantz (1985) have suggested that drought is dependent on different disciplines (meteorology, hydrology, agriculture, society) and, therefore, it needs different definitions. Tate and Gustard (2000), Demuth and Bakenhus (1994), and Dracup et al. (1980) summarized some of the most common drought definitions. They have also noted that there are confusions concerning different definitions, including "drought event" and "drought index" ("see chapter: Basic Drought Indicators"). Generally, a drought index implies a single number characterizing the general drought behavior at a measurement site, whereas a drought event definition is applied to select drought occurrences in a time series, including the beginning and the end of drought ("see chapter: Temporal Drought Analysis and Modeling"). The difference between these two time instances includes many drought characteristics such as drought duration, magnitude, intensity, and so on (Yevjevich, 1967; Şen, 1976, 1978). They continued to state that based on data availability climatic and regional drought characteristics require a suitable choice of definition. Beran and Rodier (1985) gave the most general drought definition as, "The chief characteristic of a drought is a decrease of water availability in a particular period over a particular area." Later, authors also provided similar definitions concerning different drought purposes (Allaby, 1998; Wilhite, 2000a; Boken et al., 2005; Tallaksen and van Lanen, 2004; Sheffield and Wood, 2006). Each definition is justified according to types of drought study in different sectors with different conclusions. For instance, in some seasons there may be enough precipitation events but mismanagement of water resources may lead to water shortages or water stress.

The most important motivation for this book is to provide primarily scientific, philosophical, logical, and linguistic information leading to necessary formulations, algorithms, and software for practical modeling, prediction, and applications in order to reduce the overall drought effect. The content has a wide range of practical, applicable, scientific, and mathematical models with examples and case studies for better appreciation of drought. Drought management cannot be without suitable and reliable models, which help to make future scenario predictions for the assessment of the worst and best drought mitigation strategies. Decision makers are then able to select the most suitable solution for their case among different scenarios. Risk-based drought preparedness plans