Techniques for Disaster Risk Management and Mitigation
Finally, after several ups and downs, I am about to submit this book with help of coeditors. I had been writing the acknowledgement back and forth, wherein I expressed immense gratitude toward my parents, beloved wife, and kids. However, I felt that was not enough. I started this book with esteemed Professor Tad Murty who passed away in 2018. He was an inspiration, being humble, helpful, and persistent even in difficult times.

This book would be incomplete without mentioning his dedication and perseverance towards his work. It is noteworthy that Professor Murty was an Indian-Canadian oceanographer and an expert on tsunamis. He was the former president of the Tsunami Society. He was an adjunct professor in the Department of Civil Engineering and Earth Sciences at the University of Ottawa. Professor Murty held a PhD degree in oceanography and meteorology from the University of Chicago. He was coeditor of Springer's journal, *Natural Hazards*, a renowned journal in the field.

He took part in a review of the 2007 Intergovernmental Panel on Climate Change. Professor Murty characterized himself as a global warming skeptic. In a 17 August 2006 interview, he stated, “I started with a firm belief about global warming, until I started working on it myself...I switched to the other side in the early 1990s when Fisheries and Oceans Canada asked me to prepare a position paper and I started to look into the problem seriously.”

He mentioned that “when natural disasters strike, there is more loss of life and more loss of materials in the developing world. Is it because there are more people here? Or, is it because the developing world is not as prepared as the developed world?” Hence, advanced techniques are needed to combat natural disaster; then we planned and started this book.

With his unfortunate death, I really miss having scientific discussions with him; and even more now as the book is completed, and I wish he could have been here with us. May God rest his soul in peace; he will be forever in our hearts.

—Prashant K. Srivastava
CONTENTS

Contributors ix
Preface xiii

Section I: Introduction
1. Concepts and Methodologies of Environmental Hazards and Disasters
   Nicolas R. Dalezios, George P. Petropoulos, and Ioannis N. Faraslis 3
2. Indigenous Knowledge for Disaster Solutions in the Hilly State of Mizoram, Northeast India
   Kewat Sanjay Kumar, Awadhesh Kumar, Vinod Prasad Khanduri, and Sudhir Kumar Singh 23
3. Urban Risk and Resilience to Climate Change and Natural Hazards:
   A Perspective from Million-Plus Cities on the Indian Subcontinent
   Amit Kumar, Diksha, A. C. Pandey, and M. L. Khan 33
4. The Contribution of Earth Observation in Disaster Prediction, Management,
   and Mitigation: A Holistic View
   Varsha Pandey, Prashant K. Srivastava, and George P. Petropoulos 47

Section II: Atmospheric Hazards and Disasters
5. Tropical Cyclones Over the North Indian Ocean in Changing Climate
   R. Bhatla, Raveena Raj, R. K. Mall, and Shivani 65
6. Simulation of Intensity and Track of Tropical Cyclones Over the Arabian Sea Using the Weather Research
   and Forecast (WRF) Modeling System with Different Initial Conditions (ICs)
   Sushil Kumar, Ashish Routray, Prabhjot Singh Chawla, and Shilpi Kalra 77
7. Development of a Soft Computing Model from the Reanalyzed Atmospheric Data to
   Detect Severe Weather Conditions
   Devajyoti Dutta, Ashish Routray, and Prashant K. Srivastava 85
8. Lightning, the Global Electric Circuit, and Climate
   N. Jeni Victor, Sagarika Chandra, and Devendraa Siingh 93
9. An Exploration of the Panther Mountain Crater Impact Using Spatial Data and
   GIS Spatial Correlation Analysis Techniques
   Sawyer Reid Stippa, Konstantinos P. Ferentinos, and George P. Petropoulos 111

Section III: Land Hazards and Disasters
10. Satellite Radar Interferometry Processing and Elevation Change Analysis for
    Geoenvironmental Hazard Assessment
    Sergey Stankevich, Iryna Piestova, Anna Kozlova, Olga Titarenko, and Sudhir Kumar Singh 127
11. Assessing the Use of Sentinel-2 in Burnt Area Cartography:
    Findings from a Case Study in Spain
    Craig Amos, Konstantinos P. Ferentinos, George P. Petropoulos, and Prashant K. Srivastava 141
12. Assimilating SEVIRI Satellite Observation into the Name-III Dispersion Model to Improve Volcanic Ash Forecast

13. Geoinformation Technology for Drought Assessment
Arnab Kundu, D. M. Denis, N. R. Patel, R. K. Mall, and Dipanwita Dutta ................................................................. 171

14. Introduction to Landslides
H. K. Pandey ............................................................................................................................................. 181

15. Probabilistic Landslide Hazard Assessment using Statistical Information Value (SIV) and GIS Techniques: A Case Study of Himachal Pradesh, India
Ankit Sharma, Ujjwal Sur, Prafull Singh, Praveen Kumar Rai, and Prashant K. Srivastava ................................................ 197

16. One-Dimensional Hydrodynamic Modeling of the River Tapi: The 2006 Flood, Surat, India
Dhruvesh P. Patel, Prashant K. Srivastava, Sudhir Kumar Singh, Cristina Prieto, and Dawei Han .................. 209

Section IV: Ocean Hazards and Disasters

17. Tropical Cyclone-Induced Storm Surges and Wind Waves in the Bay of Bengal
Prasad K. Bhaskaran, A. D. Rao, and Tad Murty ................................................................. 239

18. Space-Based Measurement of Rainfall Over India and Nearby Oceans Using Remote Sensing Application
Anoop Kumar Mishra and Kishan Singh Rawat ........................................................................................................ 295

19. Modeling Tsunami Attenuation and Impacts on Coastal Communities
S. Piché, I. Nistor, and T. Murty ...................................................................................................................... 309

Index ............................................................................................................................................................................. 325
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We are often told our Universe began with a Big Bang, a disaster that made the stars and galaxies we see today. And, ever since, life on earth has evolved and flourished, surviving a series of unexpected bangs and calamities of one or another type. Nowadays, every place on earth is vulnerable to some kind of disaster, whether natural or human induced. Not only are developing and third world countries with less infrastructure and facilities in danger, but leading developed economies too face severe negative impacts due to disasters in terms of human and capital losses, mostly due to our lack of understanding of the processes involved in contributing to the severity of a disaster. With the most stated reason for the increase in the number and frequency of these disasters being the recent episodes of climate change and variability in earth’s history, many researchers have directed their studies towards developing more advanced and sophisticated early warning systems and techniques for precise prediction and forecasting of disaster.

In this context, this book highlights state-of-the-art new approaches, various modelling aspects, the role of field observations and management strategies, and efficient use of infrastructure in combating disasters. It addresses the interests of a wide spectrum of readers with a common interest in geospatial science, geology, water resource management, database management, planning and policy making, and resource management. The chapters in book focus mostly on emphasizing the investigation and identification of disasters through advanced computational techniques in conjunction with Geographic Information Systems (GIS) and Earth observation data sets for better management, adaptation, and mitigation of natural disasters.

The book is divided into four sections. Section I focuses on a general introduction to the disaster management and mitigation, with an overview on the different types of disaster and the importance of the existing traditional technologies mostly widely used for natural disasters, emphasizing the relevance of indigenous approaches in disaster management. The section also underlines the importance of community-based techniques in disaster management, postdisaster management, and developing mitigation plans. Section II contains chapters presenting detailed studies on atmospheric hazards and disasters, with some studies focusing on extreme weather events such as drought and tropical cyclones. To highlight the advancement in modern technologies for disaster management on land surfaces, Section III presents the role of modern technologies for disaster management and mitigation in cases such as drought and landslides. The section contains articles focusing on the role of earth observing techniques, database management through cloud management, and emergency preparedness using Global Positioning Systems (GPS). The next section, Section IV, illustrates the application and capability of satellite and mesoscale modelling for better understanding and management of oceanic disasters disasters and hazards.

Section I, opens with an introductory chapter (Dalezios et al.) on concepts and methodologies of environmental hazards and disasters, providing the basics concepts of disasters in different fields. Chapter 2 (Kumar et al.), on indigenous knowledge for disasters solution in hilly states, discusses the role of local or indigenous people's knowledge towards understanding and developing mitigation plans for disasters in hilly areas. Chapter 3 (Diksha et al.) presents an overview of the risk of disasters in urban areas and the relationship with climate change. The chapter provides a perspective from those cities on the Indian subcontinent with more than million inhabitants. The last chapter of this section (Pandey et al.), on the role of earth observing techniques in disaster prediction, management, and mitigation, provides a brief description of remote sensing and GIS techniques in disaster monitoring.

Section II of the book focuses on atmospheric hazards and related disasters. Chapter 5 (Bhatla and team) provides detailed accounts of tropical cyclones over the North Indian Ocean in changing climate, while Chapter 6 (Kumar and team) provides a detailed analysis of the simulation of the intensity and track of tropical cyclones over the Arabian Sea using the WRF modelling system. In Chapter 7 (Dutta et al.) a soft computing model developed using reanalyzed atmospheric data to detect severe weather conditions is described. Chapter 8 (Victor et al.) covers lightning, the global electric circuit, and the relationship with the climate. Chapter 9 (Stippa et al.) provides an exploration of the Panther Mountain crater impact using spatial data and GIS spatial correlation analysis techniques.

Section III of the book focuses on land hazards and disasters; it highlights disasters on land such as drought,
landsides, volcanic eruption, and forest fires. The section starts with Chapter 10 (Stankevich and team) exploring satellite radar interferometry processing and elevation change analysis for geo-environmental hazard assessment and continues with Chapter 11 (Amos et al.) documenting the use of Sentinel-2 in burnt area cartography and the findings from a case study in Spain. Chapter 12 (Patil and team) provides an assessment of the Name-III dispersion model after assimilating the SEVIRI satellite observation for volcanic ash forecast. Chapter 13 (Kundu et al.) describes geo-information technology for drought assessment using satellite and geospatial techniques. Chapter 14 (Pandey et al.) provides an introduction to the causes and control of landslides, while Chapter 15 (Sharma and team) reviews probabilistic landslide hazard assessment using Statistical Information Value (SIV) and GIS techniques. Chapter 16 (Patel et al.) introduces 1D hydrodynamic modelling for flood risk assessment, to simulate and understand flooding risk in coastal areas.

The last section of the book contains chapters discussing oceanic hazards and disasters, with Chapter 17 (Bhaskaran et al.) covering tropical cyclone induced storm surges and wind-waves in the Bay of Bengal, Chapter 18 (Mishra and Rawat) discussing space-based measurement of rainfall over India and nearby oceans using remote sensing applications, and Chapter 19 (Piche et al.) detailing the modelling of tsunami attenuation and the impact on coastal communities.

We believe that this book will be beneficial for people with a common interest in disaster management and mitigation. The variety of techniques outlined in this book, such as geospatial techniques, remote sensing and applications, emergency preparedness, policy making, and other diverse topics, in the earth, environmental, and hydrological sciences fields will provide readers with updated knowledge. We hope that this book will be beneficial for academics, scientists, environmentalists, meteorologists, environmental consultants, and computing experts working in the area of disaster risk management and mitigation.

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Section I
Introduction
1 Concepts and Methodologies of Environmental Hazards and Disasters
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ABSTRACT

Natural disasters have significant impact on several sectors of the economy, including agriculture. Moreover, under climate uncertainty, the role of several sectors of the economy, such as agriculture, as a provider of environmental and ecosystem services, is expected to further gain importance. Indeed, increasing climate variability and climate change lead to increases in climate extremes. The objective of this review is to present concepts and methodologies of environmental hazards and extremes that affect agriculture and agroecosystems, based on remote sensing data and methods, since this is a field gaining in potential and reliability. In this chapter, the relationship between environmental hazards and agriculture is presented; this is followed by concepts and quantitative methodologies of environmental hazards affecting agriculture, namely hydrometeorological hazards (floods and excess rain, droughts, hail, desertification) and biophysical hazards (frost, heat waves, wild fires). The emphasis is on concepts and the three stages of hazard development: forecasting-nowcasting (before), monitoring (during), and assessment (after). Examples and case studies are presented using recorded data sets, model simulations, and innovative methodologies.

1.1. INTRODUCTION

Agriculture faces several current and future challenges, such as international competition and further liberalization of trade policy. Additionally, environmental hazards play a major role in agriculture; this has resulted in a gradual and significant increase of the economic cost associated with all environmental hazards. Needless to say, agricultural production is highly dependent on climate, and is adversely affected by anthropogenic climate change and increasing climate variability, which have led to increases in climate extremes. During the 21st century, scientific projections, among others, point to changes in climate extremes, such as heat waves, heavy rainfall, and droughts, in many semiarid and arid regions around the world. Specifically, southern Europe and the entire Mediterranean basin are characterized as vulnerable regions due to the combined effect of temperature increases and reduced precipitation in areas already coping with water scarcity (Dalezios et al., 2018a; Srivastava et al., 2019). Agricultural production risks could become an issue in areas such as the entire Mediterranean basin, as mainly droughts and heat waves are likely to increase the incidence of crop failure. As yield variability increases, food supply is at increasing risk.

Under a changing climate, the role of agriculture as a provider of environmental and ecosystem services is expected to gain further importance. Improvement of water use efficiency in dry regions is an example of agricultural management. Vulnerability of agriculture can be reduced through adaptation measures and tools to

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increase climate variability (EU, 2007). Some farming systems may adapt more readily to climate pressures due to an inherent resilience. Other systems may need interventions for adaptation. However, besides traditional knowledge and technologies, more sophisticated technologies seem to be required due to increasing climate variability and change. Seasonal to interannual climate forecasting is a new branch of climate science that promises to reduce vulnerability in agriculture. Improved seasonal forecasts are now being linked to decision making for cropping. The application of climate knowledge to improve risk management is expected to increase the resilience of farming systems.

Environmental degradation is one of the major factors contributing to the vulnerability of agriculture because it directly magnifies the risk of environmental disasters. In order to ensure sustainability in agricultural production, a better understanding of the environmental hazards and disasters that impact agriculture is essential. A comprehensive assessment of impacts of natural disasters on agriculture requires a multidisciplinary, multisectoral, and integral approach involving several components and factors. Priority should be given to supporting applied research, since research is necessary to understand the physical and biological factors contributing to disasters. Community-wide awareness and capacity building on environmental hazards and disasters, mainly for farmers and stakeholders, should also be included in any research effort. Programs for improving prediction and early warning methods, as well as dissemination of warnings, should be expanded and intensified. Moreover, efforts are required to determine the impact of disasters on natural resources.

Recent research findings suggest that variability of climate, if encompassing more intense and frequent extremes, such as major large-scale hazards like droughts, heat waves, or floods, results in the occurrence of natural disasters that are beyond our socioeconomic planning levels. It is estimated that about 65% of the global damage from natural disasters has a meteorological origin. Also, meteorological factors contribute to 87% of people affected by natural disasters and 85% of relevant deaths (UN/ISDR, 2015; EM-DAT, 2009; WMO, 2004). This is expected to stretch regional response capabilities beyond their capacity and will require new adaptation and preparedness strategies (Salinger et al., 2005). Disaster prevention and preparedness should become a priority, and rapid response capacities to climate change need to be accompanied by a strategy for disaster prevention. Nevertheless, each type of extreme event has its own particular climatic, cultural, and environmental setting, and mitigation activities must use these settings as a foundation of proactive management. There is significant complexity involved in homogenizing and issuing global or regional statistics for disasters affecting agriculture, since this depends on the specific climatic zone and environment where the agricultural activity takes place, as well as the type, areal extent, and microclimatic and agroecological characteristics of the crops in that zone, including agroclimatic features. Nevertheless, international organizations, such as the Food and Agriculture Organization (FAO), the World Meteorological Organization (WMO), or the United Nations International Strategy for Disaster Reduction (UN/ISDR), issue statistics periodically that refer to environmental hazards and disasters that affect agriculture and agroecosystems. There is an urgent need to assess the forecasting skills for environmental hazards affecting agriculture in order to determine those where greater research is required. It is well known that lack of good forecast skill is a constraint to improve management, mitigation, and adaptation.

A holistic and integrated approach to environmental risks has gradually explored the use of common methodologies, such as risk analysis, including risk assessment and management. Indeed, through risk analysis, there are efforts to develop preventive measures and hazard processes before the crisis. It should be stated that current natural disaster management is crisis driven. It is thus realized that there is an urgent research need for a more risk-based management approach to natural disaster planning in agriculture, which would include a timely and user-oriented early warning system (Dalezios, 2017). Agricultural risk zoning is also an essential component of natural disaster mitigation and preparedness strategies. GIS and remote sensing and, in general, geoinformatics are increasingly employed due to the complex nature of databases to facilitate strategic and tactical applications at the farm and policy levels. Therefore, additional research is required to incorporate GIS, remote sensing, global positioning systems (GPS), simulation models, and other computational techniques into an integrated multihazard risk management framework for sustainable agriculture that includes early warnings of natural disasters (Sivakumar et al., 2005). There should also be more research attention to the potential impact of the increasing frequency and severity of extreme events associated with global change and appropriate mitigation strategies.

In general, risk assessment methodologies include three stages, or sectors, such as forecasting and early warnings before the phenomenon occurs, monitoring during a natural disaster, and estimating damage after the end of a disaster. In addition, risk identification involves quantifying, monitoring, and event risk, statistical inference, and database development, which should include records and historical information on disasters and their impacts. Risk assessment also entails reviewing the risk of these events, that is, the probability of occurrence, as well as the magnitude–duration–frequency and area-to-risk ratio. Finally, the risk assessment includes an environmental
impact assessment and cost–benefit analysis of the adaptation options for the development of countermeasures (Dalezios & Eslamian, 2016).

The current scientific and technological capabilities of remote sensing cover all three areas of risk management. Remote sensing has gradually become an important tool for the quantification and detection of the spatial and temporal distribution and variability of several environmental variables at different scales. At the present time, the growing number and effectiveness of pertinent observation satellite systems present a wide range of new capabilities in assessing and monitoring several features of environmental variables. Moreover, remote sensing methods have also reached a significant level of accuracy and reliability over the last 40 years. Specifically, remotely sensed models are currently considered suitable for crop water use estimation at field as well as regional scales (Dalezios, 2014). Thus, remotely sensed forecasting-nowcasting, monitoring, and assessment of environmental hazards are becoming attractive, since these systems provide consistently available data with high resolution covering large areas.

In this chapter, the major environmental hazards affecting agriculture are considered under increasing climate variability, namely hydrometeorological hazards (floods and excess rain, droughts, hail, desertification) and biophysical hazards (frost, heat waves, wild fires). The emphasis is placed on environmental hazards concepts and methodologies on the three stages of hazard development, namely forecasting-nowcasting (before), monitoring (during), and assessment (after). Examples and case studies are presented using recorded data sets, model simulations, and innovative methodologies in selected agricultural regions in southern Europe.

### 1.2. HYDROMETEOROLOGICAL HAZARDS IN AGRICULTURE

In this section, hydrometeorological hazards affecting agriculture are considered, namely floods and excess rain, droughts, hail, and desertification. For each hazard, some concepts are presented, along with methodologies on the three stages of hazard development: forecasting-nowcasting (before), monitoring (during), and assessing (after).

#### 1.2.1. Floods and Excess Rain

Floods can be devastating disasters that can affect anyone at almost any time (Ireland et al., 2015). Flooding has been one of the most costly disasters in terms of both human casualties and property throughout the last centuries. Hazards associated with flooding can be divided into primary hazards that occur due to contact with water, secondary effects that occur because of the flooding, such as disruption of services and health impacts, for example famine and disease, and tertiary effects, such as changes in the position of river channels. The term hazard (or cause), which in this case is flood, may be defined as the potential threat to humans and their welfare (Smith, 2013). Hazards can include latent conditions that may represent future threats and can have different origins, such as natural hazards or those induced by human processes (UN/ISDR, 2005).

#### 1.2.1.1. Flood Forecasting

The prediction of flood events is of hydrological importance. As a prognosis, it is not only the estimation of the frequency of a hydrologic episode of a certain size, but also the forecast of the size and time of a flood peak. In order to reduce the risk due to flooding, three steps are considered for flood prediction. First, determination is conducted of the probability and frequency of high discharges of streams that cause flooding. Second, floods can be modeled and maps can be produced to determine the extent of possible flooding that may occur in the future. Third, since the main causes of flooding are abnormal amounts of rainfall and sudden melting of snow or ice, storms and snow levels can be monitored to provide short-term flood prediction. Determining the timing and magnitude of floods is necessary for design flood purposes. In most cases, it is also necessary to classify the flood flows according to the flood-producing mechanisms, for example in flood-frequency studies. The classification of flood flows in various physical types should provide a better and reliable estimate of the magnitude of design floods, which, in turn, is necessary for the design of hydrotechnical projects. Flood-frequency analysis is used to predict design floods for sites along a river. The frequency of occurrence of floods of different magnitude can be estimated by a variety of methods depending on the availability of hydrometric data (Loukas et al., 2002). Under normal conditions, observed annual peak flow discharge data are used to calculate statistical information, which then constitute the basis to construct frequency distributions, which delineate the likelihood of various discharges as a function of recurrence interval or exceedance probability. The choice of a design flood magnitude with its assessed return period depends both on the expected life of the scheme and on the degree of protection required. However, in ungauged watersheds, the flood flow is estimated by various methods, which require the estimation of rainfall of particular critical duration and return period. This leads to the design storm concept, which is still the dominant design method in hydrological engineering.

#### 1.2.1.2. Flood Monitoring

Flood monitoring can be achieved through hydrological simulation. A hydrological model is an approximation of
the real hydrological system. The input data and the outputs are measurable hydrological parameters and the structure of the models is a set of equations, which relate the inputs to the outputs. Modeling efforts are considered in three levels of temporal and spatial scaling (Schultz & Engman, 2000).

1. Design of water supply systems. This type of modeling requires long-term time series data records of hydrological variables with the minimum time step being the month. For instance, the conventional data source could be observed or generated runoff data. The employed hydrological model could be a transfer function model in convolution integral, which is a stochastic black-box model based on the theory of linear systems.

2. Design of flood protection measures. This type of modeling requires data from numerous cases of short-term extreme hydrological events with a time step of days, hours, or even 10 min, for example, in the case of urban systems. The data source could be observed or extrapolated runoff data. Hydrological modeling could include a rainfall model in association with a rainfall-runoff model of a distributed or lumped system type, for example, unit hydrograph.

3. Operation of water resource systems. This type of modeling requires short-term or even real-time data with a time step of 10 minutes, hours or even a day. The data source should be rainfall observed in real time, forecast of rainfall, as well as observed runoff. Additional data sources should be ground-based weather radar and IR data from geostationary meteorological satellites. The hydrological modeling system to be used should include a rainfall model and a rainfall-runoff model, preferably of distributed system type, in order to conduct now-casting of extreme events in real time or semi-real time.

1.2.1.3. Assessment and Causes of Floods

Extreme values of runoff, namely flood spikes, are typically formed abruptly after a corresponding sudden rainfall, and include massive bodies of water. There are several causes of flood peaks, where the most important of these are rainfall of high intensity and duration, melting of snow and ice, or the sudden destruction of water-saving techniques. In general, runoff is subject to rainfall fluctuations in relation to the climate of a region. Apart from seasonal variation, permanent changes in runoff usually occur due to the following causes: urbanization, abandonment of the countryside and development of wild vegetation in the catchment area, natural disasters, forest burning and destruction, changes in land use, construction of large water storage, and large development projects. Variability in runoff spatiotemporal distribution may also be expected due to climate change, since runoff is the hydrological variable that is particularly sensitive to climate change or climate uncertainty.

1.2.1.4. Damages from Excess Rain

Heavy rainfall has caused significant damages to agricultural production globally. The cost of crop damage over the next decades could increase dramatically. It is estimated that, due to climate change, the enhanced hydrological cycle is responsible for increasing the damage from recent floods. Determination of cause and effect between increases in rainfall and flood damage is difficult due to simultaneous changes in population growth, economic growth, and infrastructure, among others. However, recent data show that total annual rainfall and heavy rainfall have increased in many parts of the world during the last century, particularly during the last two decades (Milly et al., 2002), often resulting in large harvest losses and other losses due to floods (Chagnon et al., 1997). For example, floods in the US Midwest in 1993 caused damage to farmers estimated at around $6–8 billion, about 50% of total flood losses (FEMA, 1995). Also, agricultural production was negatively affected by the 1997 US North Dakota flood, which caused a total loss of about one billion dollars. In addition, the 2001 Mississippi floods delayed planting.

Heavy rainfall, leading to floods, could also cause soil erosion on farmland (Figure 1.1a, b). Excessive soil moisture is an important element of crop damage along with

![Figure 1.1](image-url)
extreme rainfall. In order to quantify the significance of the effects of excessive soil moisture on current and projected future crop production estimates, a simplified model could be used (Rosenzweig et al., 2002). During the Mississippi floods of 1993, about 70% of total harvest losses occurred in mountainous areas due to the saturation of soils by heavy rainfall. Over the past 20 years, excessive soil moisture cost US farmers five times more than direct flood damage, according to crop insurance data.

1.2.2. Hail

Hail is a natural environmental hazard and can destroy an entire agricultural production within a few minutes. Since the need to combat the devastating effects of hail on agricultural production has always been urgent, attempts to tackle hail were made long before sufficient understanding and knowledge of the phenomenon were developed.

1.2.2.1. Hail Formation

Hail forms inside thunderstorm cumulonimbus (Cb) clouds, mainly those with intense updrafts, high liquid water content, great vertical extent, large water droplets, and a good portion of the cloud layer below freezing temperature. Hail grows in the main updraft of a cloud, where most of the cloud is in the form of supercooled water. This is the water that remains liquid although its temperature is at or below 0°C. The growth rate is maximized at about -13°C, and becomes vanishingly small much below -30°C as supercooled water droplets become rare. Cumulonimbus clouds contain vast amounts of energy in the form of updrafts and downdrafts. These vertical winds can reach speeds over 176 km per hour. As a hailstone starts to form, it becomes too heavy for the top of the cloud. It starts to fall through the cloud gathering more supercooled droplets as it falls. If the hailstone is not heavy enough, the updraft pushes the hailstone back up into the upper recesses of the cloud. The hailstone once again gathers more droplets and grows even bigger. It then starts to fall again. This cycle continues until the hailstone is heavy enough to overcome the updraft. At this point, the hailstone leaves the cloud and falls onto the ground. This process creates hailstones from a few millimeters in diameter up to 15 cm that weight more than half a kilogram. Pea or golf-ball-sized hailstones are not uncommon in severe storms. Hail falls along paths, which are called hail swaths. These vary from a few square kilometers or less to large belts 16 km wide and 160 km long. Figure 1.2 illustrates the sequence of the downstream process recording the sequence of weather events leading to hail.

1.2.2.2. Climatology of Hail

Hail is most common in early summer at midlatitudes where surface temperatures are warm enough to promote the instability associated with strong thunderstorms, but the upper atmosphere is still cool enough to support ice. Hail is actually less common in the tropics despite a much higher frequency of thunderstorms than in the midlatitudes, because the atmosphere over the tropics tends to be warmer over a much greater depth. Also, entrainment of dry air into strong thunderstorms over continents can increase the frequency of hail by promoting evaporational cooling, which lowers the freezing level of thunderstorm clouds giving hail a larger volume to grow in. Hail is also

![Figure 1.2 Precipitation procedure chain.](image-url)
much more common along mountain ranges, because mountains force horizontal winds upward (known as orographic lifting), thereby intensifying the updrafts within thunderstorms and making hail more likely.

In Greece, hail produced during the cold season is of small diameter and generally causes no damage to agriculture. However, during the warm season, hail is produced in continental parts of Greece mainly from convective storms formed due to intensive heating, which creates instability in the air. The terrain of Greece, with mountains, forces air masses to lift and therefore produce thunderstorms often accompanied by hail, which often damages agricultural production as conditions allow thunderstorms to grow enough and produce hailstones of large diameter locally. The annual distribution of hail days over Greece is shown in Figure 1.3. The figure clearly indicates that hail days are more often over western and eastern parts of Greece during the cold season, while during the warm season hail days are observed in central and northern continental parts of Greece.

1.2.2.3. Hail Damage
Hail can cause serious damage, notably to automobiles, skylights, glass-roofed structures, but most commonly to agriculture. Even small hailstones can destroy crops and slice plants to ribbons in a few seconds. Thus, although a hailstorm lasts only for a few minutes (2–8 min) and rarely more, the damage caused is of great importance. Efforts for mitigation of hail damage were started by humans long before science was able to explain hail formation and processes. In the fourteenth century, people in Europe attempted to ward off hail by ringing church bells and firing cannons. Hail cannons were especially famous in the wine-producing regions of Europe during the nineteenth century, and modern versions of them are still used in parts of Italy. After World War II, scientists across the world experimented with cloud “seeding” as a means of reducing hail size. Cannons that fired silver iodide (AgI) into thunderclouds from the ground were also used. Hail suppression programs were used worldwide to reduce hail damage to crops.

1.2.2.4. Hail Suppression
Protection from hail is classified into two major methods, namely active and passive protection. Active protection includes modern techniques applied before a hailstorm hits a region in order to reduce or suppress hail and passive protection includes actions taken by farmers so that hailstones do not hit the plants. Active protection methods are cloud-seeding techniques from aircraft, hail cannons, and hail rockets. Hail cannons ignite a charge of acetylene gas in a specially designed blast chamber releasing an explosive pressure wave creating a cavitation effect, which disrupts the formation process of the hailstone embryo. Hail rockets are fired from the ground inside cumulonimbus clouds in order to influence hail clouds to prevent hail and to stimulate rainfall. Cloud seeding from aircraft includes seeding of thunderstorm clouds with silver iodide or other material (e.g., dry ice) in order to diminish hail production. Passive protection from hail is performed by applying a safety net over the ground and thus protecting crops or fruit trees.

1.2.2.5. Design of Hail Suppression in Greece
The National Hail Suppression Program (NHSP) of Greece was established in 1984 and designed as an
operational and, at the same time, as a research cloud-seeding program. The hail-suppression cloud-seeding hypothesis of the NHSP is based on the cloud microphysical concept of beneficial competition theory. This hypothesis assumes a lack of natural ice nuclei in the storm environment and that the injection of artificial nuclei of AgI (silver iodide) will increase the total ice nuclei in thunderstorm clouds. Hence, the supercooled water available to each embryo is limited and the hailstones that are formed will be smaller and produce less damage if they reach the ground. Protected areas of the NHSP are shown in Figure 1.4. The seeding criteria in the NHSP require that seeding must be conducted on every storm reaching a radar intensity of 35 dBZ or greater, at altitudes between the -5°C and -30°C levels, while these storms are within the project area or within a 20 min upwind buffer of the project area. Cloud seeding is conducted using aircraft (Piper Cheyenne II) equipped with seeding racks containing both droppable and end-burning silver iodide flares.

1.2.2.6. Quantitative Hail Forecast

Indicative methods of forecasting hail, now-casting, and storm tracking include predictive meteorology, numerical weather forecast, cloud models of one dimension (1-D), two-dimensions (2-D), and three-dimensions (3-D). Also highlighted is the use of weather radar and satellite systems. However, for quantitative hail forecast, the most prevalent methodology is to effectively combine some or all of the above methods, which has been applied to the NHSP of Greece. An objective synoptic index combines hydrostatic instability theory and scale variables to estimate the potential switching range. The index is derived from statistical linear regression, where several independent variables are combined depending on their relationship with the dependent variable, which is the index. In particular, the index is called the Convective Day Category (CDC), and each day is defined as the maximum degree of switching intensity for an area in distinct classes. The classes include all types of switching, such as rainfall, storms, and hail of various sizes. In addition, 10 internationally known indicators of atmospheric instability have been selected and are utilized together with the CDC for optimal quantitative hail forecast (Dalezios & Papamanolis, 1991).

1.2.2.7. Hail Monitoring: Operational Part and Evaluation

Weather surveillance is provided by two 5 cm C-band weather radars. A routine 20 hr a day radar operation is conducted based on scheduled shifts, which is extended to 24 hr when continued storm activity threatens the project area. A network of hail pads and rain gauges operates in the project area to provide quantitative

Figure 1.4 Map of Greece showing the three protected agricultural areas of the NHSP.
measurements of hail falls. Hail-pad data are primarily used for evaluation of the cloud seeding effect and also for an adequate sampling of hail falls and fine-scale analysis of hail swaths. Figure 1.5a illustrates a schematic view of the cloud-seeding operation. Figure 1.5b shows the operational framework of a hail suppression program. In particular, the start is done by quantification of hail (top left), followed by radar storm (bottom left), then cloud seeding by airplane (top right), and finally recording hail on the ground (bottom right).

An integrated data processing and analysis approach is conducted in order to synthesize a vast amount of multi-source data, such as radar, hail pads, aircraft, or compensation amounts, for the selection of all the appropriate parameters for the statistical evaluation.

1.2.3. Drought

Drought is a natural phenomenon repeated over time on a regional scale. Drought is referred to as “nonevent,” as its basic cause is the lack of rainfall in a region over a period of time. In addition, drought is a natural hazard with a slow onset, often seen as a creeping phenomenon. It is difficult to determine the impact of drought, as it is a complex phenomenon that evolves gradually in each region. The effects of drought are very critical and costly, affecting more people than any other natural disaster globally (Keyantash & Dracup, 2002). Indeed, drought is seen as one of the most important natural hazards, with a significant impact on the environment, society, agriculture, and the economy.

1.2.3.1. Types and Definitions of Drought

It is known that there is no precise and universally accepted definition of drought, since there is a range of drought-affected areas, there is a divergent spatial and temporal distribution and water demand for different uses. Definitions of drought must refer to area, use, or impacts. Indeed, droughts are regional in scope and each region has particular climatic characteristics. Considering drought as a risk, there is a tendency to classify droughts in different species or types. In the international literature, three functional definitions of drought have been established: (1) meteorological or climatic, (2) agricultural or agrometeorological, and (3) hydrological (Wilhite et al., 2000). As a fourth type of drought, the socio-economic impact of drought can also be considered. With the exception of meteorological drought, other types of drought, such as agriculture and hydrology, emphasize the human or social aspects of drought, namely the interaction between the physical characteristics of meteorological drought and human activities that are dependent on precipitation (Keyantash & Dracup, 2002). Needless to say, the relationship between the different types of drought is complex. Here is a brief description of the types of drought.

1. Meteorological drought is a natural occurrence at a regional scale and, in general, characterized by a rainfall irregularity being lower than the average for some time and by prolonged and abnormal lack of humidity.

2. Agricultural drought refers to agricultural impacts, resulting from shortages in water availability for agricultural
use leading to crop failure and exists when soil moisture is exhausted so that crop yields are significantly reduced.

3. **Hydrological drought** is considered to be a rather long period during which the actual water supply, either surface or groundwater, is less than the minimum flow required for normal operation in a basin as a result of meteorological drought.

4. The **socioeconomic impact of drought** is defined as a loss from the average or expected income and can be measured by social and economic indicators (McVicar & Jupp, 1998). Indeed, the socioeconomic drought refers to the gap between supply and demand of economic goods resulting from the three other types of drought, such as water, food, raw materials, or transport.

The types of drought along with the time sequence of the processes are shown in Figure 1.6.

### 1.2.3.2. Features of Drought

Several features are considered for the assessment and monitoring of drought. Conventional data and remote sensing methods are used to determine the spatial and temporal variability of the various drought characteristics (Dalezios et al., 2012). Key features are described here.

**Quantification of drought** is not an easy matter and can be considered by using indicators or indices. Indeed, drought indicators are variables, describing the characteristics of drought. Several indicators can also compose a single index, called a drought index. In addition, it is necessary to calculate various features of drought, such as severity, duration, periodicity, areal extent, start, and end of drought.

**Severity** is defined according to its category: mild, moderate, strong, and extreme. The severity is usually determined through drought indicators. **Periodicity** is the reoccurrence of drought. **Duration** of a drought episode is defined as the period from beginning to end, usually in months. Since drought is a complex phenomenon, estimating the start time and end time is a complex technical issue. **Start** is the beginning of a drought episode, identified by indications or markers, exceeding a threshold value. The **end** of a drought episode marks the end of drought, again based on the threshold values of the indications or markers. **Areal extent** of drought is considered to be the spatial coverage of the phenomenon as quantified in classes with indications or indices.

Monitoring drought development is vital for economically and environmentally sensitive areas and is a very important input into any drought preparedness and mitigation plan. Primary data for meteorological, agricultural, and hydrological droughts are climate variables, such as temperature, rainfall, runoff, soil moisture, reservoir storage, groundwater levels, snow, and vegetation. Drought indicators provide ease of application and are extensively used in drought quantification (Keyantash & Dracup, 2002).

### 1.2.3.3. Drought Monitoring: Drought Early Warning System (DEWS)

The DEWS focuses on monitoring drought conditions (Wilhite, 2009) on the basis of drought indicators. During the last decade, a web-services-based environment has been developed for integration of regional and continental drought monitors, for computation and display of spatially consistent drought indicators on a global scale, such as in situ Standardized Precipitation Index (SPI), satellite-based indices, and modeled soil moisture, and for drill-down capacity to regional, national, and local drought products. Each continental drought monitor is developed and functions according to the unique conditions of that continent. At the present time, there are several regional and continental drought monitor models, leading to a global drought monitor (GDM); these coordinate and

![Figure 1.6](https://example.com/drought_diagram.png)

**Figure 1.6** Simplified sketch of processes and drivers relevant for meteorological, soil moisture (agricultural), and hydrological droughts (from IPCC, 2012, SREX).
exchange information toward a global drought information system (GDIS) (Dalezios et al., 2018a). The four major regional-continental models are (1) the North American drought monitor (NADM), which consists of the United States Drought Monitor (USDM), Canada and Mexico, (2) the European drought observatory (EDO) model, (3) the African drought monitor (ADM), and (4) the Australian drought monitor model.

1.2.3.4. Meteorological DEWS: RDI

For illustrative purposes, a case study using an empirical model and leading to the drought early warning system (DEWS) based on the remotely sensed Reconnaissance Drought Index (RDI) (Dalezios et al., 2012) is briefly presented. By plotting the cumulative monthly areal extent values of the extreme RDI drought class, that is, class 4 (Dalezios et al., 2012) with values lower than −2, for all the drought episodes, two figures are produced: Figure 1.7 for droughts of large areal extent and Figure 1.8 for droughts of small areal extent. In addition, curve fitting is conducted for each of these figures resulting in the following polynomials: equation (1.1) for droughts of large areal extent and equation (1.2) for droughts of small areal extent, both with high coefficient of determination.

\[
y = 0.4771x^3 - 9.7934x^2 + 78.221x - 36.078 \quad \left( R^2 = 0.9676 \right)
\] (1.1)

\[
y = 0.4868x^2 - 3.3415x + 4.78 \quad \left( R^2 = 0.9618 \right)
\] (1.2)

It is worth noticing that for droughts of large areal extent (Figure 1.7), drought starts during the first three months of the hydrological year, whereas for droughts of small areal extent (Figure 1.8), drought starts in spring (April). This finding signifies the possibility of using the fitted curves for monitoring and early-warning drought

![Figure 1.7](image1.png)

**Figure 1.7** Cumulative large areal extent (number of pixels, 8 x 8 km²) of extreme drought (>2.0) during drought years based on remotely sensed RDI (from Dalezios et al., 2012).

![Figure 1.8](image2.png)

**Figure 1.8** Cumulative small areal extent (number of pixels 8 x 8 km²) of extreme drought (>2.0) during drought years based on remotely sensed RDI (from Dalezios et al., 2012).
assessment in a region. This finding justifies the use of the fitted curves of Figures 1.7 and 1.8, along with the corresponding equations (1.1) and (1.2), for drought prognostic assessment or DEWS.

### 1.2.4. Desertification

Soil is an open natural system and a nonrenewable resource that can easily be destroyed when it is facing ever-increasing pressure. Soil degradation is characterized by changes in its physical, chemical, and biological properties, leading to erosion, loss of productivity, and usually desertification (Dalezios & Eslamian, 2017a). The current definition of desertification consists of “land degradation in arid, semiarid and dry subwetlands resulting from various factors, including climate change and human activities” (UNCED: Agenda 21) (UN, 1992). Natural degradation occurs in sloping terrain and is very extensive, while the predominant process of chemical desertification is the salinization of soils through the irrational management of irrigation water. Finally, the main land use of anhydrous areas is agriculture, livestock farming, and, in particular, the production of living food.

#### 1.2.4.1. Causes of Desertification

Natural causes include dry climate, geomorphology of soil erosion processes, quantitative and qualitative alteration of the water balance, and historical features of a region. Correspondingly, human-made causes include urbanization, forest fires, overexploitation of surface and underground resources, intensification of agriculture, overgrazing, inadequate agricultural and forestry management, tourism, as well as socioeconomic factors. Desertification factors are classified and described below (Sheikh & Soomro, 2006).

**1.2.4.1.1. Climate**

Climate and desertification interact at various scales and influence desertification processes through dry land and vegetation, which have a low organic content, as well as in the hydrologic cycle of anhydrous areas (FAO, 2004). Desertification affects global climate change through soil and loss of vegetation, since dry soils contain much carbon, which could be released into the atmosphere. On the other hand, high temperatures can have a negative effect on dry soils due to increased water loss and decrease in rainfall. Similarly, the increase in carbon dioxide in the atmosphere can stimulate the growth of certain plants. Loss of biodiversity due to desertification is difficult to assess (UN, 1992). Table 1.1 shows the relationship between the aridity index, rainfall, and the climate category. Generally, when the fraction is less than 0.03, there is permanent desertification. When it is greater than 0.65, there is no desertification.

#### Table 1.1 Categories of Aridity Climatic Conditions.

<table>
<thead>
<tr>
<th>Aridity Index</th>
<th>Classification of desert climate</th>
</tr>
</thead>
<tbody>
<tr>
<td>PET &gt; P</td>
<td>No desertification</td>
</tr>
<tr>
<td>P/PET &lt; 0.03</td>
<td>Hyperarid</td>
</tr>
<tr>
<td>0.03 – &lt; 0.20</td>
<td>Arid</td>
</tr>
<tr>
<td>&lt; 200 (winter)</td>
<td></td>
</tr>
<tr>
<td>0.20 – &lt; 0.50</td>
<td>Semiarid</td>
</tr>
<tr>
<td>200–500 (winter)</td>
<td></td>
</tr>
<tr>
<td>400–600 (summer)</td>
<td></td>
</tr>
<tr>
<td>0.50 – &lt; 0.65</td>
<td>Dry subhumid</td>
</tr>
<tr>
<td>500–700 (winter)</td>
<td></td>
</tr>
<tr>
<td>&gt; 0.65</td>
<td>No desertification</td>
</tr>
<tr>
<td>600–800 (summer)</td>
<td></td>
</tr>
</tbody>
</table>

#### 1.2.4.1.2. Geology: Soils

The properties of rocks can influence the desertification process due to permeability, rock disintegration rate, and soil erosion. These rocks are limestones and marls in hilly terrain where the soil is shallow and sensitive to drought. Other formations are acidic and volcanic rocks. The soil characteristics that affect desertification rate and processes are depth, texture, humidity, fertility, organic matter, filtering surface, hydraulic conductivity, and water resistance. Soil yield is linked to desertification through soil formation rate, water retention capacity, availability of plant nutrients, and surface runoff. In addition, physiography significantly influences the three desertification processes: (1) erosion, (2) salinity, and (3) drought. Desertification also depends on the slope, appearance, and shape of the land. There are two equations: the rate of soil loss (equation 1.3) and the rate of erosion (equation 1.4).

\[
E_l = c S^a
\]  
\[
E_2 = b L^m
\]

where \(E_l\) = soil loss, \(S\) = slope, \(E_2\) = erosion, \(L\) = slope length, and \(c, a, b, m\) = empirical coefficients. By removing the most fertile surface soil, erosion reduces soil productivity and, where the soils are shallow, can lead to permanent loss of natural agricultural land. Finally, the rate of erosion is very sensitive to climate and land use.

**1.2.4.1.3. Hydrology**

The land phase of the hydrological cycle, namely, the water balance, can be used to assess desertification impacts. This process extends until the supply of available water is not enough to meet the needs of living organisms, such as plants and animals. There are water losses such as surface runoff, infiltration, groundwater in aquifers, and groundwater flow into the sea, that are very critical for desertification, particularly in fragile and sensitive areas. In addition, water losses can result from sparse vegetation, limestone rock permeability, industrial
and urban demand, environmental pollution, and groundwater exploitation. A possible solution to prevent areas from desertification may be irrigation, which replenishes soil moisture for plant growth.

1.2.4.1.4. Biology

Plant cover is the best indication of desertification, when permanent changes in plant cover are observed and more areas are rendered arid. However, the seasonality and variability of rainfall in anhydrous areas can only result in increased variability in plant cover. The vegetation coverage in a region depends on the existing relationships between the soil climate and vegetation. In essence, areas with rain P < 280 mm and high evaporation rate experience a decrease in available water, resulting in a gradual bare ground. In addition, areas with dry crops (Table 1.2) (FAO, 2004) are very sensitive to erosion and desertification, as reduced protection from plant cover cannot effectively prevent the intensity of rain on the surface of the soil.

1.2.4.1.5. Human Activities

Socioeconomic factors include population growth, constant increase in water consumption resulting in environmental pollution, and intensification of agriculture by human intervention as overexploitation of plant biomass and unreasonable crops in hilly terrain, which lead to soil erosion. In addition, factors such as deforestation and the reduction of plant cover due to forest fires, overgrazing of sensitive areas, land abandonment, and the unexpected growth of land and tourism leading to land degradation are considered. In addition, an increase in surface runoff to the sea due to deforestation and overexploitation of water resources leads to a reduction in available resources resulting in the salvage of underground aquifers and seepage of seawater into coastal aquifers. Still, inefficient irrigation design leads to irrigation water losses resulting in soil salinity. Finally, water shortages, depletion of groundwater, soil erosion, and salinization are considered as the results of institutional failures and policies.

1.2.4.2. Methodologies and Modeling

There is a wide range of methodologies and modeling efforts that has been implemented for desertification, such as the development of numerical models for future climate scenarios, simulation of atmospheric dynamics, oceans and energy exchange between atmosphere–land–oceans, short-term prognosis, forecast of long-term changes in climatic parameters under specific conditions such as changes in land use and greenhouse gas emissions, use of climate scenarios to understand future desertification conditions, simulation of climate variability and extreme phenomena with emphasis on small-scale impacts, and the use of multiple indicators to assess desertification conditions in areas with large water deficits (PET > P). Moreover, desertification methodologies incorporate Geographic Information Systems (GIS) and remote sensing, spatial modeling of desertification risk in vulnerable areas, and production of hazard maps and desertification classification. Today, one in six people worldwide suffers the effects of soil degradation. Current surveys include monitoring and preventing desertification, understanding desertification processes and interactions with the environment, and developing institutional rating systems and feedback mechanisms. There is a need for high-quality data such as crop yield data, phenological observations, remote sensing data, relief features, soil degradation, salinity patterns in irrigation systems, overgrazing features, large water erosion patterns, and burned areas of fires.

1.2.4.3. Desertification Stages and Procedures

A summary of the stages and procedures leading to desertification is presented here.

Stage 1 Soil degradation. At this stage, the main issue is to reduce coverage of vegetation in an area, which results in raindrops dropping on the ground reaching the surface.

Stage 2 Reduction of organic matter and degradation of the soil structure. Organic matter is the connecting element between soil particles. The reduction and ultimately the lack of organic matter can cause weakening of soil aggregates, resulting in reduced biomass production.

Stage 3 Dispersion of soil aggregates. Soil particles are divided into smaller ones as a result of rain drops. The degradation of the soil surface structure produces a negative impact chain, starting from the reduction of biomass production and the subsequent loss of a significant amount of water for the plants.

Stage 4 Sediment flow and transfer. This process depends mainly on rainfall, but it can also happen because of the wind. With regard to rainfall, the process can lead to surface runoff. In fact, erosion can lead to a reduction in biomass production and a reduction in the depth available in the root zone as there is depletion of organic matter and nutrients.